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DEGLI STUDI
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DIPARTIMENTO DI INGEGNERIA DELL'INFORMAZIONE

CORSO DI LAUREA IN INGEGNERIA BIOMEDICA

Preliminary Study for the Measurement of Biosignals in Driving Simulators

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Contents

1. Abstract.....	4
2. Introduction.....	7
3. Method.....	9
3.1 Study design.....	9
3.1.1 Scenarios.....	9
3.1.2 Biosensor data collection.....	11
3.2 Hardware and Software.....	13
3.2.1 Simulator.....	13
3.2.2 Biosensors devices.....	13
3.2.3 Comunication and integration.....	18
4. Data analysis.....	19
4.1 Raw datas.....	20
4.2 Examples of postprocessing.....	25
5. Discussion.....	28
6. Conclusion.....	31
7. References.....	32

1. Abstract

Questo studio preliminare si concentra sull'obiettivo di sviluppare e testare un set-up e un metodo per il monitoraggio non invasivo delle persone utilizzando biosensori durante la guida di un simulatore di auto professionale (VI-grade Compact Simulator).

Questo implica la sincronizzazione e l'integrazione di componenti hardware e software.

Per rilevare lo stato emotivo e cognitivo del conducente, è cruciale identificare quali segnali forniscono informazioni affidabili sulla loro condizione.

L'obiettivo di questo studio è osservare le persone in un ambiente controllato e ripetibile progettato per stimolare il carico cognitivo. Ciò è stato realizzato attraverso l'uso di un metodo di valutazione multimodale (iMotions), che include il tracciamento degli occhi, la risposta galvanica della pelle (GSR), l'elettromiografia (EMG) e la misurazione della respirazione, tutti condotti durante due scenari distinti di simulazione di guida controllata.

Quattro soggetti in salute (età media = 24, deviazione standard = ± 2) sono stati monitorati durante il primo scenario, un'autostrada con manovre di emergenza ripetute (slalom tra i coni e doppio cambio di corsia) e il secondo, cinque giri del circuito di Paul Ricard. Il tutto per una durata totale di circa 20 minuti. I partecipanti non erano a conoscenza che gli scenari fossero progettati con lo scopo di provocare reazioni diverse.

Questa tesi sperimentale vuole essere la continuazione ed evoluzione di una fase di testing svoltasi precedentemente durante il tirocinio presso iMotions, azienda sviluppatrice di software di streaming multimodale e rivenditrice di hardware commerciale, che sono stati forniti al NAVLAB dell'Università di Padova dove è presente il simulatore.

I risultati ottenuti sembrano, in prima analisi, coerenti con la letteratura, suggerendo che un approccio multimodale ai segnali fisiologici possa caratterizzare gli stati emotivi e cognitivi in scenari di guida.

This preliminary study focuses on the goal of developing and testing a setup and method for non-invasive monitoring of individuals using biosensors in a professional driving simulator (VI-grade Compact Simulator).

This involves the synchronization and integration of hardware and software components.

To detect the emotional and cognitive state of the driver, it is crucial to identify which signals provide reliable information about their condition.

The objective of this study is to observe individuals in a controlled and repeatable environment designed to stimulate cognitive workload. This was achieved using a multimodal assessment method (iMotions), which includes eye tracking, galvanic skin response (GSR), electromyography (EMG), and respiration measurements, all conducted during two distinct controlled driving simulation scenarios.

Four healthy subjects (average age = 24, standard deviation = ± 2) were monitored during the first scenario, a highway with repeated emergency maneuvers (slalom through cones and double lane change), and the second, five laps of the Paul Ricard circuit. All of this for a total duration of approximately 20 minutes. The participants were not aware that the scenarios were designed to provoke different reactions.

This experimental thesis aims to be the continuation and evolution of a testing phase previously conducted during an internship at iMotions, a company that develops multimodal streaming software and distributes commercial hardware. The hardware was supplied to the NAVLAB at the University of Padua, where the simulator is located.

The results obtained, at first analysis, appear to be consistent with the literature, suggesting that a multimodal approach to physiological signals may characterize emotional and cognitive states in driving scenarios.

2. Introduction

Monitoring individuals non-invasively to gather psychophysiological information in a specific moment or environment is of growing interest in various fields. One of these fields is the automotive industry, which is constantly seeking greater comfort and safety for this complex and dangerous activity that involves a significant portion of the population. Recent studies indeed report that road accidents are caused by factors such as fatigue, distraction, excessive cognitive load, or simply what is commonly referred to as stress.

For this research purpose, the professional driving simulator (VI-grade Compact Simulator) is increasingly being used. [1] Virtual reality allows for the isolation of variables and makes a task repeatable over time and space, without posing any risks.

The laboratory environment enables the use of highly sensitive real-time monitoring systems under controlled physical and environmental conditions.

Consequently, the fusion of physiological measurements with VR applications holds significant promise. Numerous studies have explored the potential and advantages of this fusion across a wide spectrum of application domains. Nonetheless, the diversity of potential application areas, along with a multitude of valuable physiological parameters, sensor types, target variables, influencing factors, as well as analysis methods and strategies, is extensive.

For our preliminary case study, the objective is to explore the potential and adaptability of commercial biomedical devices (provided by iMotions) in the field of driving simulation, including the integration and synchronization of individual systems to establish a repeatable and reliable monitoring protocol while addressing associated challenges.

In literature, several biosignals have been used often in combination with each other. In a study by Nourbakhsh and colleagues [2], they utilized electrodermal activity (EDA) and eye blink patterns to evaluate cognitive workload during an arithmetic task. In a different context, Tsunoda and associates [3] employed heart rate variability (HRV) to investigate cognitive load in the advanced trail making test. Furthermore, Heeman and his team [4] employed pupillary

diameter as an indicator to estimate cognitive load during a dialogue task. [5] Regarding respiration, an interesting study is the one conducted by C. J. Wientjes, “Respiration in psychophysiology: methods and applications,” *Biological psychology*, vol. 34, pp. 179-203, Nov. 1992 Closer to our goal, BMW in their research “Correlation Between Subjective Driver State Measures and Psychophysiological and Vehicular Data in Simulated Driving” [6] used HR and SCL (skin conductance level).

We have chosen to focus our study by using four biosensors:

EDA: Electrodermal activity is measured in areas of the body where sweat glands are present, such as the armpits, palms of the hands, and soles of the feet. The data can be a measure of resistance or potential difference. Closely linked to the activity of the sympathetic nervous system, it is used as an indicator of excitement and engagement. Prolonged activity over time can be associated with symptoms of discomfort and unease.

RESPIRATION: This refers to respiratory rate, which can be measured either directly with elastic bands around the chest or derived from the heart rate signal. It is often used in combination with other sensors.

EMG: Electromyography measures muscle activity at the muscle spindle. The sensors can range from minimally invasive to more invasive, depending on the depth and size of the muscle. The data represents a potential difference. It can be used both as an immediate response to an event and as prolonged muscle activity. It could be useful as an indicator for posture analysis, reactivity, and fatigue.

EYE TRACKING: This technology can capture various information, with the primary one being the direction of gaze detected through infrared cameras. Visual information is processed very quickly, so eye movement can be an excellent indicator of fatigue, confusion, what captures our attention and for how long (dwell time). (There is also a mention of plans to integrate eye tracking into all vehicles by 2025.)

The two driving scenarios are designed to provoke different stimuli: the first scenario aims to challenge reaction times, while the second aims to induce engagement and fatigue.

3. Method

In this chapter, a detailed description of experimental environment, study design and protocol. For our preliminary study, we monitored four healthy participants (mean age = 24, std = ± 2) in two different scenarios, totaling approximately 20 minutes.

The participants were brought into the NAVLAB laboratory, only one of them had ever driven the simulator before. Electrodes were applied, and during this phase, it was explained that in case of nausea or discomfort, the test would be stopped. A check of sensor connectivity and functionality was conducted before they got onto the simulator. Once inside, they were briefed on the basic operation of the vehicle with automatic transmission, and seat belts were set in a comfortable position relative to the pedals and steering wheel. Subsequently, calibration for eye tracking was performed, followed by the maximum contraction of the two monitored neck muscles. With the lights turned off to achieve maximum immersion in the scenario, the task was explained.

3.1. Study design

3.1.1 Scenarios

First Scenario (3 lanes): Driving on a straight road with the task of accelerating as much as possible and then braking with maximum intensity near the cones.

First maneuver: Slalom.



Second maneuver: Double Lane Change.



