A Laboratory Based Study of Driver's Performance to Investigate the Influence of On-Axis Glare Source for Detection of Object Under Simulated Road Lighting Environment

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of the requirements of the degree of

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in
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Submitted by

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CERTIFICATE OF RECOMMENDATION

This is to certify that the thesis entitled **" A Laboratory Based Study of Driver's Performance to Investigate the Influence of On-Axis Glare Source for Detection of Object Under Simulated Road Lighting Environment "** submitted by **DEBTANU RAY**, (Exam. Roll No. **M4ILN19007** , Registration No. **140673 of 2017-18**) of this university in partial fulfillment of requirements for the award of degree of Master of Engineering in Illumination Engineering, Department of Electrical Engineering, is a bonafide record of the work carried out by him under my guidance and supervision.

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This foregoing thesis is hereby approved as a creditable study in the area of Illumination Engineering, carried out and presented by **DEBTANU RAY**, in a manner of satisfactory warrant its acceptance as a pre-requisite to the degree for which it has been submitted. It is notified to be understood that by this approval, the undersigned do not necessarily endorse or approved the thesis only for the purpose for which it has been submitted.

FINAL EXAMINATION FOR EVALUATION OF THESIS.

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(*Signature of Examiners***)**

DECLARATION OF ORIGINALITY AND OF ACADEMIC ETHICS

I hereby declare that this thesis contains literature survey and original research work by the undersigned candidate, as part of my Master of Engineering in Illumination Engineering studies.

All information in this document have been obtained and presented in accordance with academic rules and ethical conduct.

I also declare that, as required by these rules and conduct, I have fully cited and referenced all materials and results that are not original to this work.

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Dated: **DEBTANU RAY**

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CHAPTER- 1

1.1 Abstract

Object detection in presence of road-lighting is a very complex task due to various factors like continuously changing luminance level along the road axis, visibility level of the object or state of mind of the driver. As a result of this, in presence of road lighting, i.e. at night-time, the rate of accident is much higher than day time. Previous studies have shown that light level, spectral sensitivity of photoreceptors, lamp type, illumination level, age of the subject influence the reaction or response time. [1][2]

In this laboratory-based experiment, participants were instructed to responds to a simple object detection task on a projected screen for two types of lighting condition: first, in presence of on axis glare, second, in absence of on axis glare source. In both types of lighting condition same participants were involved. The reaction/response time data along with event related potential at different coordinates of the scalp are measured for each of the participants in both the conditions.

These data are analysed and compared afterwards, and it is found that in presence of glare source the reaction time of the participants increases. Also, from the scalp topographic plot it is found that brain engagement is more under the presence of glare.

1.2 Introduction

The visual task of a person driving a car during the night in presence of road lighting consists mainly, apart from seeing the carriageway itself, in detecting objects in the field of interest, i.e. on the carriage way and in the surroundings, in recognising these objects and judging their character and present and future movement.

The judgement of the object is based on experience and involves higher mental processes. These processes are not very well known but it is at least certain that an object must be seen before it can be recognised and judged. The seeing process is therefore the basis of all later processes including any decision taken by the driver. The seeing process and later the judgement task is highly dependent on lighting condition [3]. The presence of discomfort glare source is an important factor in visibility study, hence in presence of a glare source i.e. when faced with a very high luminance in the visual field the usual behaviour is to blink and look away, or to shield the eyes from the source of high luminance. This behaviour can be taken as an indication that glares is present. Vos (1999) has suggested eight different forms of glare [4]. Of these eight, one has been used in this experiment, which is the discomfort glare, produced by bright, flashing lights in the on axis visual field, e.g. lights on emergency vehicles at night.

A wide range of perceptual experiences have been reported by the road user under different lighting conditions. Behavioural results of different perceptual experiments, done in different road lighting conditions also fail to give a clear picture of this type of situation. It is still unknown that how particular lighting condition triggers higher level brain processes and cortical circuitry. As a result, even simple object detection becomes highly complex. Therefore, only behavioural response of a subject under a simulated environment is not enough to justify the result. The brain wave distribution for that task must also be examined to reach a concrete conclusion. A paradigm shift in the approach of study has been brought about by EEG based study of brain wave distribution under different lighting conditions, which gives the complete picture of the performance of the driver.

1.3 The Aim of the work

This thesis work depicts a laboratory based study, where, both behavioural and cognitive performance of the driver has been measured and compared in presence and then in absence of an on axis glare source. The result thus obtained can give a concrete conclusion of influence of the on-axis glare in human performance for a driving scenario.

Reference:

[1] C. Fotios S. A.; Cheal, "Lighting for subsidiary streets: investigation of lamps of different SPD. Part 1---Visual Performance," Light. Res. Technol. 39, 3 pp. 215--232, vol. Vol. 39, no. 3, pp. 215–232, 2007.

