CHARACTERISATION OF DROWSY DRIVER BEHAVIOUR AND DROWSINESS BASELINE DATA SET IN A DYNAMIC DRIVING SIMULATOR

Cristina Periago
James Jackson
Clara Cabutí
Fiona Azcarate
Elena Castro
Francesco Deiana
Adrià Roig

IDIADA Automotive Technology SA
Spain

Paper Number 23-0316

ABSTRACT

Drowsiness is one of the mean causes of road accidents, accounting for 1,200 fatalities and 76,000 injuries per year, according to several authors [1]. This transitional state between awake state and the sleep state behaves physiological symptoms such as yawning, loss of neck muscle tone, pupillary constriction, ptosis, decreased attention, psychomotor and cognitive performance [2]. The purpose of the present study is to observe the effects of monotonous driving on long journeys on driver behaviour in order to develop driver monitoring systems capable of detecting symptoms of drowsiness and thus be able to reduce its negative impact on the road. The experiment is conducted on a dynamic driving simulator, where conditions were configurated according to the aim of having a monotonous environment free from any distraction. Participants drive for 90 minutes and every 5 minutes the experimenter ask about their level of KSS, using the Karolinska Sleepiness Scale, a standardized instrument that measures the participant's subjective level of drowsiness. Moreover, participants are instrumented to collect physiological data (ECG, EEG, EDA and respiratory rate) and an eye-tracking system monitors other drowsiness behaviours such as blinking or yawning. The test finish when 90 minutes passed, or participants reached an advanced level of drowsiness on the Karolinska Sleepiness Scale (KSS). The study consists of two phases of testing. The first phase, with 10 participants, aims to validate the test method for both sleep induction and the integrated data collection setup. The second loop of testing, planned in January 2023, will involve 20 participants with different age and gender representation and aim to try to define the sleep behaviour patterns in relation to the different levels defined by KSS. In this paper we present the preliminary results of first phase of testing.

BACKGROUND

In recent years, it has been noticed that driving in a sleepy state poses a high risk to road safety. According to the DGT, drowsiness intervenes, directly or indirectly, in between 15-30% of traffic accidents in Spain [3]. Also, as reported by the recent statistics, drowsiness-related accidents account for 1,200 fatalities and 76,000 injuries per year [1] For this reason, there is growing interest in finding automatic systems capable of detecting the state of driver fatigue. In addition, as the implementation of this technology becomes more widespread, driven by the current regulations of entities whose objective is to reduce traffic accidents, such as the European Commission or EuroNCAP, the requirements for drowsiness detection systems validation tests are increasing. Validation tests can be conducted on test tracks (involving high cost and limitations by safety restrictions) and in a driving simulator (requiring a time and cost intensive integration process). Benefits of carrying it out in a laboratory-based driving simulator are the safety and the reproducibility of the experiments. [4]. To date, IDIADA has already developed specified methods for this type of testing, with a first successful application in proving ground since 2021.

Drowsiness definition

Drowsiness can be defined as the transition between the awake state and the sleep state where one's ability to observe and analyse are strongly reduced [5]. This transitional state usually goes hand in hand by physiological manifestations such as yawning, loss of neck muscle tone, pupillary constriction, ptosis, decreased attention, psychomotor and cognitive performance [2]. In addition, drowsiness mainly causes the following disruptions: increased reaction time, decreased concentration and more distractions, slower and more errors in decision making, motor disturbances and automatic behaviours, occurrence of micro dreams, sensory and perceptual disturbances, and changes in your behaviour [3].

Because of there are so many definitions of this concept, some authors disagree with each other. Even so, there are two concepts important to emphasise due to the contribution in developing different instruments that quantify drowsiness (instruments that we use in the present study): objective drowsiness and subjective drowsiness. The first refers to a person's tendency to fall asleep, and the second is considered as the subjective perception of the need to sleep associated with several subjective sensations and symptoms mentioned above [2]. Another way to measure drowsiness is gathering data from physiological parameters like electroencephalography (EEG), electrooculography (EOG), electrocardiography (ECG), respiratory rate and conductivity of the skin in where changes have been observed [6]. These changes include heart rate slowing, blinking, eyelid movement and breathing slowing, among others [7].