The two emergency maneuvers are separated by 500 meters, during which the task is once again to accelerate maximally. This sequence is repeated ten times. Second Scenario (Paul Ricard): Driving on Paul Ricard circuit, participants were instructed to complete 5 laps with the goal of staying on the track.



All participants completed both scenarios consecutively (first the 3 lanes scenario and then the circuit). During the experiment, six vehicle channels were recorded (brake, steering wheel angle, throttle, lateral acceleration, longitudinal acceleration, vertical acceleration).

3.1.2 Biosensors data collection

RESPIRATION. Respiration rate was recorded using a stretch belt on the chest. Respiration rate (cycles/min) was determined based on the respiration count. It used the inductive sensing technology. It is designed to extract temporal and spectral parameters to provide information about the breathing dynamics, such as respiratory rate, amplitude parameters, and basic spectral analysis.

EMG. EMG activity was recorded from the right upper trapezius muscle (agonist) and right sternocleidomastoid muscle (antagonist) using bipolar surface EMG electrodes. The reference electrode was placed on the right acromion. EMG signals. The maximum voluntary contraction of both of the muscles has been recorded before each task. For the upper trapezius the MVC has been measured asking to the participant to push with the back of the head against the hand for 4/5 seconds, for the sternocleidomastoid push with the foreign instead.



Figure 1. EMG electrodes sternocleidomastoid muscle.

EDA. EDA positioning the two electrodes on the palm on the thenar eminence zone and one on the hypothenar eminence of the non-dominant hand, using skin resistance measurement.

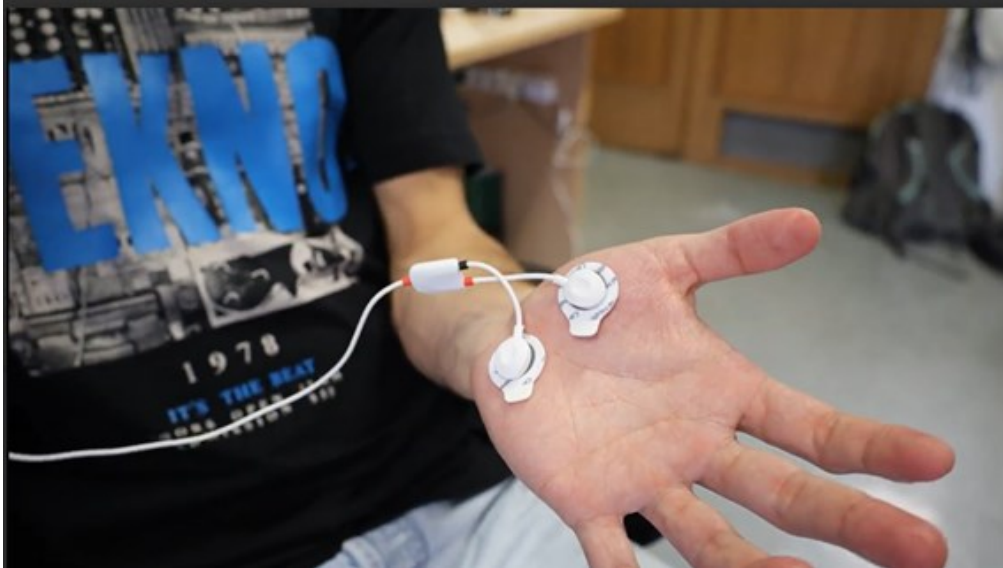


Figure 2. EDA electrodes.

EYE TRACKING. Tobii Glasses 2 system has been used for the eye tracking. Calibration was performed on each participant before each task using the single-point calibration integrated into the iMotions software.

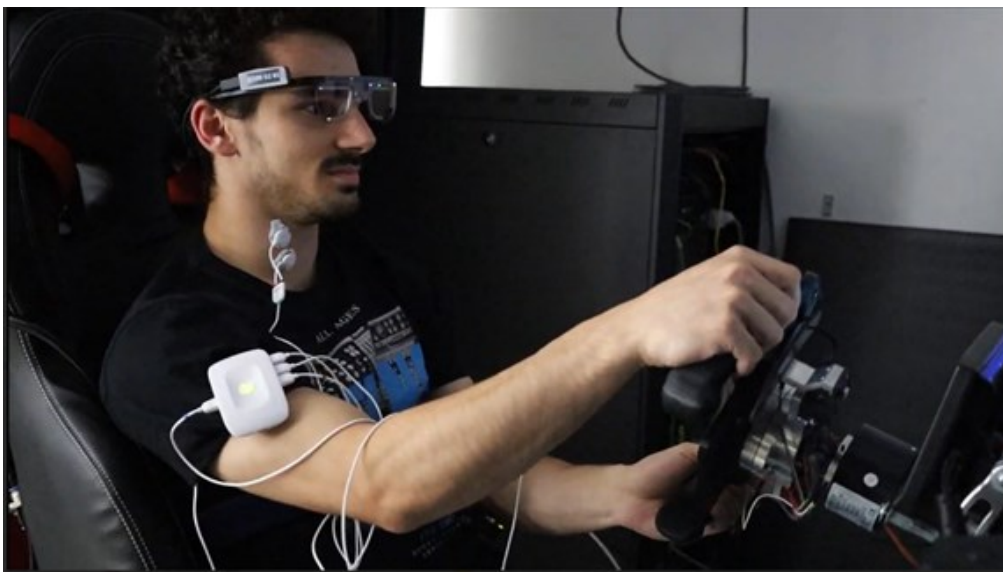


Figure 3. Participant wearing eye tracking glasses.

3.2. Hardware and Software

3.2.1 Simulator

The driving simulator used is a Compact Simulator by VI-grade. It consists of a static driving station with a steering wheel, pedals, and automatic transmission. The image is projected onto a curved screen (dimensions: 2.5x1.5m , 2 m distance from the head) by a projector positioned on the ceiling behind the driver. It is equipped with systems to enhance the level of immersion: Active belt: A five-point seatbelt that is activated with varying intensity to simulate the inertia force that should be felt on the body during braking.

Active seat: A system of cushions inside the seat, both lateral and longitudinal, that are inflated and deflated to simulate the pressures experienced on the body due to longitudinal and centripetal forces.

The main software VI-Drivesim runs on a Concurrent Computer pc (LINUX OS) that is responsible for all the operations of the simulator through a specialized GUI: it activates VI-CarRealTime (the vehicle physics simulator), connects to active seat and belts through beckoff I/O units and to a graphic WIN OS pc on which the VI-Graphsim graphic software for the scenario rendering is running. On the same pc, also the audio software is commanded by the VI-CarRealTime simulation.

3.2.2 Biosensors

Biosignals Plux: A device with up to 8 channels, including one reference channel and the Digital Port.



Figure 4. Biosignal Plux device.

Electrodermal Activity: Channel #1, with a cable that has one end connected to the device and two clip heads on the other end to attach to electrodes.

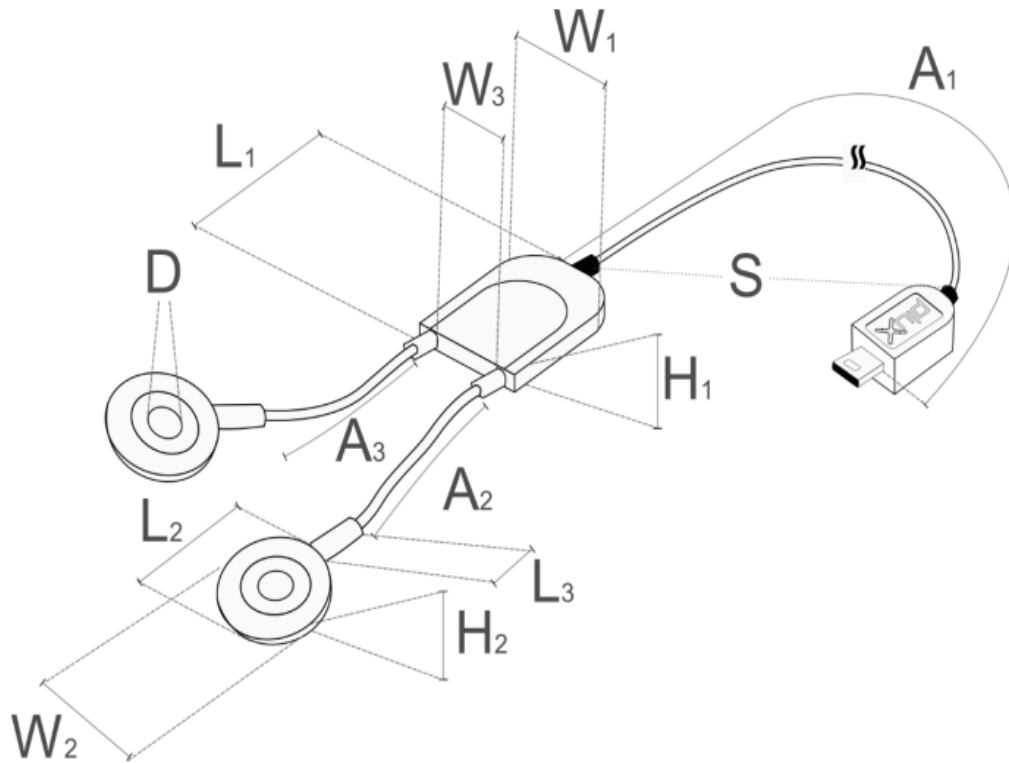


Figure 5. EDA cable.

