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USING BCI AND EEG TO PROCESS AND ANALYZE DRIVER'S BRAIN ACTIVITY SIGNALS DURING VR SIMULATION

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Abstract:

The use of popular brain–computer interfaces (BCI) to analyze signals and the behavior of brain activity is a very current problem that is often undertaken in various aspects by many researchers. This comparison turns out to be particularly useful when studying the flows of information and signals in the human-machine-environment system, especially in the field of transportation sciences. This article presents the results of a pilot study of driver behavior with the use of a proprietary simulator based on Virtual Reality technology. The study uses the technology of studying signals emitted by the human mind and its specific zones in response to given environmental factors. A solution based on virtual reality with the limitation of external stimuli emitted by the real world was proposed, and computational analysis of the obtained data was performed. The research focused on traffic situations and how they affect the subject. The test was attended by representatives of various age groups, both with and without a driving license. This study presents an original functional model of a research stand in VR technology that we designed and built. Testing in VR conditions allows to limit the influence of undesirable external stimuli that may distort the results of readings. At the same time, it increases the range of road events that can be simulated without generating any risk for the participant. In the presented studies, the BCI was used to assess the driver's behavior, which allows for the activity of selected brain waves of the examined person to be registered. Electroencephalogram (EEG) was used to study the activity of brain and its response to stimuli coming from the Virtual Reality created environment. Electrical activity detection is possible thanks to the use of electrodes placed on the skin in selected areas of the skull. The structure of the proprietary test-stand for signal and information flow simulation tests, which allows for the selection of measured signals and the method of parameter recording, is presented. An important part of this study is the presentation of the results of pilot studies obtained in the course of real research on the behavior of a car driver.

Keywords: *signal processing, EEG, BCI, emotion recognition, virtual reality*

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1. Introduction

For many years, research simulators have been the basis of universal tools allowing to study the behaviour of vehicle drivers and to identify road incidents giving rise to potential situations considered dangerous in road traffic. Nowadays the international market presents newer and newer solutions of devices for scientific research or professional tests in this area. This advanced technology has become so popular that these systems have even found their use for entertainment industry (Hasan et al., 2021). The determinant of this situation is the fact that it is easy to obtain an electrical signal emitted by areas on the human scalp, where the accuracy of the analysis depends only on the method of processing this signal. It means that the actual signal can be read easily. Universal devices available on the market have various interfaces for connecting electrical signals generated by the brain with converters. Then, electric signal amplifiers and input interfaces, from where the signal goes to the recording computer, are subjected to observation and analysis. Devices working as electroencephalographic devices connecting man with the machine, such as MUSE (EEG) or EMOTIV EPOC, are widely available, and their designs are subject to permanent modifications (Latuszynska, 2012; Law and Kelton, 1991).

Among the various neurophysiological research methods, electroencephalogram (EEG) technology is emerging as one of the most popularized. The EEG signal is the non-invasive recording of electrical potentials that are generated by the activity of neurons in the brain (Mert and Akan, 2018). Its advantages include low research costs, the highest time resolution and the lack of invasiveness. For this reason, it is also the longest-used method of neurophysiology research (Herrmann and Debener, 2008; Hajinoroozi et al., 2016; Cudlenco et al., 2020). As indicated by Wang et al. (2017), it should be remembered that the signals collected from the scalp are heavily contaminated by various types of artifacts and background noise. In their work, they proposed a method based on reducing the dimensionality of the time–frequency image.

When analyzing image projection methods, the possibility of glare and isolating the influence of the environment on the test result should be considered. The parameters recorded during the tests are also important (Tomczuk et al., 2017), and shall be selected for a given study.

For studies requiring high realistic simulation, an immersive virtual environment is preferred. However, data acquisition methods are usually invasive in these studies and run counter to the goal of a highly confident reality (Lin et al., 2006).

The authors Noor and Aras (2015) used the zSpace virtual holography platform. Thanks to the simplicity of its construction, the final production costs and the ease of human–machine coupling, these structures are widely available and, thanks to extensive databases, universal libraries and drivers that allow these interfaces to be coupled with devices of common use, there is a wide and growing range of applications. It is still a pioneering market in terms of creating software for users, and the number of applications using the analysis of data from EEG records is growing rapidly.

As demonstrated by the authors of the work (Wei et al., 2011), EEG activities can also be effectively tested in a driving simulator based on virtual reality. With the help of the performed studies, the authors tried to estimate the level of the patient's motion sickness based on the main EEG power spectra from the areas of the brain related to motion sickness in their study. They found that regions of the parietal, motor and occipital brain showed significant changes in EEG power in response to vestibular and visual stimuli. Consequently, thanks to these tests, it will be possible to detect the severity of motion sickness earlier.

On the other hand, the authors (Huang et al., 2016) used the online closed-loop electroencephalogram (EEG) human fatigue detection and alleviation system to study the neurophysiological changes caused by fatigue. They demonstrated the effectiveness of this online closed-loop EEG-based fatigue detection and fatigue alleviation mechanism to identify cognitive decline that can lead to catastrophic incidents in countless operating environments. The indicated solutions are extremely important because, as is well known, and has been demonstrated, inter alia, by the authors of the work (Lin et al., 2009), driver fatigue contributes to road accidents. The authors, based on their research, showed that, additionally, audible warning signals significantly improved the drivers' precision and behaviour level.

Applications for tracking brain activity during activities require the popularization of Brain–Computer Interfaces (BCIs), also known as the brain–machine interface (BMI) (Evans et al., 1967; McFarland and

Wolpaw, 2017; He et al., 2020). These interfaces convert the brain's signal into a digital signal, which is then sent to devices that allow computer applications and electronic equipment to be controlled without muscle input (Hassanien and Azar, 2014; Pfurtscheller et al., 2006).

It has been argued that effective BCI systems require a reliable robust high-quality EEG recording (Krishnan and Bai, 2021). Better sensors would be easier to apply, more convenient for the user and would produce higher quality and more stable signals, the authors say. Moreover, they believe that greater attention to the issues of real-time signal processing and optimization of the mutually adaptive interaction between the brain and BCI is necessary to improve BCI performance.