Purpose of the study
Considering the intention of increasing the benefits in terms of road safety for both driver and occupant [8] the aim of this study is to observe the effects of monotonous driving on long journeys on driver behaviour and to find patterns in variables for the development of driver monitoring systems.

OBJECTIVES

These testing activities have so-far involved representative inducements of sleepiness in naïve driver participants, with principal use of metrics for verification of sleepiness condition. Based upon discussions with existing and potential future automation industry needs, as identified two key areas of development for these types of sleepiness tests which form this paper objectives:

Technical objectives
The KSS (Karolinska sleepiness scale), regarded as the principal means of comparative evaluation, relies on participant subjective assessment. This additional objective measures have the potential to greatly improve the robustness of the assessment of participant condition. These are readily identified in literature, however there is a lack of a clear reference to critical KSS values.

Strategic objectives
Use of driving simulator and test tracks both involve prohibitive cost and timing implications for some validation activities. In response to this, a concept for a HiL (Human in the Loop) testing methodology has been developed, where relevant driver behaviour metrics would be fed into a client module for assessment of DMS sleepiness detection performance. Central to its potential implementation is the availability of a data set of relevant metrics for the detection of drowsiness / sleepiness in drivers with the KSS as a reference for subjective driver condition.

METHODOLOGY

Subjects
In this first phase of the study, 10 volunteers between 20 and 70 years were selected for the experiment, the proportion of which, between men and women, was almost equal: five and four respectively. Participants were separated into 4 groups during the course of the night: from 10 to 12pm, from 12 to 2am, from 2 to 4am and from 4 to 6am. This made it possible to englobe all the driving around the period of 2 pm to 4 pm, where it has been scientifically proven that the circadian rhythm renders a person more likely to get drowsy [3]. In addition, they were deprived of sleep by staying awake for the preceding 24 hours and were not allowed to drink coffee or any other type of stimulant either. All subjects signed a consent form, received a briefing (Annex 1), and did a previous questionnaire specifying driving characteristics and biometric measures as age, gender, height, skin tone among others (Annex 2).

Scenario's definition
Certain elements as the environmental stimulation, the time of the day, the hours of continuous wakefulness and driver's activity level can have an impact to the onset of drowsiness [3]. Taking this into consideration, we have implemented the following conditions for the test environment:

Table 1.
The conditions set for the KS-SLEEP tests

Time of the day	Participants did the test during the following interval of time: from 10pm to 6am. The scenario is configurated with to modes:

		- Day - Night
Wakefulness hours		Participants cannot sleep before the test to increase the hours that they are awake. They were not allowed to drink coffee or any other type of stimulant either.
Driver's activity level	Traffic	No random car traffic to avoid stimulating the driver's attention
	Luminosity of the environment	Dim light, that it is like at night and that the time also advances with the duration of the simulation
	Noises	No random noise. The scenario has been predefined with vehicle noise and ambient noise. To improve immersion, the sound of crossing the lane line has been reproduced.
	Speed	Sensation of speed at 80km/h. Annotation: We raise the speed in the simulator at 110 km/h to be able to reach this sensation.
Test track		A 20km highway loop, where you have a monotonous driving with a slightly changing environment in different places.
ACC ADAS system		The ADAS ACC system has been integrated into the vehicle model so that the participant can activate it during the test.

Measurement
Corresponding technologies and tools are used depending on the type of data. The data collected by the different data acquisition systems is integrated into the *iMotions* software. This software is an integrated analysis platform designed for human behavioural research and synchronizes all data obtained during testing.