Range: 0-25 μ S (V_{CC} =3V) > Bandwidth: 0-3Hz > Consumption: \pm 0.1mA > Input Bias Current: \pm 70pA > CMRR: 130dB > Measurement: continuous > Current: DC.

TRANSFER FUNCTION:

$$EDA(\mu S) = \frac{ADC}{2^n} \times \frac{VCC}{0.12}$$

$$EDA(S) = EDA(\mu S) \times 1 \times 10^{-6}$$

[0 μ S, 25 μ S]

$V_{CC} = 3V$ (operating voltage)

$EDA(\mu S)$ – EDA value in microsiemens (μS) $EDA(S)$ – EDA value in siemens (S) ADC – Value sampled from the channel n – Number of bits of the channel

Electromyography: Channel #2 and Channel #3. Are both and the references a cable that has one end connected to the device and two clip heads on the other end to attach to electrodes.

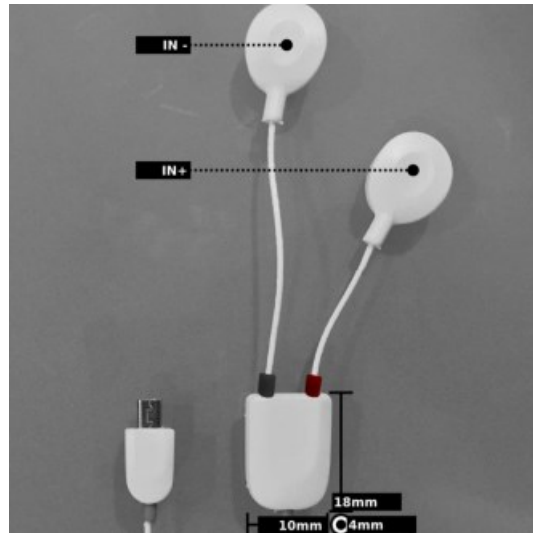


Figure 6. EMG cable.

Gain: 1000 > Range: $\pm 1.5mV$ (with $VCC = 3V$) > Bandwidth: 25-500Hz > Consumption: $\sim 1mA$ > Input Impedance: $> 100G\Omega$ > CMRR: 100dB

TRANSFER FUNCTION:

$$EMG(V) = \frac{\left(\frac{ADC}{2^n} - \frac{1}{2}\right) \cdot VCC}{G_{EMG}}$$

$[-1.5mV, 1.5mV]$

$EMG(mV) = EMG(V) \cdot 1000$ $VCC = 3V$ (operating voltage) $G_{EMG} = 1000$ (sensor gain) $EMG(V)$ – EMG value in Volt (V) $EMG(mV)$ – EMG value in millivolt (mV) ADC – Value sampled from the channel n – Number of bits of the channel

Respiration: Channel #7.

Bandwidth: 0.075-1Hz



Figure 7. Respiration stretch belt.

TRANSFER FUNCTION:

$$RIP(\%) = \left(\frac{ADC}{2^n} - \frac{1}{2} \right) \cdot 100\%$$

[-50%, 50%]

RIP % – Displacement value in percentage (%) of full scale ADC – Value sampled from the channel n – Number of bits of the channel.

Tobii Glasses 2: Head Unit: 1. High-definition scene camera – Captures a Full HD video of what is in front of the participant. 2. Microphone – Picks up sounds from the participant and its surroundings. 3. Eye tracking sensors – Records eye orientation e.g. the direction of the eye gaze. 4. IR illuminators – Illuminates the eyes to support the eye tracking sensors. 5. Micro HDMI connector – Connects to the recording unit via the supplied HDMI cable. 6. Cable guide – Guides the HDMI cable towards the participant's back. 7. Protective lens – Both clear and tinted versions supplied 8. Nose pad — Exchangeable and available in different sizes.

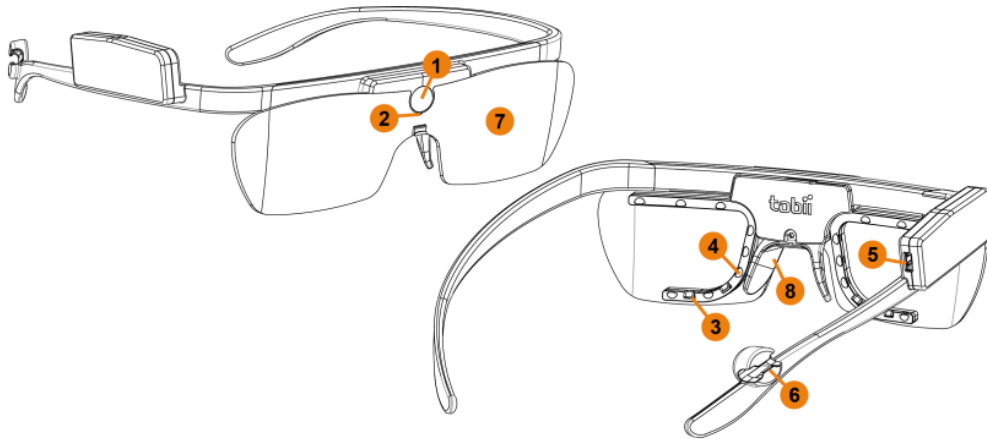


Figure 8. Tobii Glasses 2 head unit.

Recording Unit: 1. Power button and power indicator LED - Touch button that turns the recording unit on and off. LED indicates power state and remaining battery power. 2. 3.5 mm connector for data synchronization – TTL pulse for synchronization with external data sources. 3. LAN port – Connects to a Windows tablet or computer running the controller software, via the supplied Ethernet cable. The recording unit can also be connected to the tablet or computer via WLAN. 4. Connection status LED – Indicates connection to the controller software. 5. SD card Activity LED – Indicates if SD memory card is present and if the recording unit is busy writing on the SD memory card. 6. HDMI connector – Connects to the head unit via the supplied HDMI cable. 7. Micro USB connector – Connects to USB charger for powering the unit and charging the battery. 8. Slot for SD memory card for storage of recorded data.

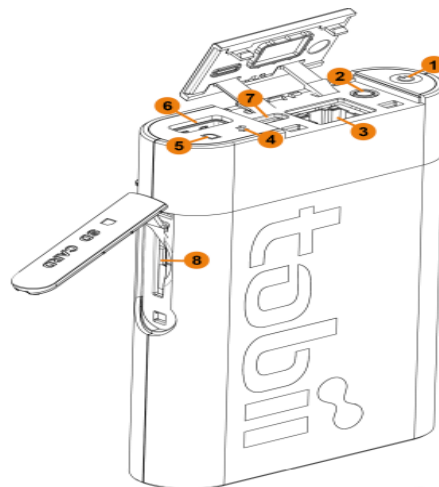


Figure 9. Tobii Glasses 2 recording unit

OpenSignals: OpenSignals software supports real-time data acquisition and visualization from all Biosignalsplux devices. The acquired data can be visualized after the acquisition and exported in the .TXT, .H5, and .EDF file formats to compatible third-party software in addition, OpenSignals comes with built-in streaming features which allows you to stream the acquired data to third-party software using the open-source Lab Streaming Layer (LSL) and TCP/IP protocols.

Tobii glasses 2: Tobii Glasses Controller enables the simultaneous viewing of real-time eye tracking data overlaid on the scene camera video during recording. Additionally, it displays essential details such as remaining battery life, available memory time, and recording duration. It's important to note that the streaming function is operational only when the Recording Unit is connected to the Glasses Controller Software, either through WLAN or a wired connection.

iMotions: The iMotions software (iMotions 9.3.3, iMotions A/S, Denmark) has been used. Is a modular system, allowing for the integration of various biosensors and their corresponding modules. This versatile approach aims to simplify the process of conducting human behavior studies, synchronizing different devices. In this study the stimulus is the Tobii Glasses 2 scene so what is recorded with the camera of the glasses.