To study and control the read stimuli, the method proposed by Mita A. et al. (2010) could also be used. They have developed smart sensor units with data acquisition and data management capabilities. For this, they used a structural health monitoring (SHM) platform. This platform could also be used for the construction of the simulator chair, which transfers the stresses during simulated driving. SHM has also been studied by Chen et al. (2019). The authors studied multi-radio multi-channel multi-power communication to go beyond the bandwidth limitations of traditional single-channel radio, as well as to improve data collection efficiency in wireless sensor networks. For the detection and analysis of brain signals, Quirós et al. used Bayesian dynamic linear models, which helped to reduce the number of parameters needed for this analysis (Quirós et al., 2015). The algorithms proposed by Chen et al. (2019), which are similar to the algorithm for embedded synchronization of structural response datasets in the wireless SHM system proposed by Dragos et al. (2018), could also increase the accuracy of the results obtained by the authors of this work; however, for the set goals, it will not be as important.

According to the literature analysis, the currently used driving simulation devices are based on the observations of people participating in the study and the assessment of responses to external factors. The analysis is performed in terms of the type of stimulus and the examination of the distribution of reaction time to the stimuli. For this purpose, cameras and sets of specialized sensors are often used to observe the subject. The construction of such simulation devices takes into account a human observing the dynamically changing virtual world, embedded in the realities of the real world. The examined person receives external impulses and sets of images generated in the simulator. This study proposes a solution based on virtual reality with the limitation of external stimuli emitted by the real world. The proposed solution is based on greater identification with virtual reality, thanks to which the simulated stimuli better translate into the reactions of the tested individual. A similar approach was proposed by Hasan et al. (2021), in which they proposed a framework for improving microscopic traffic simulation models and extending their capabilities by incorporating distributed human-controlled vehicles in a loop with virtual reality technologies. However, the proposed research stand only included a Half-Dome Projection Screen, without the use of VR Head Mounted Display, which better reflects external stimuli in virtual reality. This is also confirmed by the numerous studies carried out by Kim and Rhiu (2021), who presented a final comparison of terminals with visual display terminals (VDTs) and head-mounted displays (HMDs). They showed that a HMD was superior in terms of the user experience in walking and driving situations. Duann et al. (2009) also analyzed the application of VR technology to the feasibility of using an EEG on the forehead to detect sleep-related brain activity during long-distance night driving.

In turn, Kim et al. (2021) used an HMD in a study to test a drone control application using a P300-based BCI in two environments, both virtual and augmented reality (VR, AR).

What is important, in these studies (Hilfert and König, 2016; Schroeter and Gerber, 2018), is that the authors point out that head-mounted devices represent great potential for the architectural, engineering and construction industries, as a person can experience realistic situations from the first person without having to worry about injuries. Automated processes to simplify content creation, the use of existing models, and the use of visual programming languages enable even non-programmers to create scenarios tailored to their needs. VR can be also a fulfilment of the already existing studies of the transport systems such as (Jacyna and Semenov, 2020).

Bozkir et al. (2019) examined how the application of virtual reality (VR) technology together with HMD can be used by train drivers in various road situations and especially in the safety-critical events, such as unexpected pedestrian incursion on a road.

The authors of the work (Li et al., 2021), however, conducted a VR experimental study equipped with HMDs to assess the influence of correlated color temperature (CCT) on visual and non-visual efficiency in a normal driving situation and an accident. According to the authors of (Taheri et al., 2017A), despite the advantages and disadvantages, simulators are the best solution from the point of view of safety and its improvement. In their research, the authors developed a driving simulator based on a virtual reality (VR) head-mounted display (HMD) to demonstrate the analysis of driver performance and behaviour.

A very interesting approach to the use of VR technology was presented by the authors of (Bian et al. 2013), where they proposed a driving simulator based on a virtual urban environment, which they want to use in the future to convey driving skills to young people with autism spectrum disorders (ASD). A similar solution was proposed by (Fan et al., 2015). In their study, the authors additionally integrated the EEG data acquisition module with a VR-based driving system and examined the reliability of detecting the level of involvement, emotional states and mental strain in adolescents with ASD while driving.

A similar application of VR technology to the one proposed by the authors of this manuscript was presented by the authors of (Xiongqing et al., 2021). In order to improve convenience, gesture recognition technology was used, which was recorded by a camera, and the meaning of these gestures was recognized by the algorithm used. The authors showed that the VR simulator can be used for training, road safety education and related scientific experiments.

Similarly, the authors of the work (Taheri et al., 2017B) wanted to use VR technology to show how much driving fast can influence the performance of the driver.

More and more studies bring a new look at the use of modern technology based on virtual reality. They even prove that useful results can be obtained without direct analysis of brain signals. Agudelo-Vélez et al. (2021) used VR in order to study the parameters such as safety perception while travelling by different modes of transportation. It means that virtual reality technology can be used for collecting data and experimenting in laboratory conditions without using models whose simplifications affect the results. Nevertheless, by adding an element of brain analysis and signal emission to research, especially in which the human and his reactions are of major importance, it is possible to achieve a comprehensive approach. Afanasieva and Galkin (2018) decided to take up the issue of the flow of information, as well as its quantity, between the outside world and the driver, which is a response to changes in the space of vehicle movement evolving over time. Despite the fact that the tests carried out in real traffic did not give comprehensive results, it allowed to analyze the driver's level of concentration and make some values dependent on each other. This shows that the EEG is a good tool for analysis in this area.

The analyzed studies usually tried to show how helpful the use of VR technology can be to test drivers' skills or to improve them. Additionally, as in our case, BCI and EEG were used. However, this study presents a fragment of research conducted on the use of popular BCIs to analyze the behaviour of brain activity during research with the use of a proprietary simulator based on VR (Virtual Reality) technology. As the literature review shows, the availability of research aimed at assessing the possibility of using VR technology in driving is not yet accessible to a sufficient degree. Hence, in this research, an attempt was made to build a proprietary test stand, where it will be possible to conduct research with the use of VR technology. An additional advantage of the work, by assumption, was its attempt to obtain information about the registered electrical activity of the brain during such research.

Taking into account the research problem presented by the authors, the structure of the article is as follows. In the first part of the work, the literature from the research area was analyzed, in particular, the methods and tools based on VR technology and the simulation research technique used for the analysis of signals based on VR technology and the simulation research technique sent by the brain. The analysis of the literature in this context highlighted the complexity of the problem of the influence of stimuli caused by vehicle operation on the driver's ability to perform a basic task - safe driving during a non-standard operation (non-standard conditions of mental load while driving at high speed on the racetrack). The research problem is presented in the next chapter. A proprietary experimental test stand was described - a driving simulator using VR technology.