[2] J. D. Bullough and M. S. Rea, "Simulated driving performance and peripheral detection at mesopic and low photopic light levels," Light. Res. Technol., vol. 32, no. 4, pp. 194–198, 2000.).

[3] E. Frederiksen and N. Rotne, "Calculation of Visibility in Road Lighting" Report No. 17, Lysteknisk Laboratorium, March 1978.

[4] Peter R. Boyce "Human Factors in Lighting" Third Edition.

CHAPTER- 2

2.1 Background of the Work (Object Detection in Road Lighting)

In order to find the human performance for a visual task under specific lighting condition, numerous laboratory and field based research works has been conducted. The generalised idea in most of these research works are to investigate how the task and lighting condition affects the task performance, which is highly dependent on visual performance. Some of the most influential research works are given below.

In his study of "Human Factors in Lighting", Peter R. Boyce has given a conceptual framework of three major pathway through which lighting can affect human performance [1]. These are through visual performance inter-related with motor and cognitive performance, mood and motivation at the time of the task and circadian timing system. The complete framework is shown in figure: 1.

In the research paper "Simulated driving performance and peripheral detection at mesopic and low photopic light levels" , Bullough and Rea has shown that how object detection percentage depends for a simulated driving task at mesopic and low photopic light levels under different spectral power distributions (SPDs)[2].

Another research work by R. Biswas, S. Chakraborty et al has shown a comparative analysis of scalp activity and driver's performance for an object detection task designed under metal halide (MH) and high-pressure sodium (HPS) light sources [3].

This research work is a result of a thorough analysis of the previous works done in this field; the vast research work done by the previous researchers are summarized here in two sub-categories:

1. Previous work on visibility calculation and
2. Previous object detection experiment.

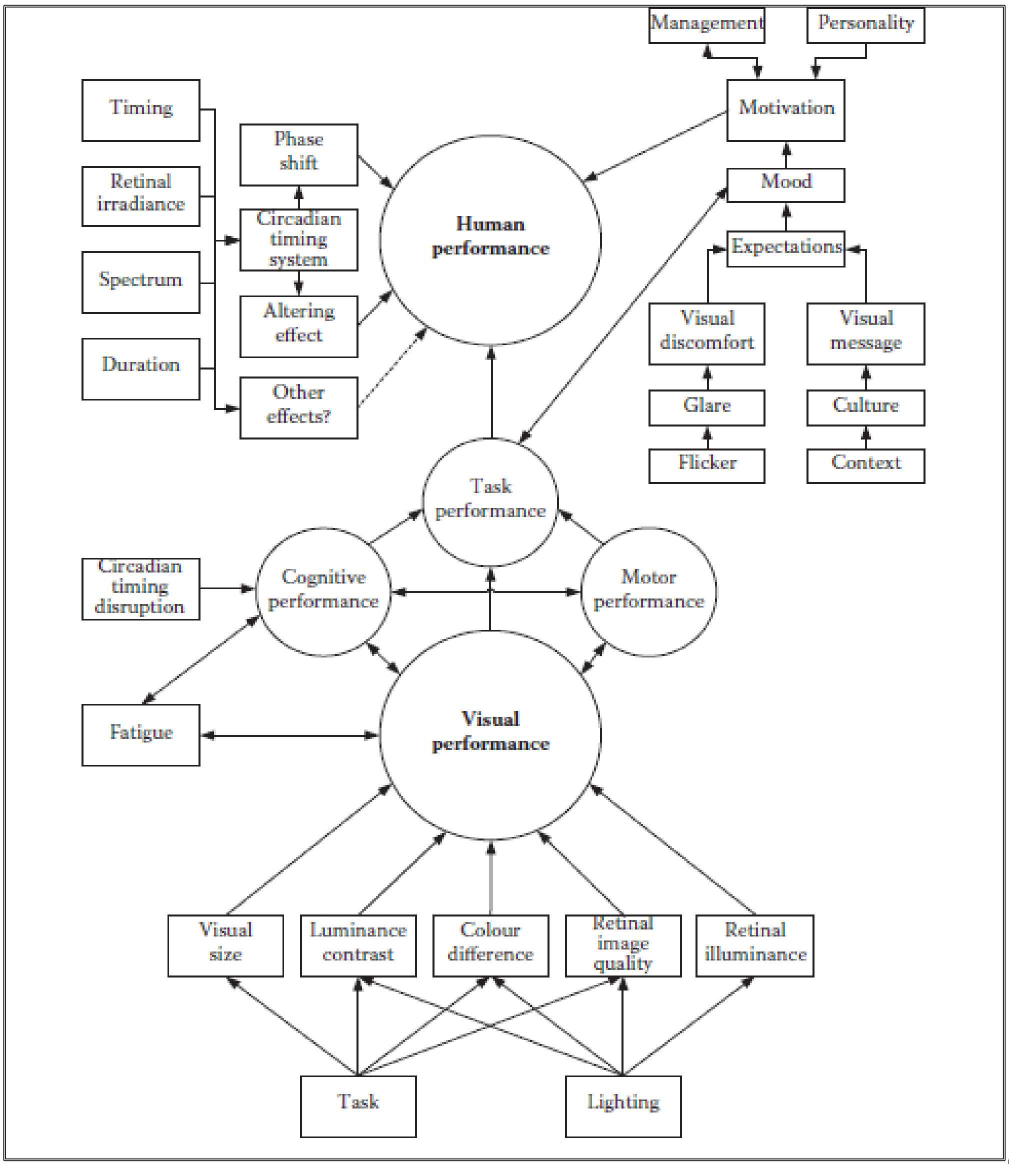


Figure 1: A conceptual framework setting out the three routes whereby lighting conditions can influence human performance. The arrows in the diagram indicate the direction of effect.

2.1.a Previous work on Visibility Calculation

The seeing process or more specifically the object detection process depends on the visibility of the object under the specific lighting condition. Although, the term "Visibility" refers to a very large domain with respect to lighting engineering, but its principles can be concretised in a mathematical model (this model obviously does not include the physiological processes in the eye and brain), which is a function of the visual system as a whole, i.e. "contrast sensitivity function".

In the technical report no 17, "Calculation of Visibility in Road Lighting" by Frederiksen et a[4] has shown that this "contrast sensitivity function" (p) depends on background luminance (l_b) (cd/m^2), luminance difference of object and background ($\boldsymbol{\Delta} l$) (cd/m^2), the size of the object (α) (minutes) and observation time(t) (sec).

$$p = f(L_b, \Delta l, \alpha, t)$$

"p" is the probability of detection of an object.

Frederiksen with the help of Berek and Blackwell's experiment data had tried to find the visibility level as defined in CIE report no. 19.

Later several researchers have tried to find the most accurate visibility level calculation model, of which Adrian's visibility model [5] is considered as the most suitable one.

The Adrian's model is also modified later in the years and later published by the Illuminating Engineering Society of North America in "ANSI/IESNA RP-8-00".

In this model the factors which affects visibility are:

1. Adaptation Level – Relative contrast Sensitivity
2. Disability Glare
3. Contrast
4. Size
5. Time of viewing
6. Transient Adaptation
7. Observer Age

Hence, it has been well acknowledged internationally that visibility depends on disability glare. Disability glare is associated with veiling luminance caused by light from bright sources being scattered within the eyes of observers, thereby reducing retinal luminance contrast. The above discussion on the previous studies on Visibility Level calculation is summarised in the following table: -

Serial Number	**Publication**	**Author**	**Name/Description of the Study**
1	CIE 19/2, 1980	Blackwell	"An Analytic Model for Describing the Influence of Lighting Parameters Upon Visual Performance"
2	Report No. 17, Lysteknisk Laboratorium, Denmark	E. Frederiken, N. Rotne	"Calculation of Visibility in Road Lighting"

3	ANSI/IESNA ANSI/IESNA RP-8-00	Werner Adrian	Visibility model based on: • 60-year-old moving observer • 8 cm, 50 % reflectance target viewed at a height of 1.45 m and 83 m distance (1-degree downward angle) • 0.2 second viewing time • Visibility Model accounts for eye adaptation, target/background contrast and glare from the luminaires

Table 1: Summary of previous work on visibility calculation.

This research work focuses on the influence of on-axis glare on driver's performance in conditions like street lighting.

2.1.b Previous object detection experiment

Numerous research studies have been done in the field of target detection at mesopic light levels in a driving context. Of which, the most relevant experiments are described here. In most of the experiment the target was presented in the periphery of the 2-degree visual field.

In the research work conducted by Akashi et al [6], a field study was conducted to find the influence of different types of light sources (Metal halide and High pressure sodium vapour) on response time for a real time driving scenario. The subjects participating in this study were asked to drive a vehicle for the two types of lighting installation and had to identify the direction of an off-axis target. (i.e. towards or away from the street). The subject driving the vehicle has to accelerate or brake accordingly thereafter. The study resulted in better peripheral visibility under metal halide and also suggest that lighting installation having unified luminance distribution results in a quicker response.

Similar study was done by Barrett et al [7], where different glare installation was used to perform an object detection task. It was found that veiling luminance has a significant effect on the performance of the observer.