Physiological sensors
The system used to collect EEG, ECG, EDA and respiratory data is *OpenSignals*. This *software* then shares the information with *iMotions*. The specifications of the sensors used are as follows:

a) Electroencephalography (EEG), one channel.
b) Electrocardiography (ECG), one channel.
c) Electrodermal Activity (EDA), one channel with two electrodes placed on the second and third finger of the hand.
d) Respiratory frequency with wearable chest-belt with an integrated localized sensing element.

Eye tracking
The system used for eye tracking is *SmartEyePro*. This system can determine the position of the head, the participant's features and iris and pupils' behaviour. Despite its multiple functionalities, the most relevant information for this project is eye opening and blinks. The instrumentation required to install this system consists of three cameras with their corresponding infrared light connected to the *SmartEyePro* computer where the software that processes the data is installed. This data is subsequently sent to *iMotions.*

The interest in this data collection lies in the measures of PERCLOS and blink measurement because they are one of the best indicators of drowsiness. Moreover, this data can be detected with non-intrusive, real-time detection systems, which is of benefit to users.

KSS
Karolinska Sleepiness Scale (KSS) is a 9-point scale able to measure the subjective level of sleepiness indicating which level is more in line with the psychophysical condition experienced [9]. It has been used in some studies to assess driving abilities and fatigue [10] [11]. Current regulations state that sleep monitoring systems must warn the driver when the driver is at KSS level 7 or higher.

This self-rated scale is assessed every 5 minutes by the experimenter asking to the volunteer "What is your perception of drowsiness in the last 5 minutes?". The participants were informed previously that was important to understand the scale for the proper functioning of the test. The experiment finalises when the participants reach the 8 level of drowsiness (where it is considered a certain effort to keep alert) or when 90 minutes have passed. Drowsiness subjective level is defined as follows:

Table 2.
Karolinska Sleepiness Scale (KSS)

Rating	Verbal descriptions
1	Extremely alert
2	Very alert
3	Alert
4	Fairly alert
5	Neither alert nor sleepy
6	Some signs of sleepiness
7	Sleepy, but no effort to keep alert
8	Sleepy, some effort to keep alert
9	Very sleep, great effort to keep alert, fighting sleep

Driving simulator

One of the main axes of this research is the Dynamic Driving Simulator: a cutting-edge tool with high added value that allows you to drive and experience dynamic driving sensations close to reality in a totally safe environment.

The simulator set-up consists of a cockpit based on a real VW Golf Variant 8 mounted on a dynamic platform with 9 degrees of freedom. The platform consists of a tripod for low frequencies and a hexapod for high frequencies which allows having movement and vibrations sensations while driving.

The cockpit interior is based on the actual vehicle, so all interior details are virtually the same. In addition, the cockpit also incorporates a parameterized active steering wheel and brake pedal, as well as a pneumatic seat and seat belt, which offer a more than correct response to the limitations of the platform movement when maintaining constant longitudinal and transversal accelerations. The driver's position inside the cockpit has no blind spots in terms of visibility and immersion within the virtual environment. The visual component is very important, so the driver will be surrounded by 5 fully merged and synchronized conical screens with a 240-degree field of view at frequency of 120Hz and 2k resolution.

At the software level, two different company tools are integrated. On the one hand we have the dynamic simulator software, provided by Vi-Grade, and on the other hand we have the virtual environment software, from AV Simulation. Both are being co-simulated and are fully integrated. The communication between the simulator computers and *SCANeR* is done entirely through the UDP protocol.

<u>**VI-Grade**</u>

VI-Grade is the company which provides the simulation tools and licenses. This includes different software such as SIMulation Workbench (for real-time execution and configuration of the processes and tests to be executed), VI-DriveSim (as a slightly more user-friendly interface of SIMulation Workbench), VI-CarRealTime (for the dynamics of the vehicle), VI-SimSound (for sound), etc.