An important part of this work is the development of a test scenario in the form of a simulation experiment and the performance of tests on driving simulators corresponding to real driving conditions during non-standard vehicle operation.

In the next part of this article, for the prepared research scenarios, studies are presented that take the driver's load with external stimuli coming from driving in conditions that use VR technology fully into account.

2. Design of the test stand

2.1. Assumptions

The following assumptions were made for the test stand and research:

- selection of a mixed population, varied in age,
- use of a realistic driving simulator in non-standard operating conditions - driving on a closed track, in the same scenario for the studied population,
- using a software simulator with an extensive human-machine interface,
- isolating the subject from the influence of undesirable external factors,
- using VR technology to image a repetitive driving scenario,
- analysis of the possibility of using the BCI interface to record EEG signals,
- surveying the surveyed population after the end of the tests.

The concept of the proposed test stand is shown in Figure 1. The figure shows:

1 – tested specimen;
2 – adjustable seat with adjustable backrest and distance from the pedal unit;
3 – VR goggles;
4 – isolating headphones with the function of providing sound stimuli;
5 – steering column equipped with actuators reacting to unevenness of the track, engine operation and feedback impulses from the working suspension and steering system;
6 – a set of clutch, brake and gas pedals;
7 – camera recording the behaviour of the participant during the route;
8 – group of computer control unit generating VR image and sound, receiving signals and recording feedback signals;
9 – computer unit allowing to record signals coming directly from BCI interfaces installed on the subject's head.

A Sony PS4 Pro unit with the Gran Turismo sport VR simulator software was used as a computer control unit (8). Additionally, a second computer unit, not shown in the figure, was taken into account, allowing signals to be recorded directly from BCIs (EPOC Electroencephalograph) installed on the subject’s head. For this purpose, a standard Apple MacBook portable computer was used, equipped with drivers and software that allowed for the registration of signals from the Emotiv BCI Program and the Emotiv Brain Map program.

Fig. 1. Concept of building a test stand

2.2. Method of parameter registration

The EEG/EPOC interface was used to enable the recording of signals and EEG parameters. The resulting analogue signal is received by the computer using cables and analogue-to-digital converters. Then, a digital EEG recording allows you to track the continuous changes in the amplitude of specific frequency bands, corresponding to the brain waves for the behaviour or stimulus we are interested in (eye blink or muscle tension) (Duann et al., 2009; Wu et al., 2021). The device uses a gyroscope, fourteen dry (Ag/AgCl without electrolytic gel) active electrodes, two reference electrodes, a WLAN module and battery power. Figure 2 shows the arrangement of the sensors.

Points 1L, 1R, 3L and 3R belong to the area of impact of the frontal lobe, responsible for planning (a plan of a specific positioning in the vehicle path), challenges and their implementation (minimizing excursions), initiating actions (braking, accelerating), making decisions and monitoring their effects, predicting the consequences of actions (speed selection for corner entry) or modifying the assumed plan. As it turned out, these signals were extremely active during rapidly changing research situations. Points 4L and 4R, 2L and 2R are located in the area of the frontal lobe, which is responsible for spatial orientation (route memory), understanding symbolic language (signs), understanding abstract and geometric concepts, feeling and touch (steering feedback), motion and sight integration (driving) as well as feeling and sight. Points 8L and 8R, 7L and 7R belong to the occipital lobe area that is responsible for vision, colour analysis, motion analysis, shape analysis, depth analysis, emotion analysis and visual associations (Chen et al., 2021).

As part of the work, the signals from sixteen electrodes were recorded and analyzed as a function of the existing road situation with the use of VR technology. The signals were recorded with the use of computer software, which consists of the following two modules: the interface controller and the recorder.

2.3. System architecture with the selection of equipment

Figure 3 schematically shows the directions of the flow of impulses as well as control signals and those of an informative nature. During the research, the possibility of receiving external information coming from the environment, received by the examined person with the senses of sight and hearing, was cut off.

Figure 3 distinguishes the following blocks: the environment from which the ex-ternal signals and interferences in the test process come; the VR - virtual reality block; the block of the tested individual embedded in real and simulated realities; the input–output module (IO) block, in which two modules are distinguished, i.e., M1 - the bi-directional steering wheel driver module - and M2 - the pedal position change re-cording module; block K1 - a PS4 computer unit responsible for generating virtual reality and handling IO devices; block K2 - a computer unit responsible for recording signals from the Emotiv Epoc interface.

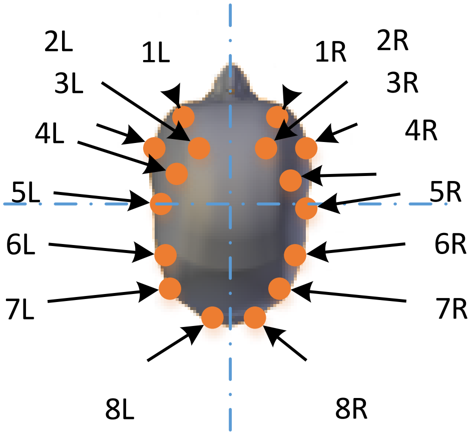


Fig. 2. Arrangement of sensors

The following instrumentation was used in this research:

- Sony PlayStation 4 PRO console;
- Sony VR eyepiece, adapted to the PS4 PRO console;
- Sony V2 3D camera;
- a steering wheel and a set of pedals to operate the vehicle in the simulator - the "Thrustmaster T-GT" model, commercially dedicated to the Gran Turismo Sport VR simulator;
- "Playseat" frame with seat, WRC model;
- Emotiv EPOC and electroencephalograph;
- Emotiv Brain map 3D standard edition program;
- Emotiv BCI program;
- Gran Turismo Sport VR driving simulator.

In order to enable the recording of signals and EEG parameters, the Emotiv EEG/EPOC interface (manufactured by Emotiv Systems) was used. Figure 4 shows the appearance of the Emotiv Epoc interface. The device uses a gyroscope, ICM-20948 motion sensor, a triaxial accelerometer with a range of +/- 4g, a three-axis magnetometer with a range of +/- 4900uT and a resolution of 16 bits and a sampling frequency of 0–64 Hz, 14 dry (Ag/AgCl without electrolytic gel) 1L, 2L, 3L, 4L, 5L, 7L, 8L, 8R, 7R, 5R, 4R, 3R, 2R, and 1R active electrodes and 2 reference electrodes 6L/6R, a 2.4GHz WLAN module, and a lithium–polymer battery power battery with a capacity of 640mAh. A very desirable feature of this interface is the ease and speed of preparing the equipment for testing and the possibility of carrying out wireless operations. Figure 5 shows the control panel of the brain-computer-interface - allowing us to observe and record the EEG signals during the implementation of the study.