In the laboratory experiment done by Bullough and Rea [2], a simulated driving task with a commercial racing game was used to find object detection percentage under different spectral power distributions (SPDs). The scene was projected on a screen. The subjects were able to control the car with a steering wheel and an accelerator pedal and were asked to drive as quickly and safely as possible i.e. number of accidents were less. The colour of the scene (S/P ratio) and luminance level were controlled by neutral density filters mounted in front of the projector lens. The target was presented for about half a second at random time intervals during the runs. Subjects were asked to respond verbally. It appeared that with increasing background luminance the driving speed increases, and the number of crashes decreases. There was no such influence of colour on speed and number of crashes.

2.2 Original Contribution by the Author

The original contribution of this thesis work by the author are as follows:

1. The design of the experiment along with stimulus preparation,
2. Statistical analysis of the behavioural data to investigate the influence of on-axis glare source,
3. The result obtained is again validated with the help of cognitive data obtained using Electroencephalography.

References

[1] Peter R. Boyce "Human Factors in Lighting" Third Edition

[2] Bullough, J. D. and Rea, M. S. (2000) "Simulated driving performance and peripheral detection at mesopic and low photopic light levels". Lighting Res. Technol. 32, 194–198.

[3] Rakesh Biswas, Suddhasatwa Chakraborty and Pratik Nath. "Laboratory based EEG study to investigate the influence of light sources on brain processing for detection of object designed with metal halide and high-pressure sodium lamp". Journal of Science and Technology in Lighting Vol.41, 2017

[4] E. Frederiksen and N. Rotne, "Calculation of Visibility in Road Lighting". Report No. 17, Lysteknisk Laboratorium, March 1978.

[5] W. Adrian**, "**Visibility of targets: Model for calculation". Lighting Research & Technology, 1989.

[6] Yukio Akashi, MS Rea and JD Bullough, "Driver decision making in response to peripheral moving targets under mesopic light levels". Lighting Res. Technol. 39,1 (2007) pp. 53–67.

[7] N Davoudian, P Raynham and E Barrett, "Disability glare: A study in simulated road lighting conditions". Lighting Res. Technol. 2014; Vol. 46: 695–705.

CHAPTER- 3

3.1 Human Vision

The human eye is an organ of the visual system. The eyes provide organisms with vision, the ability to receive and process visual detail, as well as enabling several photo response functions that are independent of vision. Human eye works like camera obscura with a convex type of lens. There are two types of photoreceptors in human retina:

1. *Rods*: responsible for vision at low light levels. Do not mediate colour vision and have a low spatial acuity.
2. *Cones*: active at higher light levels, are capable of colour vision and are responsible for high spatial acuity.

The central fovea is populated exclusively by cones. There are three types of cones: short-wavelength sensitive cones, the middle-wavelength sensitive cones and the long-wavelength sensitive cones or S-cone, M-cones, and L-cones respectively. Broadly these three types of cone cells correspond to Red, Green and Blue colour respectively.

3.1.a Central and peripheral vision

The vast majority of the area in the visual field can be divided in two areas; "Central or Foveal" and "Peripheral" vision. The range of human visual field is 100-110° from central Fixation. Of which, 5° from the central fixation is referred as central vision and rest of the visual field comes under peripheral vision. The peripheral zone can be further subdivided in "Far peripheral" vision, refers to the area at the edges of the visual field, "mid-peripheral" vision, refers to medium eccentricities, and "near-peripheral", sometimes referred to as "para-central" vision, exists adjacent to the centre of gaze. Figure 2 shows the division of the complete visual field.

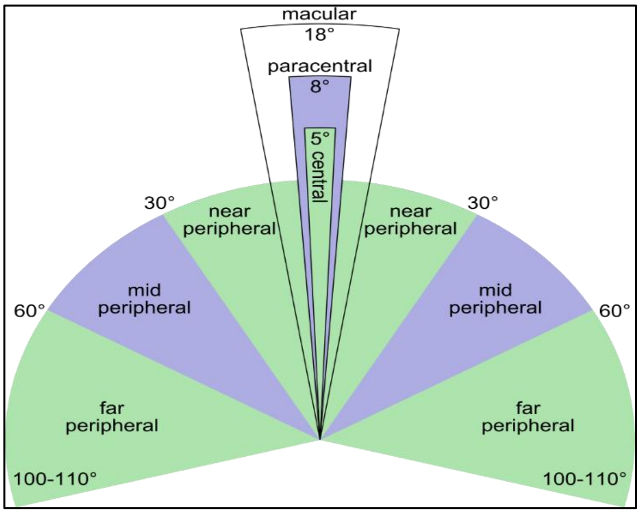


Figure 2: Human field of view (FOV) for both eyes showing far, mid- and near peripheral vision, macular, paracentral, and central (foveal) vision. (Source: Wikipedia)

3.1.b Photopic, Scotopic and Mesopic vision

The role of lighting is facilitating human visual tasks and creating comfortable visual atmosphere. To design, specify, install, and maintain lighting, light needs to be dealt quantitatively so that the quantities can correspond to human visual sensations evoked by the light. The method to quantify light in such a way is photometry. In current practice, a photometry system based on the spectral luminous efficiency function for the CIE (Commission Internationale de l'Éclairage) standard photometric observer, V(λ), is always used. This function represents the visual perception by light at equal power for each wavelength, as shown in Figure 3.