The three software were running on Windows on the Solver Computer.

3.2.2 Communication and integration

Sending to iMotions: In the VI-Drivesim software, has been incorporated iMotions iodb, which generates an .xml file containing selected vehicle channels. When the simulator is activated, it initiates the transmission of data packets via UDP for the car channels. In OpenSignals, the software is launched in the background, and we select channels (EDA #1, EMG1 #2, EMG2 #3, RIP #7) and their positions using the GUI. Additionally, we set the sampling frequency (noting that the chosen frequency applies to all channels) at 1000Hz. Enabling the Lab Streaming Layer option is also necessary.

For Tobii Glasses 2, we initiate the controller and, once the connection is established, close the background software. Subsequently, it begins transmitting data via TCP with a frequency ranging between 50-60 Hz.

Receiving from iMotions: In the iMotions software, we enable the "Event Receiving" option, specify the port, and load the required formatted .xml file to facilitate data reception.

Within the iMotions directory, we've added an LSL_NotebookMapping_BiosignalPlux.json file, containing the channel names in OpenSignals and their corresponding counterparts in iMotions.

To enable the Eye tracker server in iMotions when using Tobii Glasses 2.

We encountered several challenges during the setup construction, including:

1. The VI-grade Solver computer lacks Wi-Fi and Bluetooth cards, making the connection of biometric devices more complex. The Tobii Glasses recording unit had to be connected via LAN, necessitating manual data retrieval from the SD card for each participant.
2. The use of a Bluetooth dongle for connecting the Biosignal Plux, resulting in a highly unstable connection.
3. The limited battery capacity of the Tobii Glasses recording unit, which couldn't sustain a full testing session, and slow recharging times.

4. Data analysis

All signal processing was conducted using the iMotions (iMotions 9.3.3, iMotions A/S, Denmark) and Matlab. The raw data was exported from the multimodal iMotions software (version 9.3.3) to a CSV file and then imported into MATLAB. The raw data was analyzed for quality and reproducibility, and subsequently, we wanted to provide some examples of possible analyses.

4.1. Raw data

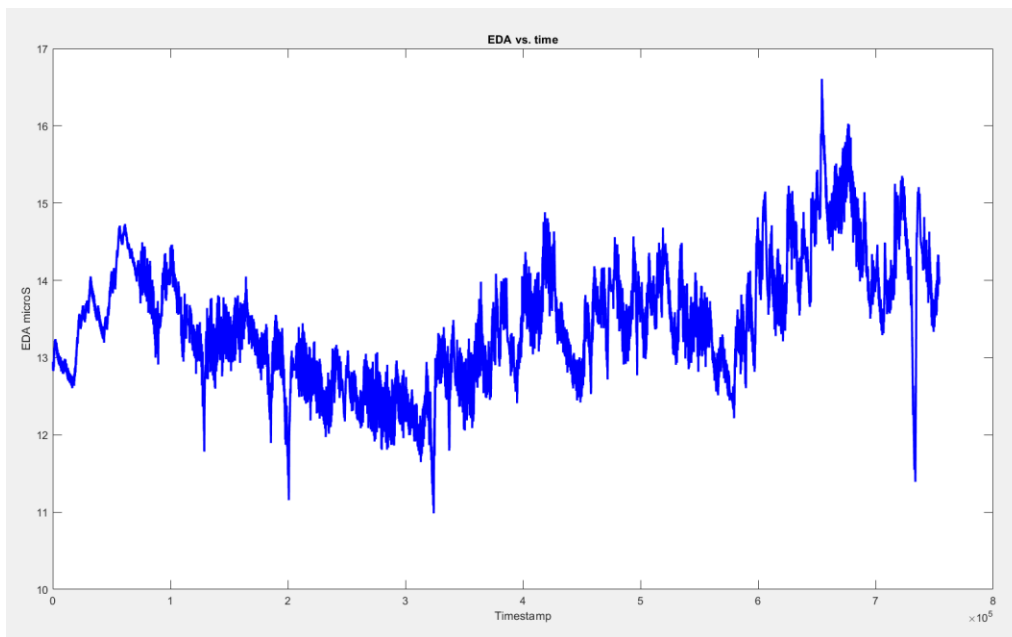


Figure 10. EDA vs time.

This plot represent the raw data of the galvanic skin response signal of a participant during the 5 laps driving session at the Paul-Ricard circuit. Two different frequencies can be observed: the tonic signal (which represents low-frequency variations) and the phasic signal (which represents high-frequency variations). We were able to use the EDA data from only one out of four participants in both scenarios.

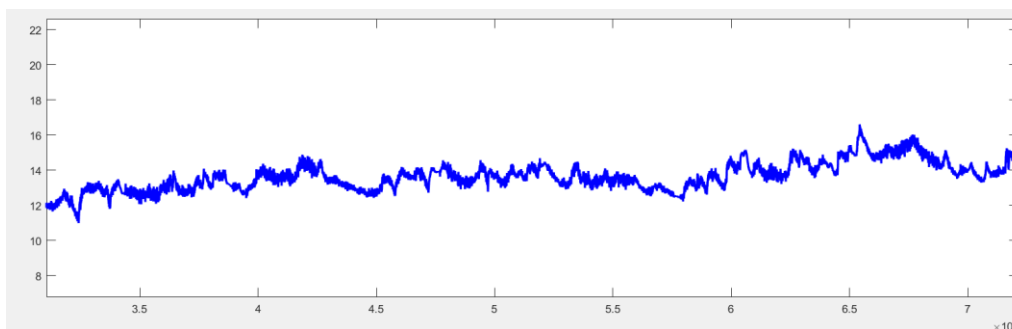


Figure 11. Zoom in of the EDA signal

The signal is quite noisy, likely due to motion and environmental noise, but it is perfectly recognizable. In the EDA plot, it is represented in microSiemens, and the time is in milliseconds.

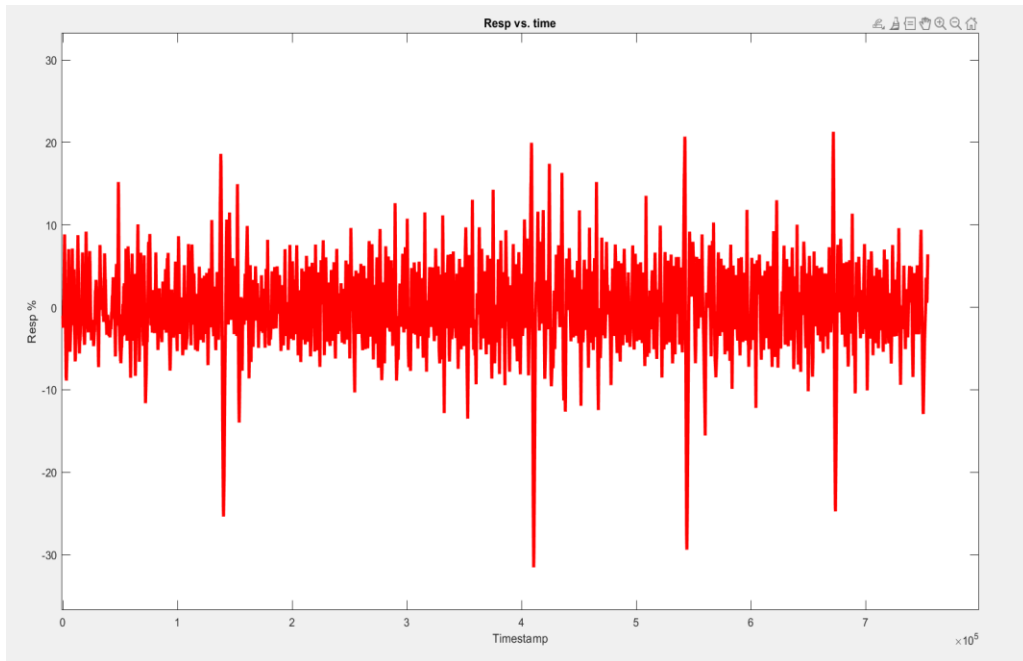


Figure 12. Resp vs. time

The figure represents the respiration of the same participant during the 5-lap driving session at the Paul-Ricard circuit.