The sampling method is based on the sequential acquisition of signal values in individual electrodes (single ADC), with a frequency of 2048 Hz. The user can configure waveform recording with a frequency of 128 or 256 Hz. We used 16-bit signal converters (1 LSB = 0.51μV, 16-bit ADC, 2 bits of device noise with adjustable threshold level and 14 bits for signal processing). The frequency range of the recorded signals is 0.16–43Hz, and the device also uses digital blocking filters for 50 and 60Hz as well as 5th order digital filters. The range of the measured signals for the peak-to-peak value is 8,400 μV (pp). The available options for identifying commands or behaviours using the BCI soft-ware include neutral mental command detection and up to 4 preprepared traits per training profile, performance indicators such as excitement, commitment, relaxation, interest, stress, focus, changes in facial expressions, blinking eyes, response to surprise, frowning, smiling, clenching muscles and laughing.

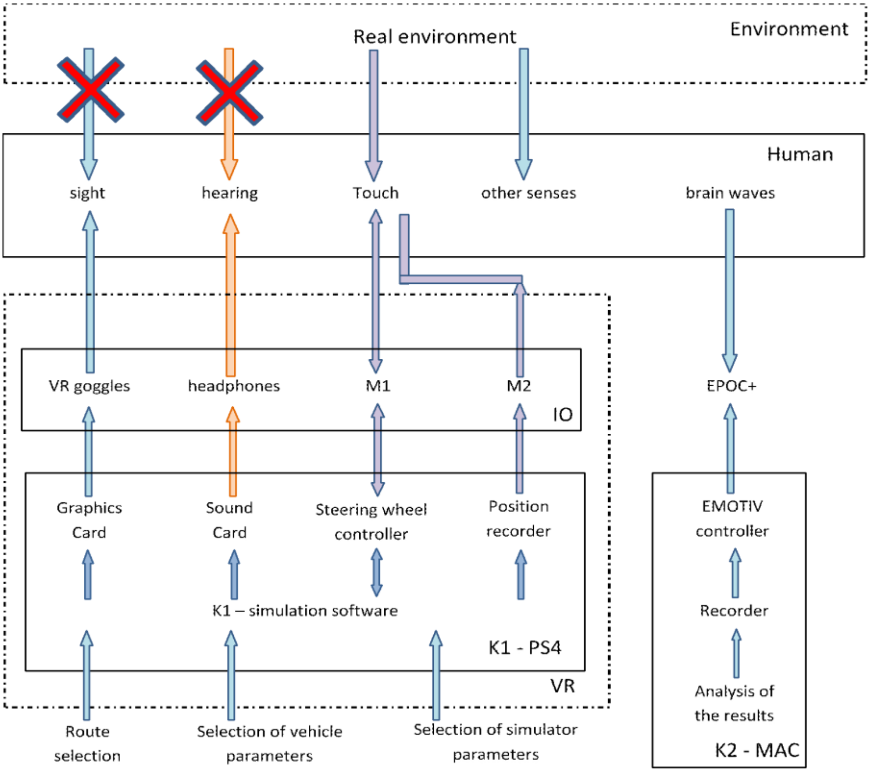


Fig. 3. Principles of conducting the proposed simulation tests

Fig. 4. Emotiv measurement interface and location of measurement points

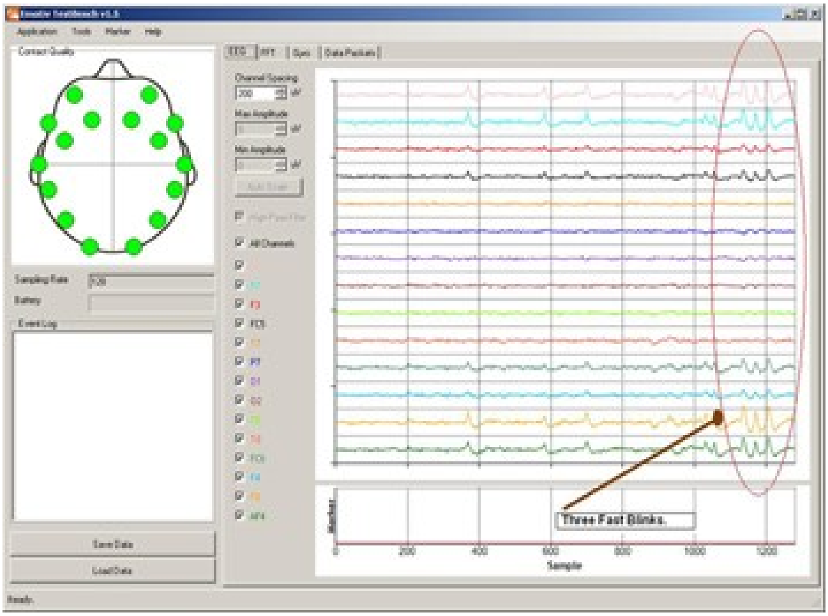


Fig. 5. The EEG recorder control panel

3. Results and Discussion

3.1. General assumptions

An important element of the conducted research is the selection of the studied population. Due to the limited availability of people willing to participate in the study, it was found that the group of volunteers should include representatives of women and men, both with and without a driving license, with or without experience in using VR system components, in the following age groups: below 20, 20–30, 30–40, 40–50, 50 and above.

3.2. Procedure of performed tests

The first stage was a conversation with the examined person. During the interview, an initial classification (surname and first name) occurred, during which the volunteer was asked about diseases to eliminate unwanted threats. The next stage of the test was the preparation of the BCI device, which included ensuring the 16 sensors obtained electrical contact with the scalp by moistening with a salt solution, checking the battery charge status in the device and putting the device on the volunteer's head and checking the operation of individual sensors during the test. We then tested the operation of the device and the control of the reception of brain waves, which consists of viewing the waves of detected nerve impulses, by asking the respondents to do the following:

- maintaining maximum concentration,
- close their eyes,
- clench their teeth,
- force anger,
- smile,
- move a hand,
- clench a fist.