The V(λ) function is based on measurements of the spectral sensitivity at the centre of the field of view by using small stimuli subtending angles of 2° or 3°. An area in the retina corresponding to the small centre field of view, which is called fovea, is almost occupied by cone cell. Thus, the V(λ) function can roughly be considered as a model based on the spectral sensitivity of the cones.

In the periphery of the retina, the situation is completely different from that in the fovea. Almost all area, except for the fovea, rod cells are dominant and the cones are minority. The rods work principally in lower luminance levels while the cones work mainly in higher luminance levels. Thus, the peak spectral sensitivity of the peripheral retina shifts toward shorter wavelengths in lower light levels. This phenomenon is known as the Purkinje effect.

To deal this complex phenomenon of the human vision in photometry, three types of vision were identified as:

- photopic vision, where the eyes adapt to higher luminance levels and the cones contribute visual perceptions mainly;
- scotopic vision, where the eyes adapt to extremely lower luminance levels and the rods contribute visual perceptions mainly; and
- mesopic vision, where the eyes adapt to intermediate luminance levels between the photopic vision and the scotopic vision, and where both the cones and the rods contribute visual perceptions.

CIE 191 defines the mesopic spectral luminous efficiency function as a set of functions to be chosen depending on the adaptation, the adaptation state for a lighting scene need to be determined to identify which function should be applied to the scene.

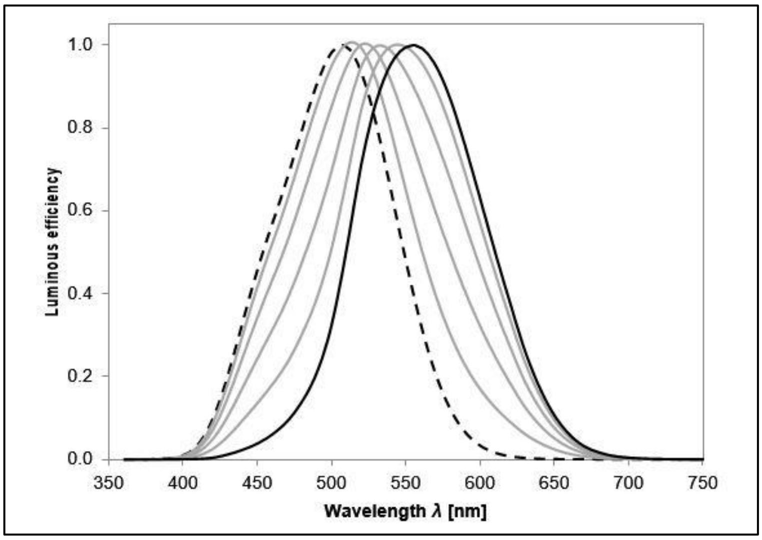


Figure 3: Spectral luminous efficiency functions. The black solid line and the black dash line show the photopic spectral luminous efficiency function V(λ) and the scotopic spectral luminous efficiency function V′(λ), respectively. The grey lines show some mesopic spectral luminous efficiency functions with various adaptation coefficient

3.2 Brain Wave Distribution

The visual information from the eye is processed in the "visual cortex". It is located in the occipital lobe. Visual nerves run straight from the eye to the primary visual cortex to the "Visual Association Cortex". Both hemispheres of the brain contain a visual cortex; the visual cortex in the left hemisphere receives signals from the right visual field, and the visual cortex in the right hemisphere receives signals from the left visual field.

The basic building block of the visual cortex or the brain is neurons. Neurons communicate with each other by electrical changes. One can see these electrical changes in the form of brain waves with the help of an electroencephalogram (EEG). An EEG device records electrical signals from the brain, specifically postsynaptic potentials of neurons originating from the cerebral cortex, through electrodes that are attached to the subject's scalp. The electrodes attached to the subject's scalp transmit the electrical signals produced by the brain to the EEG monitor. Since these electrical signals are very small (of the order of 10s of microvolts) the EEG acts as an amplifier, typically amplifying them by 10,000 times, as well as a device to measure them.

Brain waves are measured in cycles per second (Hertz; Hz). The lower the number of Hz, the slower the brain activity or the slower the frequency of the activity. Researchers in the 1930's and 40's identified several different types of brain waves. Traditionally, these fall into 5 types: Alpha, Beta, Gamma, Delta and Theta. A brief description of these 5 brain waves are given in table 2.