<u>**AV Simulation**</u>

The AV SIMulation tool used in this study is comprehensive simulation platform called SCANeR Studio. SCANeR software takes care of everything related to the environment in which the car moves: the scenery. In addition, it also controls the interaction of the scenery with all the elements that appear on it. SCANeR is used to design the route and what the participant will see. The designed route runs along a 20km highway loop which is practically a linear road. In this way, a calm and smooth driving is achieved so that the participants have a high state of comfort and relaxation during all tests.

Procedure

The experiment has been distributed over 3 days, with 3 participants on the first day, 4 on the second day and 3 on the third day. Subjects were informed of the content of the study and signed the consent forms previously. They also completed a questionnaire beforehand (explained in Annex 1). Participants were transported by taxi from their home to our facilities to avoid driving before the test, which would have affected their alertness, and on their return home, to avoid the risk of driving after having been induced to sleep and due to the recommendation not to drive 30 minutes after driving on the simulator.

The experiments were preceded by a few minutes of pre-driving to make the participant comfortable with the driving simulator. Subjects were instructed to drive safely, respecting traffic rules, and behaving as close as possible to a real situation. When the participant felt adapted, the driving simulation started and was extended for 90 min. Procedures were prepared to begin the driving session around 2 pm. This made it possible to englobe all the driving within the period of 2 pm to 4 pm, where it has been scientifically proven that the circadian rhythm renders a person more likely to get drowsy [3]. Aside from the driving task, participants were asked to rate their levels of drowsiness/alertness through the KSS, in 5-minute intervals.

PRELIMINARY RESULTS AND DISCUSSION

Expected results from this paper was obtaining objective measures to give robustness to the subjective Drowsiness Detection Assessment and to develop a drowsiness baseline data set. This also will be useful for the current development of ADAS, and ADS technologies related with driver drowsiness detection.

Objective measures of sleepiness are identified in the literature, but there is no clear correlation with KSS values, suggesting the complexity of identifying behavioural patterns easily generalisable to the population. In this first phase of the analysis, we have focused on validating the methodology to be applied in a second phase of the experiment and, secondly, on obtaining a data profile in relation to the results expected by the literature and exploring a possible relationship with the level of KSS. The study is still ongoing, and although we will not draw firm conclusions at this stage, it is a good opportunity to analyse objective data on drowsy behaviour collected under controlled test conditions. Thus, the following is a sample of some of the data obtained by one of the participants:

Physiological data

Regarding heart rate, the expected results are that it decreases as the level of drowsiness increases, being aware that the normal heart rate ranges between 60-100 beats per minute (bpm). Two further indicators that participants are approaching a state of drowsiness are increased yawn frequency and decreased respiratory rate. Normal breathing in adults is regarded as between 12 and 25 breaths per minute. In both cases the trend of the data is as expected. Figure 1, Figure 2 and Figure 3 show participant results in relation to the declared KSS level.

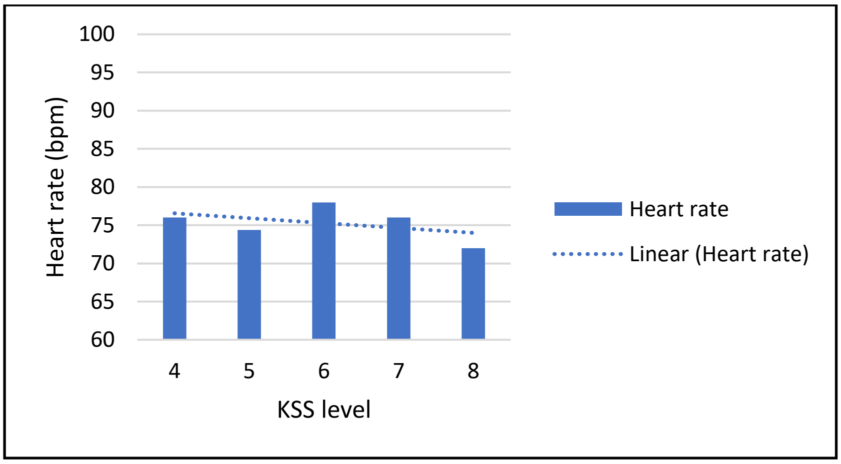

Figure 1. Heart rate-KSS level.