During the above mentioned activities, the EEG signal was saved in the computer's memory. The activity of the measurement points is shown in Figure 6.

Fig. 6. Activity of measuring points during the test

After checking the above mentioned reactions, the next stage included adjusting the frame and seat to the height of the tested person, adjusting the steering wheel height, adjusting the distance to the brake and accelerator pedals, providing a detailed explanation of how to operate the simulator, how to change gears and the availability of functions. The next step was to launch the driving simulator application and prepare a record in the measurement environment, which allowed us to view the waves in real-time during the first and second ride. The first stage was a free ride with an electroencephalograph, for any road scenario, without other road users. This was very important because it allowed us to analyze how the conductor behaves in the familiar observation mode of a classic computer monitor. Most of the respondents knew the feeling of driving on the track and the brain did not generate increased activity during the first run, as it read the test as entertainment. From the point of view of the first ride, the most important thing was for the participant to familiarize themselves with the equipment and the way the vehicle is driven and how it reacts, as well as with feedback signals before introducing them to the virtual world. The trip was recorded to compare potential changes in behaviour during the repetitive elements of the simulation.

The second stage was to embed the subject in a virtual world, combined with the following:

- wearing headphones through which the sound will flow appropriate to the events and behaviour of the vehicle, and which will cut off external sound stimuli;
- putting on VR goggles, which will completely eliminate the possibility of observing the real world and enable observation of the virtual environment.

During this stage, the participant was asked to control the environment to become familiar with the technology, during which most of the respondents reacted with surprise to the detail and accuracy of the vehicle cabin representation. After the introductory stage, the participant started a second run, during which their behaviour was recorded via a camera and the software recorded the activity of the brain waves again. The staff kept notes of events as a function of time, such as falling off the track, hitting the board, braking, accelerating. The last element was the analysis and synthesis of the information obtained.

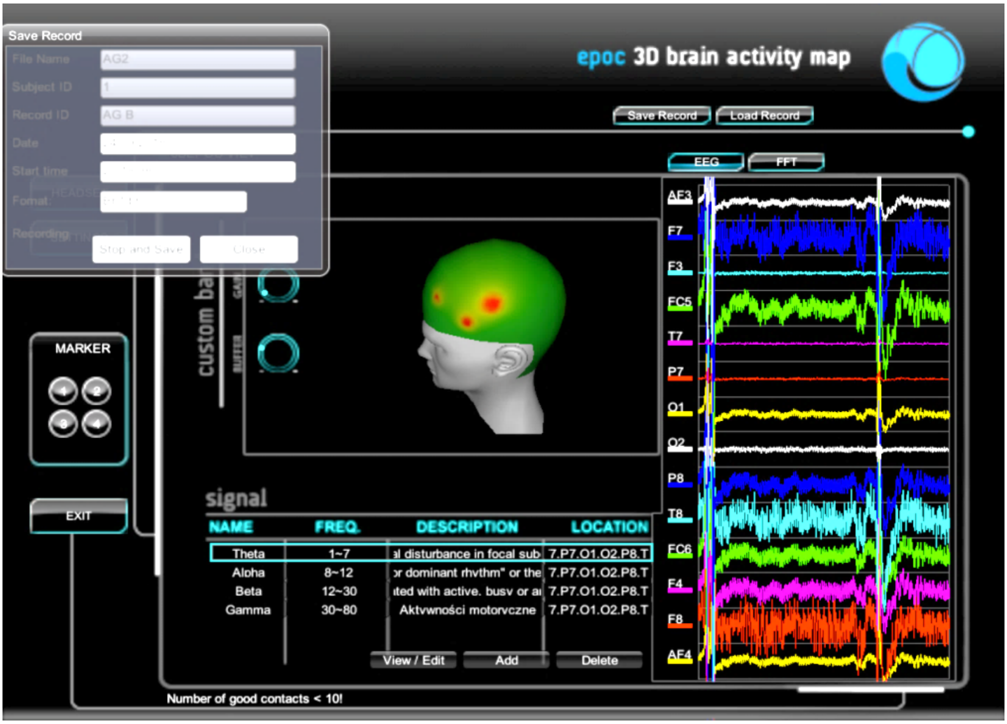
3.3. Analysis of the results

The recorded signals were subjected to analysis of the amplitude–time activity as a function of the occurrence or not of road incidents, and quantitative analysis. Figure 7 shows the activity recorded during the research. The data is presented as a brain activity map.

The road situations and events recorded by the observer that took place during a representative journey using VR simulation are as follows: skidding; hitting the gang; coming back onto the road (the car did not stop on the gang); vehicle leaving the road (but not hitting anything); the vehicle skidding on the right side of the car (only the wheels); an attempt to exit from a strong slide; front side of the vehicle hitting the gang; the uncontrolled car falling on the track; slipping; vehicle keeping track of the track; the vehicle drifting out of the way; the vehicle hitting a gang; loss of vehicle control - skidding; frontal hitting the gang; the vehicle continuing to run on the track; the vehicle catching on the gang but continuing to drive; skidding on a bend and an attempt to control the vehicle; controlled skid without a collision - the car continuing to drive; the left side of the car falling to the side of the road, but without a skid or collision, the driver hitting another vehicle; the vehicle hitting the gang on a bend; re-turning to the road and continuing to drive; the driver braking too late and driving into the vehicle ahead, losing control of the vehicle after impact and falling into a dangerous skid; after being hit, cars colliding with each other, causing a dangerous collision; the vehicle crashing into the road; the vehicle arriving at the finish point.

Figure 8 shows the signals occurring in the left hemisphere during the entire drive, and Figure 9 shows this for the right hemisphere. The signal levels are even, but at critical moments, e.g., when leaving the track, very strong impulses appear; therefore, we can observe that some signals suddenly become very active. The course of the route and especially its beginning, for the left hemisphere, is dominated by 4L, and for the right hemisphere 2R, i.e., the parietal lobe signals are responsible for spatial orientation and the integration of movement, sight and feeling. Only at critical times of excursion, very strong 8L and 8R pulses from the occipital lobe (vision, motion analysis, depth, focus and visual associations) occur, sometimes followed by 3L signals from the frontal lobe (initiation of action, decision making, monitoring of action).

Figure 10 shows the decision-making process in the frontal lobe (3L and 3R). In this case, the behaviour of the left hemisphere is more intense than that of the right. The signal levels are small, hence the interferences at 50 Hz are captured.