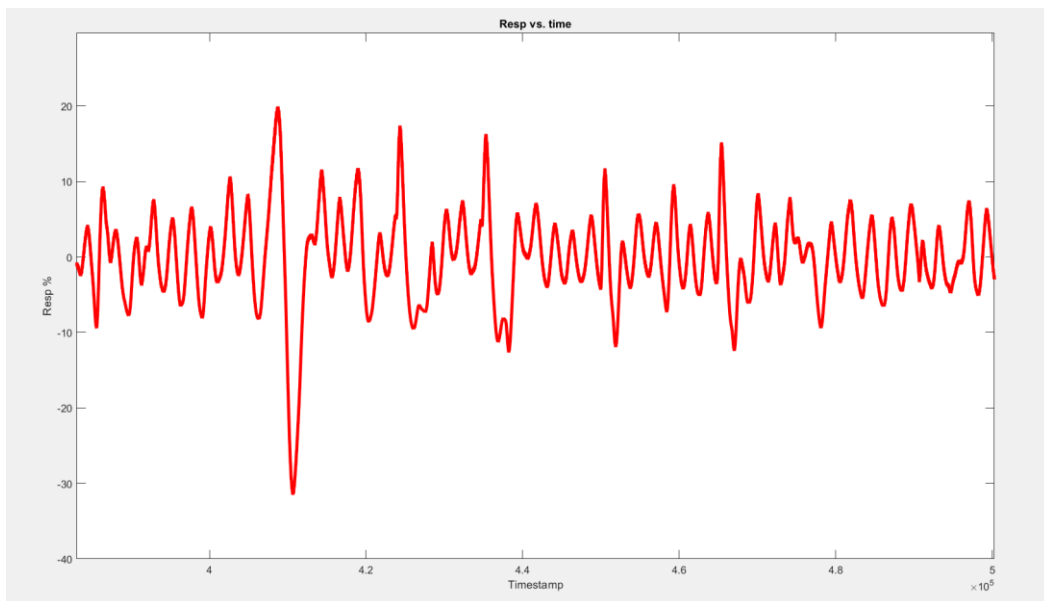


Figure 13. zoom in one minute of respiration signal.

In one minute zoom the signal is smooth and clear despite the movement and the active belts positioned on the shoulders and chest. The percentage unit is how RIP band measures the "Displacement measurement.”:

- 0% displacement = at rest
- + % positive displacement = inhaling
- % negative displacement = exhaling

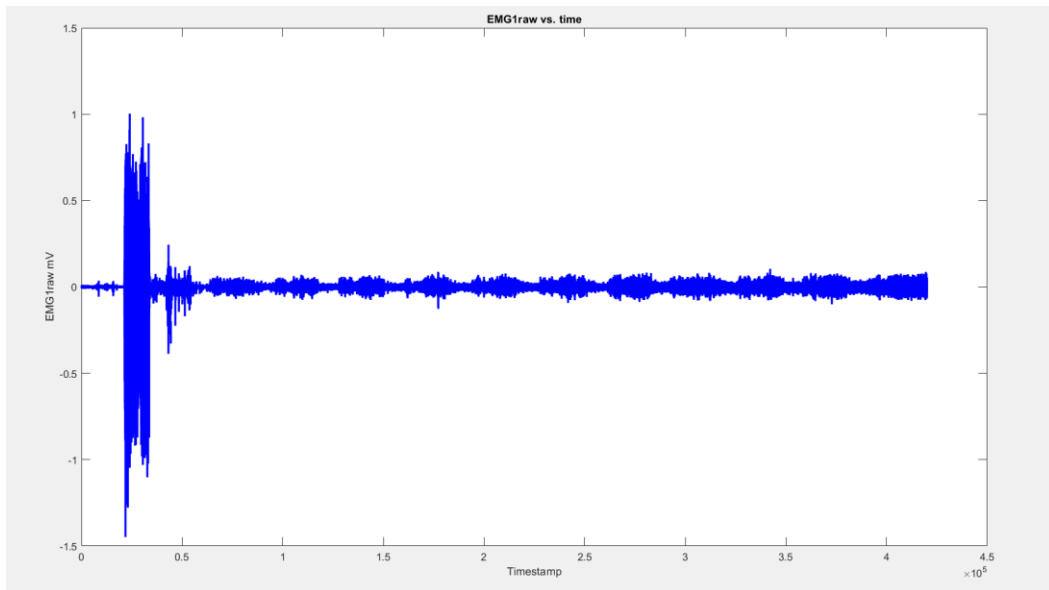


Figure 14. All record EMG1rawdata vs. time.

The figure represent the complete recording of the sternocleidomastoid muscle during driving between the cones, the signal is noisy but clear. Not all participants had a clear signal from both muscles before applying smoothing and filters. This is likely due to interference from hair on the electrode, cable movement caused by the active seat and active belts. In particular, the upper trapezius muscle, on average, had lower signal quality. EMG signal is rappresented in mV.

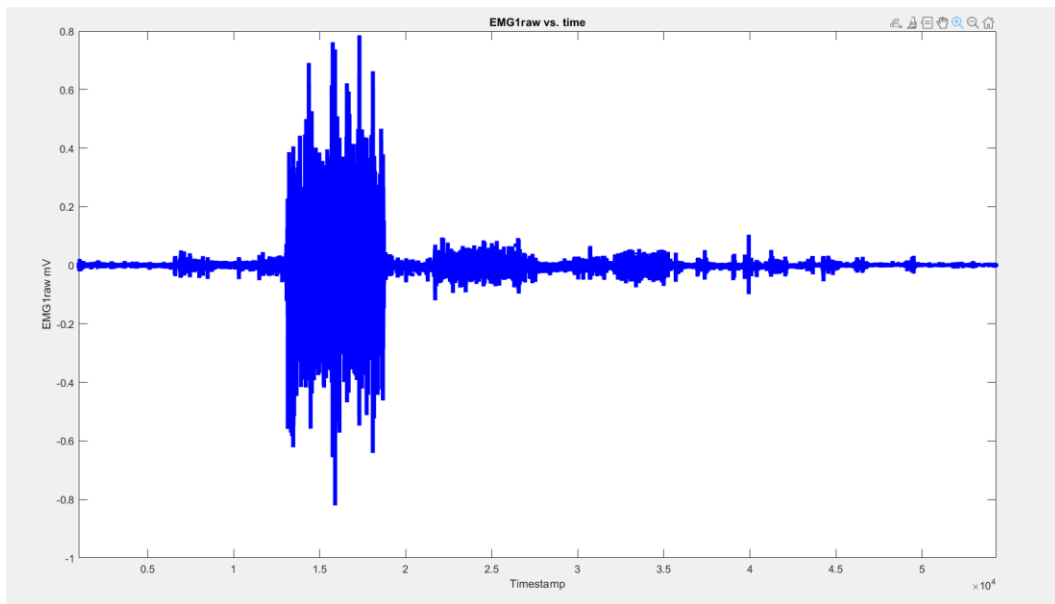


Figure 15. Maximum Voluntary Contraction sternocleidomastoid muscle vs. time.

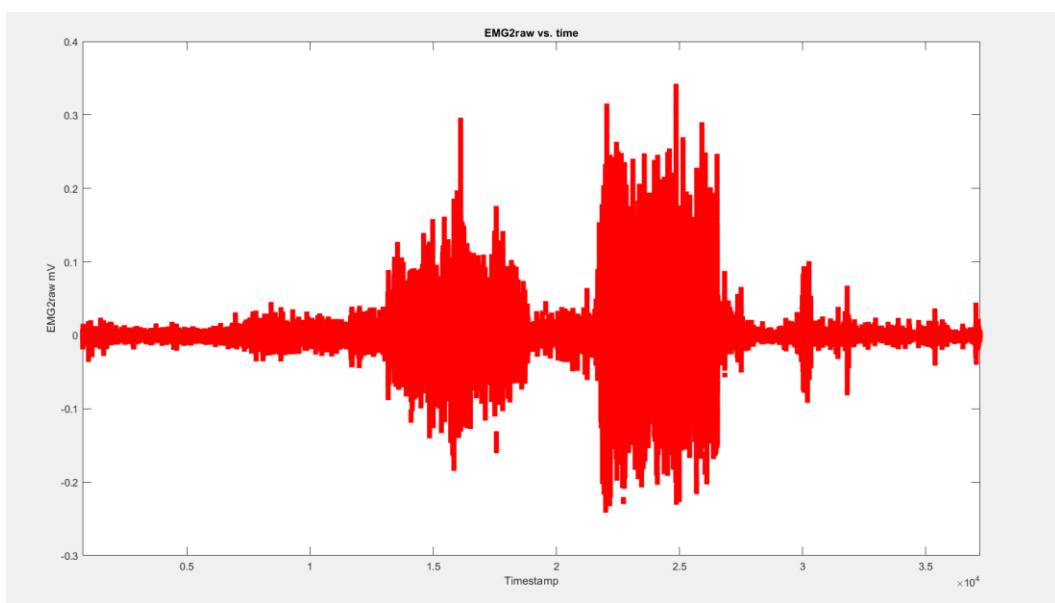


Figure 16. Maximum Voluntary Contraction upper trapezius muscle vs. time.