Brain Wave	Frequency	Import Features
Delta	0.5-8 Hz	Most prominent in deep sleep and meditation (Suspends external awareness and source of empathy)
Theta	3-8 Hz	Mostly during sleep and meditations. Mainly focusing on signals originating from within the body rather than external worlds.
Alpha	8-12 Hz	Denotes overall mental co-ordination, calmness, alertness, mind-body integrity. Most prominent at the time of learning.
Beta	12-38 Hz (Beta 1: 12-15 Hz, Beta 2: 15-22 Hz, Beta 3: 22-38 Hz)	Denotes states of consciousness, mainly towards a cognitive task. Most prominent at the time of alertness, attentive, decision making, problem solving, judgement.
Gamma	38-42 Hz	Fastest of brain waves, Highly prominent when expanded consciousness and spiritual emergence, altruism.

Table 2: Summary of different types of brain waves.

References

[1] Recommended system for visual performance based mesopic photometry. CIE 191, Commission Internationale de l'Éclairage, Vienna, 2010.

[2] The basis of physical photometry, 2nd edition. CIE 18.2, Commission In- ternationale de l'Éclairage, Vienna, 1983.

[3] Zuzana Koudelková, Martin Strmiska "Introduction to the identification of brain waves based on their frequency", MATEC Web of Conferences.

CHAPTER- 4

4.1 Experimental Setup and Method

The task of finding human performance for a specific type of lighting condition falls under the category of real-task studies. Unlike the abstract studies, the real-task studies involve a specific task that must be performed by the participants, so that their performance can be measured, and different control condition can be changed easily. Measurements in this type of studies are made either using a real task in the field or a simulated version of the task in the laboratory. The special characteristics of real-task studies is that they attain high value of face validity. Face validity is the attribute for a specific lighting condition of a particular task, hence these studies do not give a generalised model, the measured value obtained from these studies yields specific visual, cognitive and behavioural result.

The abstract studies on the other hand has high value of generality and low value of face validity. These types of studies are ideal for finding the generalised result for a simple visual task whose lighting condition are not specific and cognitive and motor responses are minimally influenced by the lighting condition. These types of study are used for predictive modelling.

In this research work, the human performance in presence of an on-axis glare source of an object detection task is required. Hence, this research work is a type of real-task studies. The experiment has been specifically designed to find the reaction/response time data, i.e. behavioural and brain wave distribution, i.e. cognitive data for this specific road lighting scenario.