File Name: AG2
Subject ID: 1
Record ID: AG B

NAME	FREQ.	DESCRIPTION	LOCATION
Theta	1~7	al disturbance in focal sub	7.P7.O1.O2.P8.T
Alpha	8~12	or dominant rhythm" or the	7.P7.O1.O2.P8.T
Beta	12~30	ited with active. busy or a	7.P7.O1.O2.P8.T
Gamma	30~80	Aktywności motoryczne	7.P7.O1.O2.P8.T

Number of good contacts < 10!

Fig. 7. Activity of recorded signals during the test

In Figure 11, the signals from two other frontal lobe electrodes 1L and 1R are shown. Their changes are of a slightly similar nature to those of the previous 3L and 3R, but you can see the differences when leaving the track and before the next one, and during a slip. Some of the signals appear as pre-information (3L/2R) that can be interpreted as a goal and monitoring its implementation.

Figures 12 and 13 show the moment of falling outside the road contour.

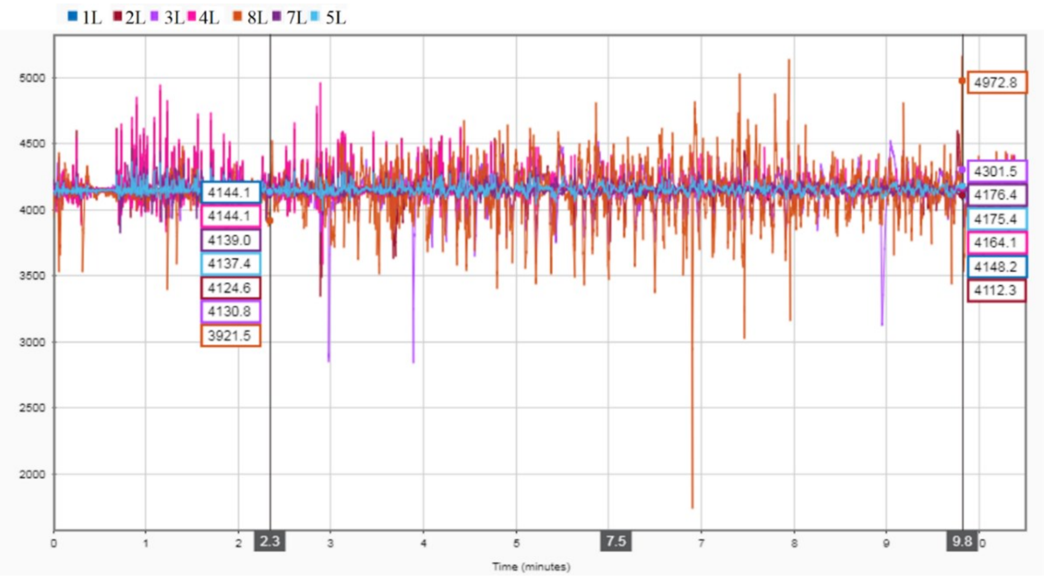


Fig. 8. Results of the entire run using VR technology, left hemisphere, electrodes 1L, 2L, 3L, 4L, 8L, 7L

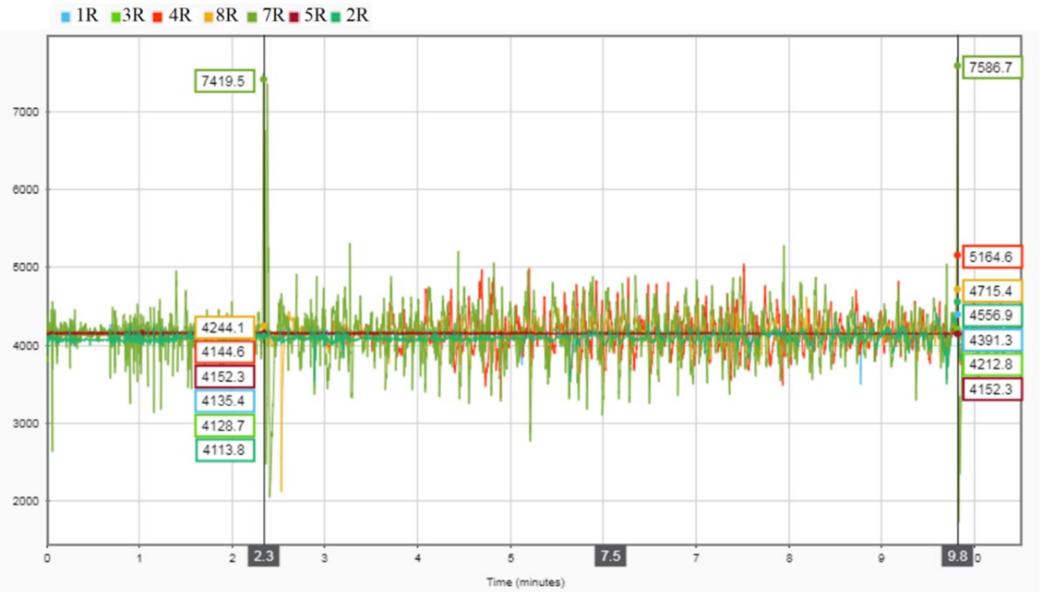


Fig. 9. Results of the entire run using VR technology, right hemisphere, electrodes 1R, 2R, F8, 4R, 8R, P8

In the case of falling outside the road contour, focus (8L, 7R), visual-motor sensations (4L) followed by decision making (3R), combined with the dominance of visual analysis (8L) are especially visible.

Additionally, Figure 14 shows the behaviour of the sensors that analyzed the head movement in the horizontal plane when falling outside the contour of the route.