The recording of the Maximum Voluntary Contraction (MVC) was performed for each participant in each scenario. Subsequently, this recording segment was separated to be used for signal normalization.

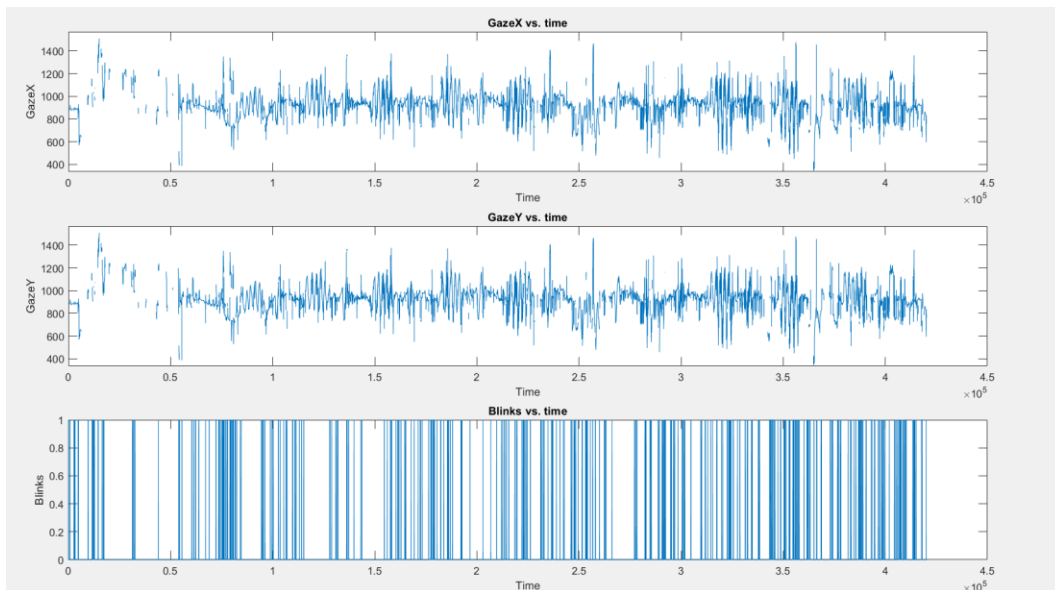


Figure 17. GazeX , GaxeY raw signal and Blink detection

The quality of the eye tracking signal is calculate in percentage in the iMotions software. This percentage represents the rate of the samples in the recording that are detected. An acceptable percentage is above 80%. In our recordings, 3 out of 4 participants have a value higher than 80%. In the figure below the missing datas are simultaneously with the blink, in this recording the achieved quality was 98%

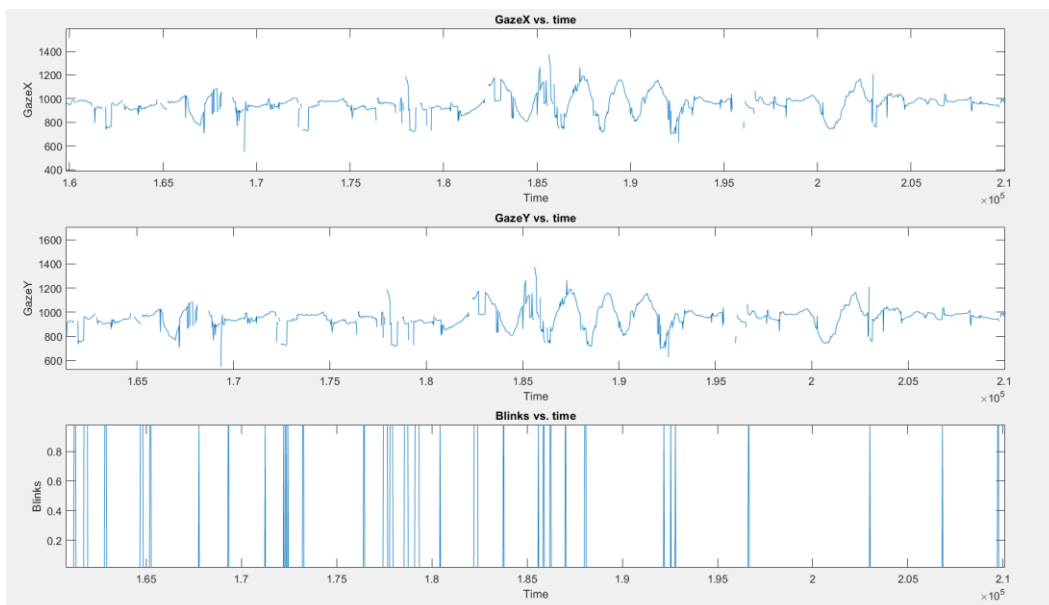


Figure 18. Zoom in GazeX , GaxeY raw signal and Blink detection

4.2 Examples of postprocessing

One example of what can be done, for instance, to make the galvanic skin response signal cleaner is to apply a low-pass filter. The galvanic skin response is a very slow signal, so a cutoff frequency of 1 Hz can be applied.

```
sampling_frequency = 1000;  
cutoff_frequency = 1 ;  
% for a low-pass filter using a moving average  
window_size = floor(sampling_frequency / cutoff_frequency);  
filter_coefficients = ones(1, window_size) / window_size;  
% Apply the low-pass filter to the signal  
filtered_signal = conv(gsr, filter_coefficients, 'same');
```

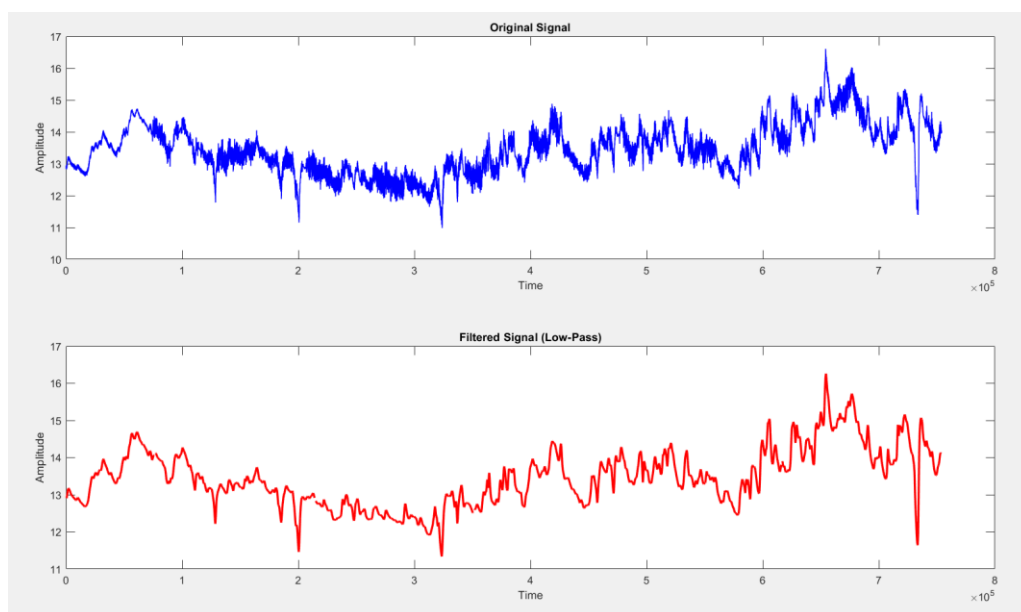


Figure 19. Original and filtered EDA vs. time

Regarding the EMG signal, another example of analysis that can be performed is to apply a 50 Hz notch filter to remove power line noise. Subsequently, the RMS (Root Mean Square) can be calculated using the following formula provided by R-Library in iMotions:

```
window_lenght(ms) = 150;
```

```
window_overlap_percentage = 10;
```