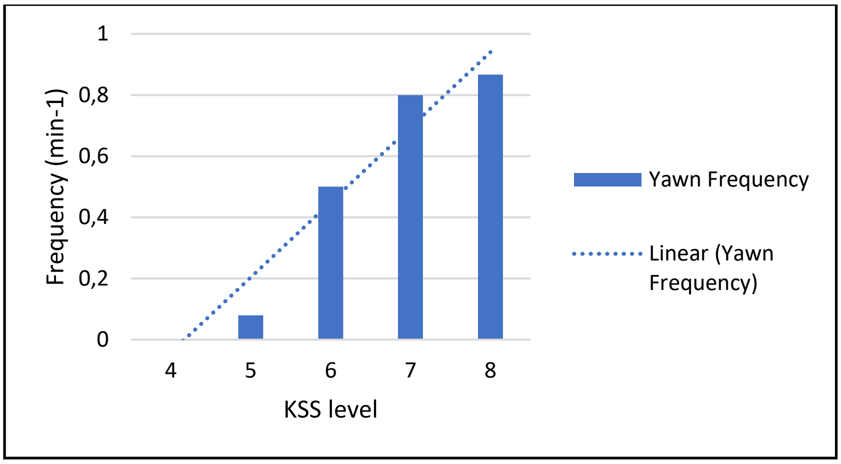

Figure 2. Yawn frequency-KSS level.

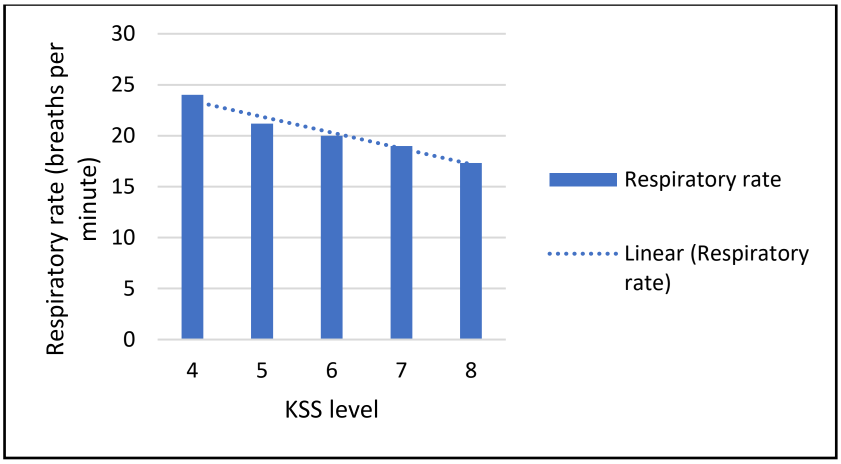

Figure 3. Respiratory rate-KSS level.

CONCLUSIONS AND NEXT STEPS

In this paper we present data that validate the method proposed in this first phase. This will be used to apply it in a second testing phase. The most relevant observed trends concerning one participant are: a) A relation between KSS level and yawning frequency: as the level of KSS increases, so does the frequency of yawning. This is not best explained by the time the participant resides in each KSS phase, as it refers to KSS=5 level for 25 minutes, while KSS=8 level only lasts for 15 min.; b) Regarding heart rate, it seems that decrease while KSS level increase. Even so, empirical assessment of the data will be necessary to draw definitive conclusions; and c) Respiratory rate decrease as expected while KSS level increase.

Once the methodology has been designed and validated, two parallel future lines of action emerge. On the one hand, consolidate the application of the methodology in the second testing phase in order to be able to reach definitive conclusions and, on the other hand, its improvement and extension.