The above discussion is summarised with the help of following figure: -

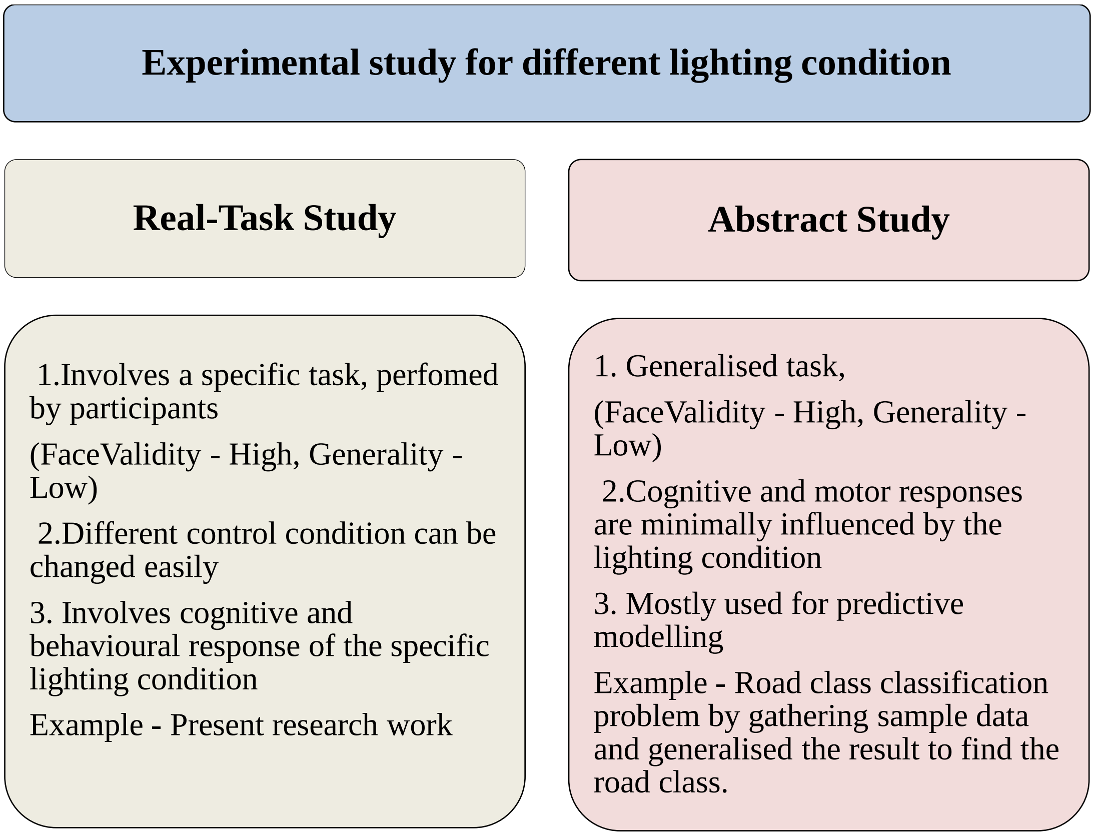


Figure 4: Comparison of real task study and abstract study.

4.1.a Approach

The aim of this research work is to find, how human performance of object detection task is getting influenced in presence of an on-axis glare source. The term Human Performance in context of task performance refers to the visual, motor and cognitive performance, i.e. cumulative performance of the Eye and the Brain. Hence, the output data collected for this study is both behavioural and cognitive.

The object detection task in the specified lighting condition requires a controlled lighting environment, the face validity of the present research work is high hence the whole experiment has been conducted in a simulated environment. Although the real field factors affecting the mood of human like temperature change, rain, sound noise etc are not possible to mimic in the simulated environment, but as their effect on the human performance is very minimal in the current context hence the simulated setup with controlled lighting condition yield a satisfactory result.

The whole experiment is divided into two separate trials depending on the lighting condition. The aim is to find the behavioural and cognitive data for each trial for the same participants. The behavioural data is obtained with the help of response time collected using a pressure switch (buzzer switch) operated by the participant at the time of each experiment. On the other hand, event related potential of the scalp or the cognitive data is collected with the help of electroencephalogram (EEG).

Hence, the response time data from pressure switch and event related potential data are collected for both experiment of different lighting condition for same participant.

The whole experimental approach is described in the following figure: -

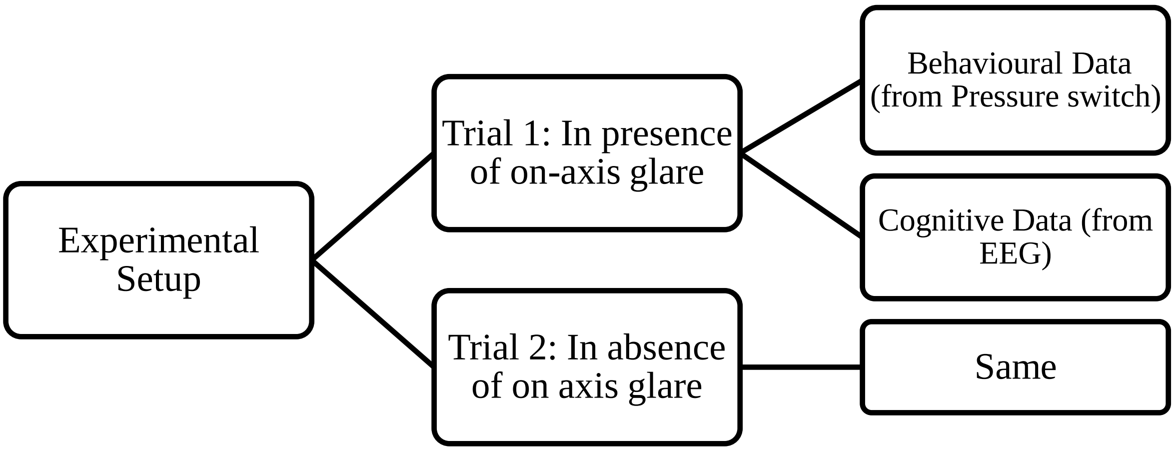


Figure 5: Flow diagram to describe the approach of the experiment.

4.1.b Experimental Setup

The experiment for this research work has been performed in a simulated environment. The experiment was carried out in a completely dark room of dimension 4m X 4m X 2.5m. The dark room was set up at the Illumination Engineering Laboratory, Electrical Engineering Department, Jadavpur University (figure 7).

The basic apparatus required for the experiment is as follows: -

1. Two R-G-B LED projector
2. Three laptops
3. Pressure switch connected with laptop via USB
4. EEG headset (Emotiv Epoc+)
5. Tripod

The complete description of the apparatus is given in annexure. The layout of the experiment is shown in figure 6. As shown in the layout, two projectors were used. One to project the background along with the stimulus, another to project the on-axis glare source. Hence, in Trial 1 (in presence of glare) both the projectors are on and in trial 2 (in absence of glare) only the projector projecting the background image is on. Three laptops were used to control the projectors and to collect the response data.