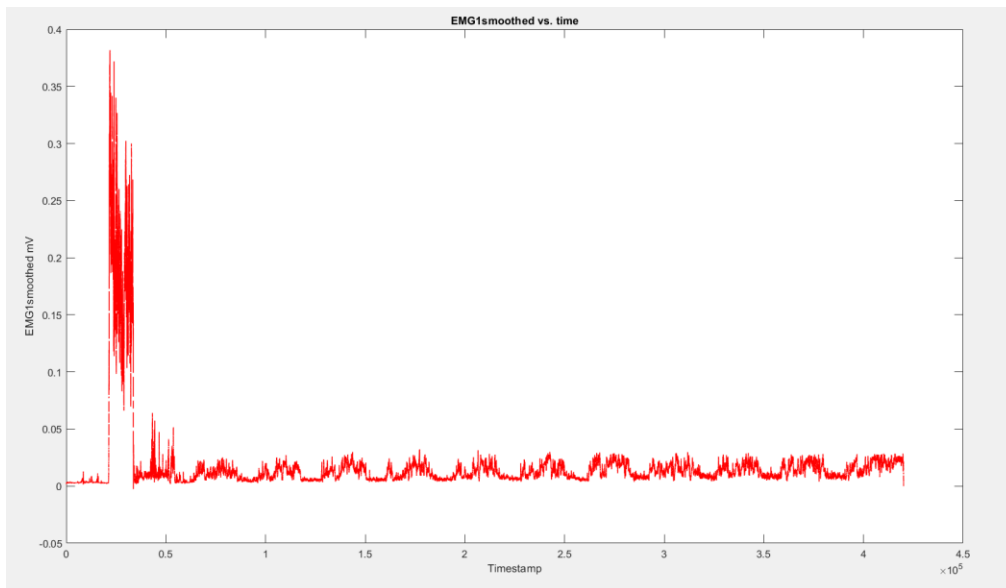


Figure 20. EMG1smoothed vs. time.

R-Library in iMotions enables to use the MVC (seen before) to normalize the signal. Fundamentally, the scale changes, enabling the comparison of participants.

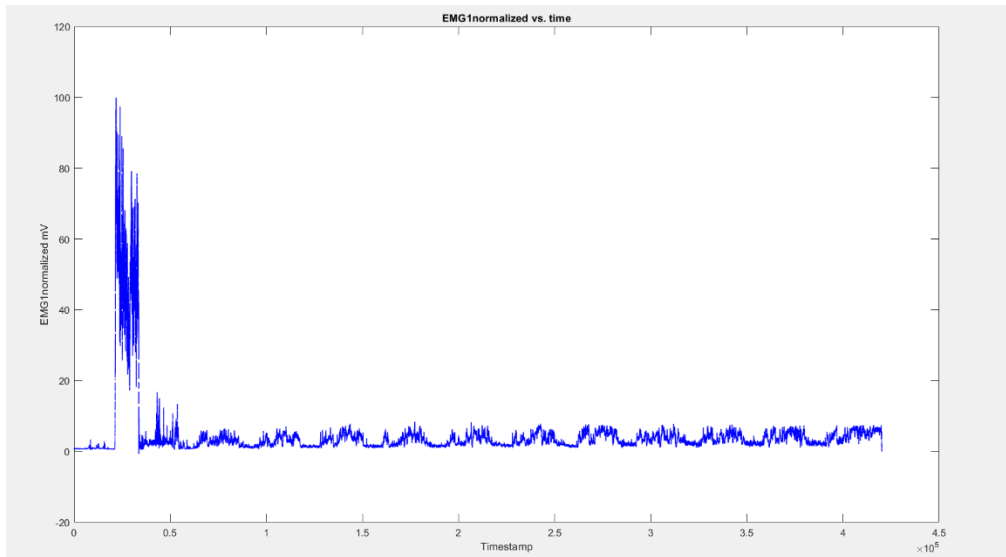


Figure 21. EMG1normalized vs. time.

Peaks detection in the GSR would be useful to compare the activation in different tasks. Has been used the peaks detection algorithm in the R-Library and then plotted in Matlab.

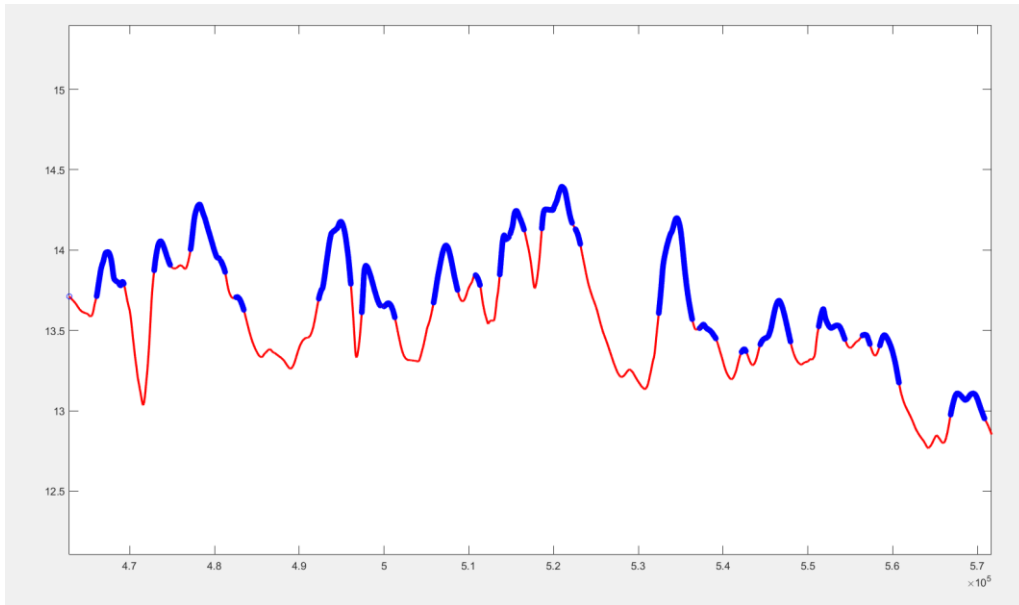


Figure 22. EDA smoothed with peaks detected of a part of recording.

The same idea can be applied to the breathing signal.

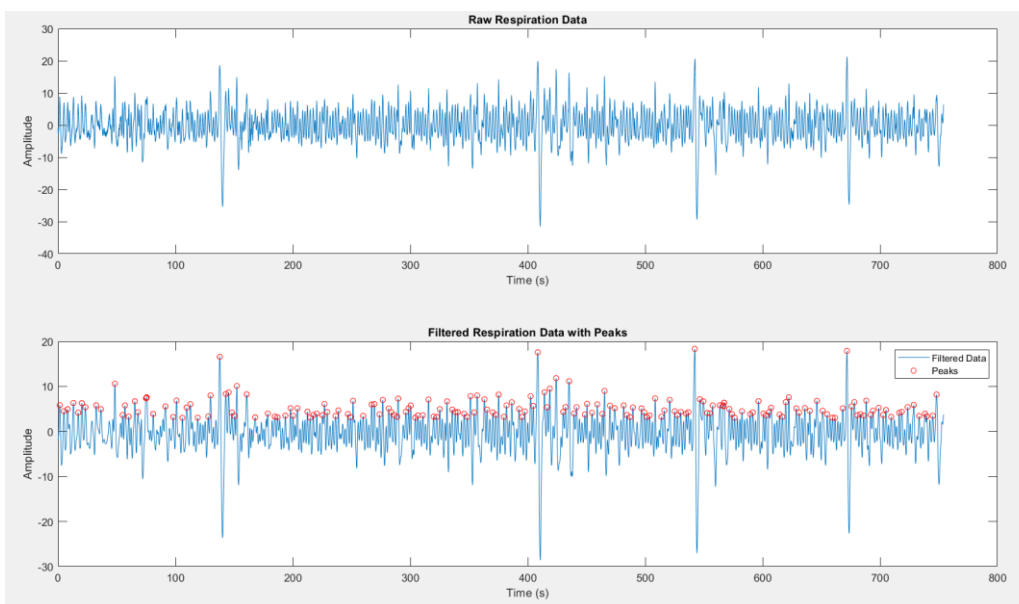


Figure 23 . Filtered Respiration with peaks

The moving average filter to the raw data has been applied, following the algorithm:

```

sampling_rate = 1000;
window_size = 1000;
filtered_respiration_data = smoothdata(raw_respiration_data, 'movmean',
window_size);
% Find peaks in the filtered respiration signal (inhalations)

```

```
[peaks, peak_indices] = findpeaks(filtered_respiration_data,  
'MinPeakHeight', 3, 'MaxPeakWidth', 6);
```

5. Discussion

At this point, it is possible to open a discussion about what can be done with these signals and their potential correlations to establish physiological responses in relation to specific events or the flow of time.