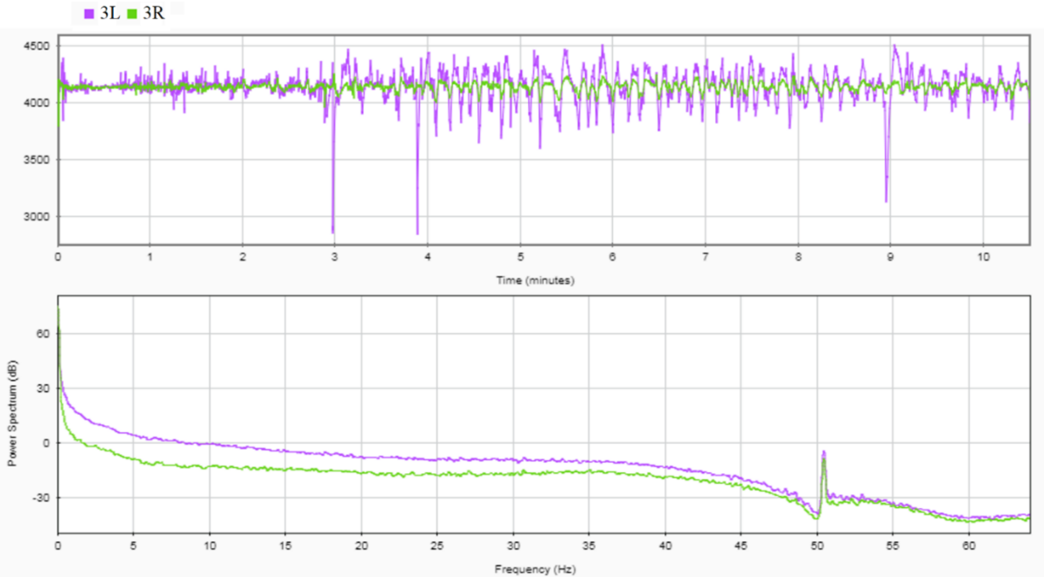


Fig. 10. The results of the travel test using VR technology, the temporal lobe area, the 3L and F8 electrode and the distribution of the spectral density of signals

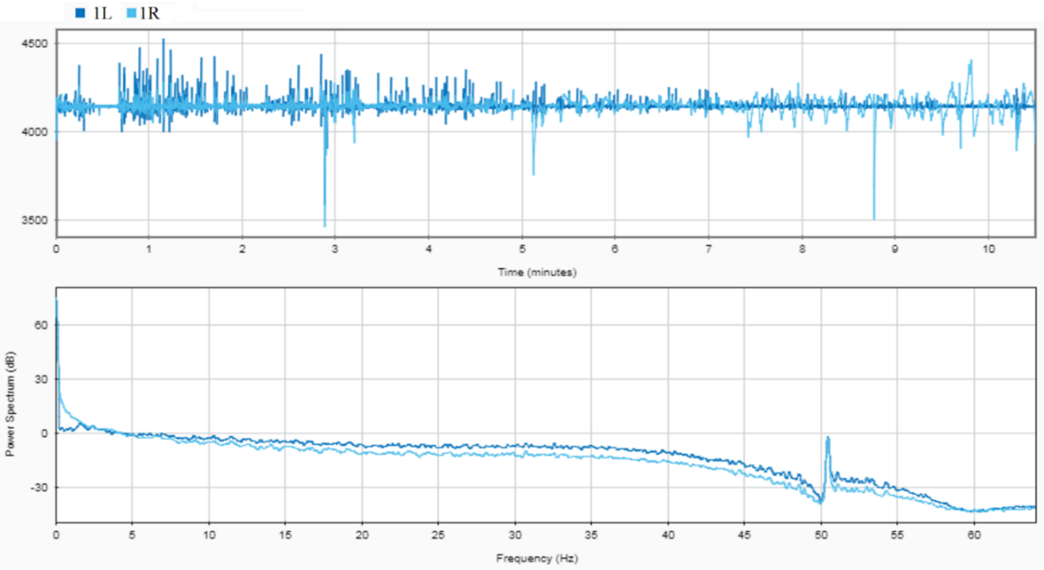


Fig. 11. The results of the riding test using VR technology, frontal lobe area, electrodes 1L (left), 1R (right)

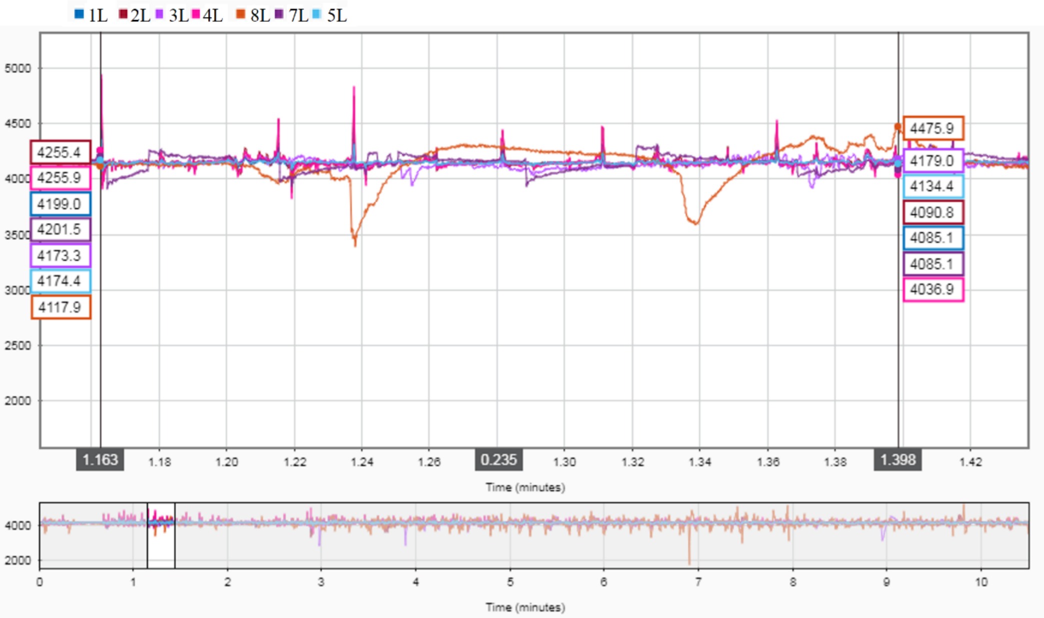


Fig. 12. The results of the riding test using VR technology, left hemisphere area, electrodes 1L, 2L, 3L, 4L, 8L, 7L, 5L, detailed analysis of the reaction to falling off the road