- After a first analysis of this first loop of testing, the following aspects have been detected and should be considered for the second testing phase: Initially, the premise was to reach KSS level 8. However, as the simulator was assessed as a safe and risk-free space, it was considered to increase this level to score 9 to assess a further stage of sleepiness and its effects.
- Participants: it is important to EEG sensors signal that the volunteers come without products on hair. It has been observed that this interferes with the sensor signal.
- Extension of the instrumentation: it is proposed to extend the ECG sensors instrumentation to optimise their signal and to place some more cameras to obtain better visualisation of the participant's behaviour.
- Instrumentation variation: change EDA sensors (Electrodermal Activity) to obtain clearer results than with the present sensors.

As for the application of this methodology in future development, these are the main proposals for its implementation:

- Assessment of the effect of drowsiness on drivers.
- Comparative analysis of different drowsiness detection systems.
- Evaluation of the influence of distractions on the evolution of sleepiness.
- Validation of new systems in an autonomous vehicle.
- New users: the idea is to be able to apply the methodology developed to new groups of users.

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APPENDICES

Appendix A

Participants' briefing
Thank you for participating in this study. In this document we explain the details of the test that you will voluntarily take as part of a research project of the Human Factors team of the ADAS department at APPLUS+ IDIADA.

Before it is important that you understand why the research is being conducted and what it consists of. Please read this document carefully and ask the research staff any questions you may have. You will be asked to sign a consent form confirming that you have read and agreed to all the information contained in this document. In addition, you will be given a document requesting your consent to share the data recorded during the test with the client responsible for the study.

It is important that before the test you do not drink stimulating substances or beverages such as coffee, nor are you under the influence of any medication, alcohol or other drugs that could affect your alertness during the test. The research staff will inform you when the test is completed.

Description of the activity
The aim of this test is to observe the effects of monotonous driving on long journeys on driver behaviour. This type of study is important for the development of new driver monitoring systems capable of improving the safety of both driver and occupants.

The test will be conducted on the dynamic driving simulator. During the test, you will be asked to drive for 90 minutes in the centre of the lane at a constant speed.

Every 5 minutes, the researcher will ask you about your drowsiness, which will be assessed using the Karolinska Drowsiness Scale. It is important that you carefully read and understand the scale for the proper functioning of the test. It is defined in Table A1.

Table A1.
Karolinska Sleepiness Scale (KSS)

Rating	Verbal descriptions
1	Extremely alert
2	Very alert
3	Alert
4	Fairly alert
5	Neither alert nor sleepy
6	Some signs of sleepiness
7	Sleepy, but no effort to keep alert
8	Sleepy, some effort to keep alert
9	Very sleep, great effort to keep alert, fighting sleep

You will report your state of sleepiness by giving a value from 1 to 9 according to your actual state. In the course of the test, we will collect data from different sources: your driving behaviour, your interaction with the vehicle controls and your visual behaviour while driving will be recorded. In order to measure behavioural effects, we will instrument you with a total of 9 sensors (distributed on the head, abdomen and right hand) that will collect physiological signals such as heart rate, respiratory, skin conductivity and brain waves.

During the first 5 minutes of driving feel free to ask any questions you may have, but please remain silent for the rest of the test to avoid influencing your alertness through no fault of your own.

We remind you that participation is entirely voluntary. If for any reason you wish to stop driving, please inform us and you are free to leave the test.

Appendix B

Table B1.
Biometric data

1. Age
2. Gender
3. Driving experience (years)
4. Overall driving frequency (hours/week)
5. Commuting frequency (hours/week)
6. Skin tone (Fitzpatrick scale)
7. Standing stature (cm)
8. Maximum distance between eyes (mm)
9. Minimum distance between eyes (mm)
10. Nose length (mm)
11. Vertical relaxed left eye-opening aperture (mm)
12. Vertical max left eye opening aperture
13. Horizontal relaxed left eye-opening aperture
14. Vertical relaxed right eye-opening aperture (mm)
15. Vertical max right eye-opening aperture
16. Horizontal relaxed right eye-opening aperture