For example, compare muscle response to braking.

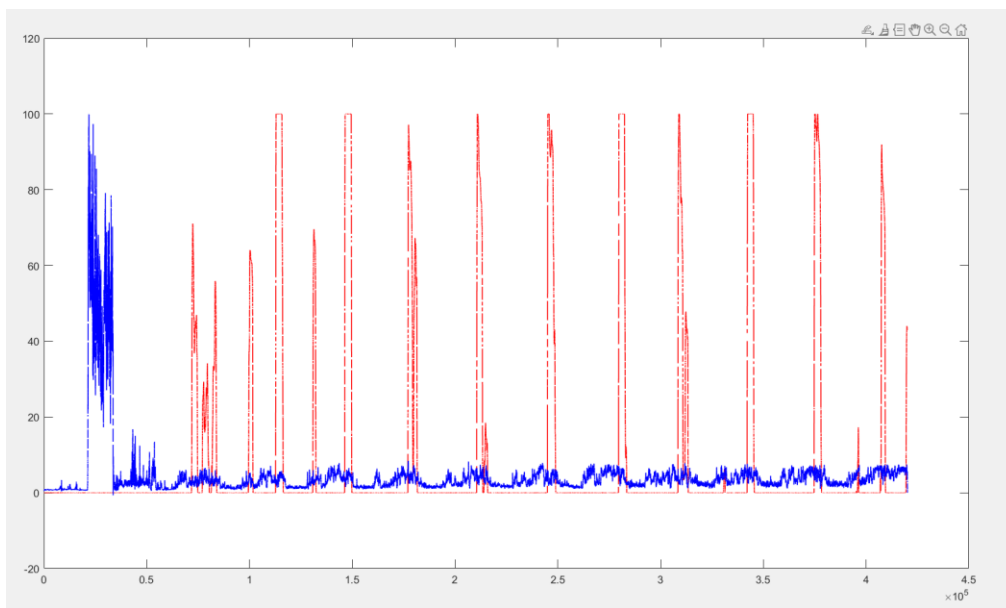


Figure 24. EGM1 normalized in blue and brake in red.

By analyzing eye tracking data, it's possible to extract the times when the cones are first seen (first fixation), allowing us to focus on reaction times concerning brake activity. The figure below represents a zoomed-in view of the three moments when the first cone was spotted during the first three slalom tasks.

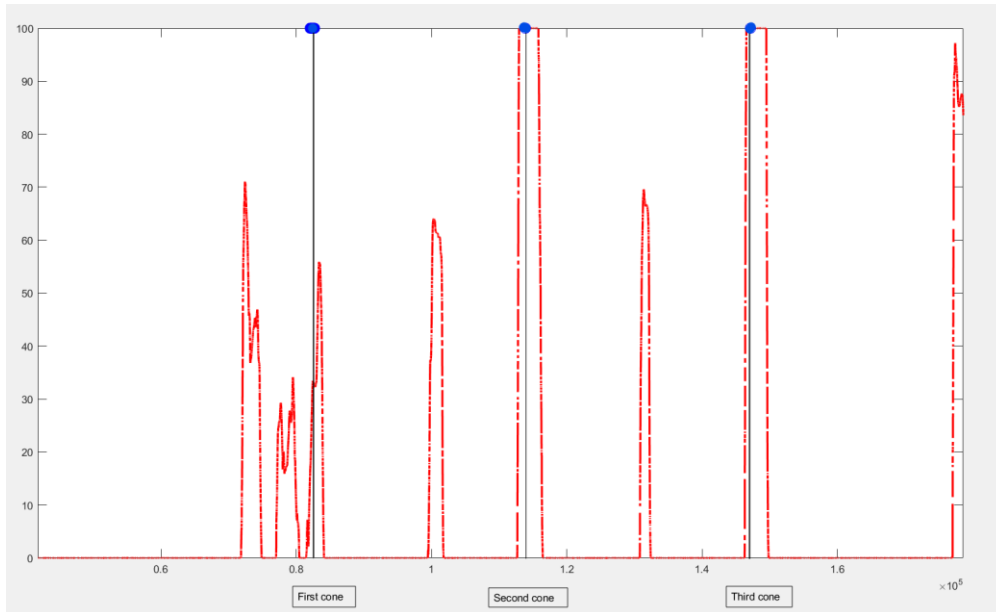


Figure 25. Brake and Events label

As observed, [7]the initial fixation on the second and third cones happens after the braking has already begun. This might suggest at the participants relying on alternative reference points for their reactions. One potential explanation could be the utilization of the speed indicator, a common practice in simulators when participants don't have a complete sense of speed, leading them to adjust their actions based on the dashboard.

Regarding the GSR data and respiration, an assessment can be conducted through by comparing the number of peaks during the first lap to the last lap(five in total), one option can be observe how workload and fatigue, for example, increase. The same can be done with the frequency of the respiration.

Running R-Library peak detection algorithm in iMotions, the table show this results:

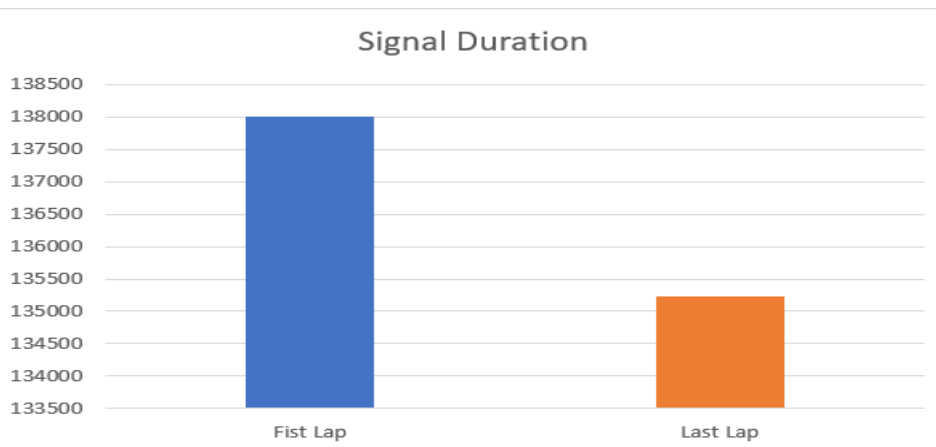


Figure 26. Firstly, it can be observed that the lap duration is shorter by 3 seconds in the last one.



Figure 27. Number of peaks and average.

For a shorter duration, it can be noted that the sum of the EDA peaks, their average, and their amplitude are greater. This can be interpreted as increased engagement in the performance, combined with an accumulation of fatigue and mental workload [8].

To better investigate the origin of this type of physiological response, it would be necessary to select additional signals and combine them with the galvanic skin response. For example, as mentioned above, comparing breathing, the frequency of blinking can be another indicator of fatigue, or the heart rate.

The applied method proved to be effective for its intended purpose, with the exception for the galvanic skin response, whose signal was usable for only one participant. The very high temperature during the monitoring session caused participants to experience excessive perspiration, causing the electrodes to detach after just a few minutes. Therefore might be helpful to consider a solution for keeping the electrodes adhered to the skin, such as using gloves.

On the other hand, one sensor that had been chosen based on the literature written about it is the ECG. Heart rate and heart rate variability are two of the most frequently mentioned signals in the literature for the sympathetic and parasympathetic nervous system responses [9]. Unfortunately, the device likely experienced hardware damage during shipping, it failed to power on.

8. Conclusion

The purpose of this thesis was to encompass all the stages of a preliminary study for an experimental test that includes many components, such as the one has been assembled. Starting from the choice of suitable commercial biosensors in order to fulfill the requirement for a multimodal approach and to ensure compatibility with the existing environment setup.

A high-immersion virtual environment, such as a professional driving simulator, enables the isolation of physiological response variables and focuses

on the reproducibility, combination, and comparison of these signals. The obtained results are aligned with this objective. To reach more solid statistical data and isolate the variables further, we could consider additional randomization of tasks, repeating sessions multiple times for the same participant, and increasing the number of individuals involved.

For a potential future project, one might aspire to develop, following an initial phase in virtual reality, the reproduction on the roads. This would enable a comparison between the two experiences and maybe a permanent integration of sensors in a real car.

9. References

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