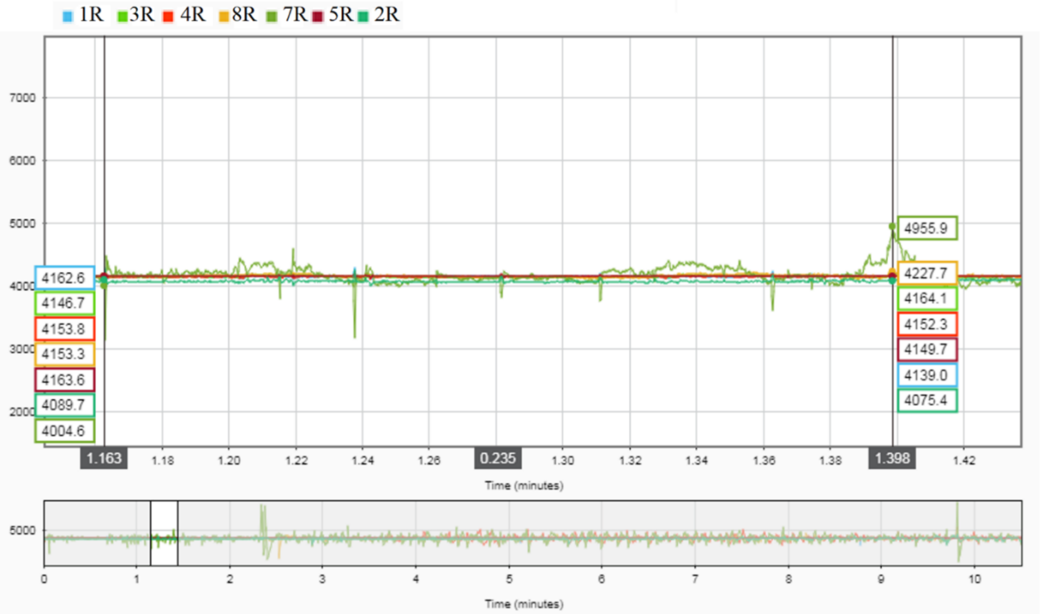


Fig. 13. The results of the riding test using VR technology, left hemisphere area, electrodes 1R, 2R, F8, 4R, 8R, P8, 5R, detailed analysis of the reaction to falling off the road

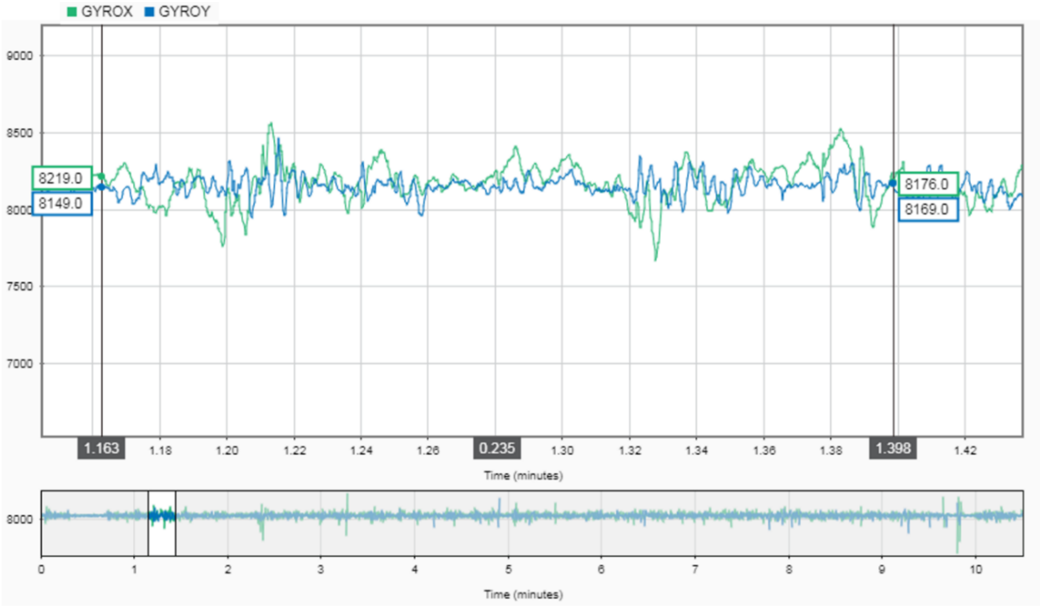


Fig. 14. The results of the trip test using VR technology, GYROX, GYROY signals, detailed analysis of the reaction to falling outside the route outline

3.4. Discussion

Summarizing the runs using the VR technique, it can be stated that before take-off, there was an activity of signals from the 6L, 6R, 5L, 5R electrodes responsible for the temporal lobe, which, in turn, correspond to, among others, hearing, speech, the categorization of objects and sound impressions.

During uninterrupted straight-ahead driving, the activity of 6L, 6R, 5L, 5R was joined by the increased activity of 1L, 1R and 3R responsible for the frontal lobe, which is responsible for setting goals and their implementation, monitoring the activity of 4L and 4R, responsible for the parietal lobe, which is responsible for spatial orientation, integration of movement, sight and feeling.

In the case of the vehicle accident, connected with hitting the band, the active signals came from the 3L electrodes responsible for the frontal lobe (operation monitoring); 2L and 2R electrodes responsible for the parietal lobe and responsible for spatial orientation and the integration of movement, sight and feeling; and 8L and 8R, corresponding to the occipital lobe, which, in turn, is responsible for vision, movement and depth analysis, focus and visual associations. The study allowed to distinguish active areas of the brain in selected situations.

4. Conclusions

This study presented a preliminary analysis of the applied solutions and available methods and tools for examining the impact of stimuli caused by vehicle operation on the driver's ability to perform a basic task - driving safely during a non-standard operation. This allowed the authors to define the desired features when building a simulation test stand for performing tests on the behaviour of, inter alia, drivers while driving a car.

The basic assumptions were presented and the structure of the designed and built proprietary research stand, which uses VR technology, was discussed. The research was conducted on this stand. To evaluate the behaviour of the tested driver, the BCI was used, which allowed us to record the activity of selected brain waves of the tested person. A questionnaire was developed that allowed the behaviour of the tested driver to be specified.

Taking into account the research carried out on the proprietary test stand using tools based on VR technology, it can be concluded that regardless of the required weather conditions, they can replace the real conditions in a situation of operating in non-standard driving conditions, posing a high risk to road safety (driving at high speeds).

The conducted research confirms the usefulness of using VR technology to conduct simulation tests, which, if carried out in real conditions, would pose a threat to health or life. As indicated by the results of this research, the actual feelings of the respondents are at a very high level, and the observed defensive reactions prove the relationship between the behaviours that occur and the real fears of the people participating in the study.

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