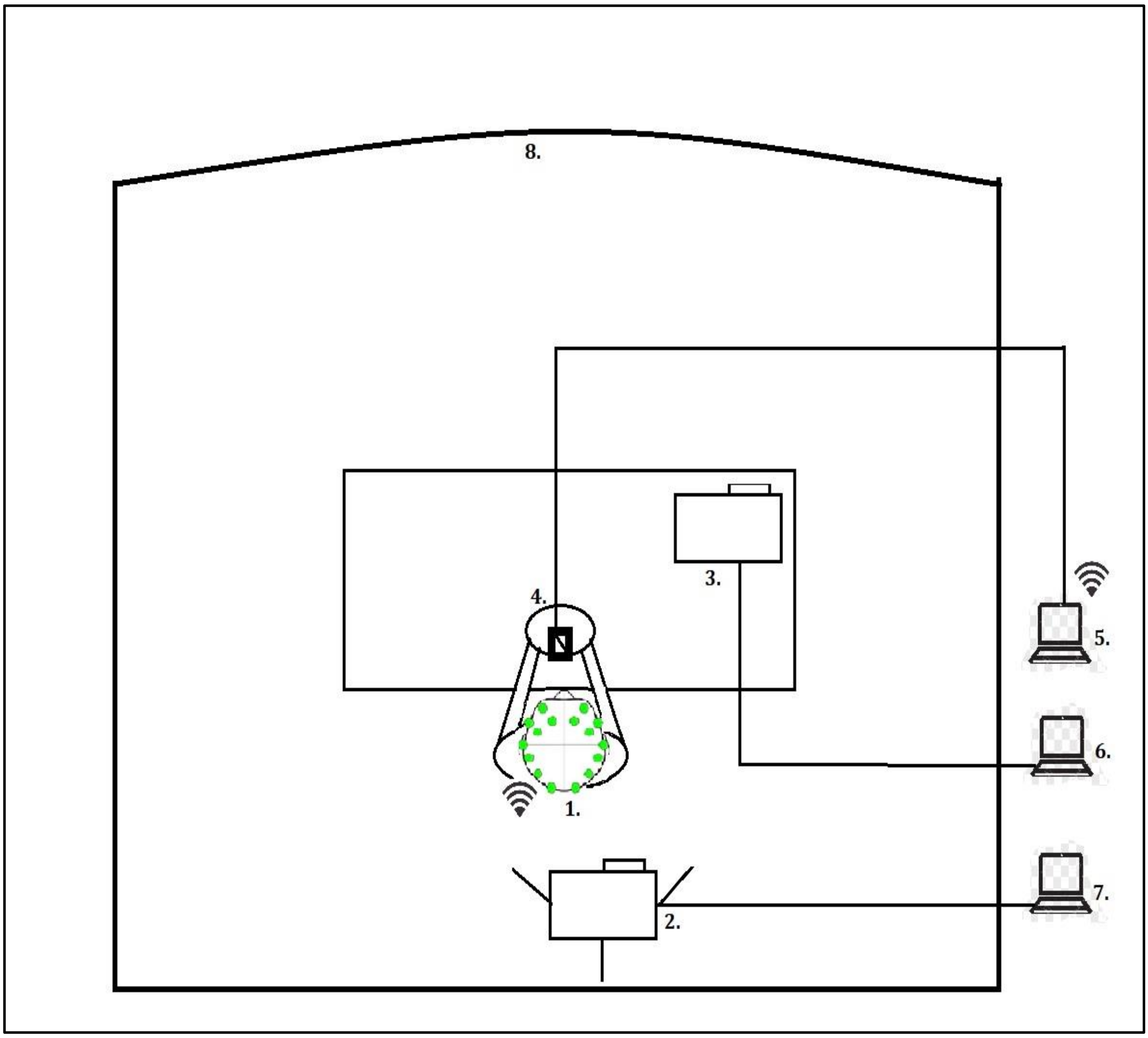


Figure 6: Layout of the Experiment

<u>*Description of the figure 6*</u>

1. *Subject wearing dynamic EEG Headset connected laptop "a" via wifi*
2. *Projector a to project the background image along with the stimulus for the object detection task, connected with laptop "c"*
3. *Projector b to project the on-axis glare connected with laptop "b"*
4. *Pressure switch on driver simulator connected via USB to laptop "a"*
5. *Laptop "a"*
6. *Laptop "b"*
7. *Laptop "c"*
8. *On axis projection screen*

The photograph of the complete experimental setup is shown in Figure 8. The Photograph of the dark room is shown in figure 7.

Figure 7: Dark room for the experiment

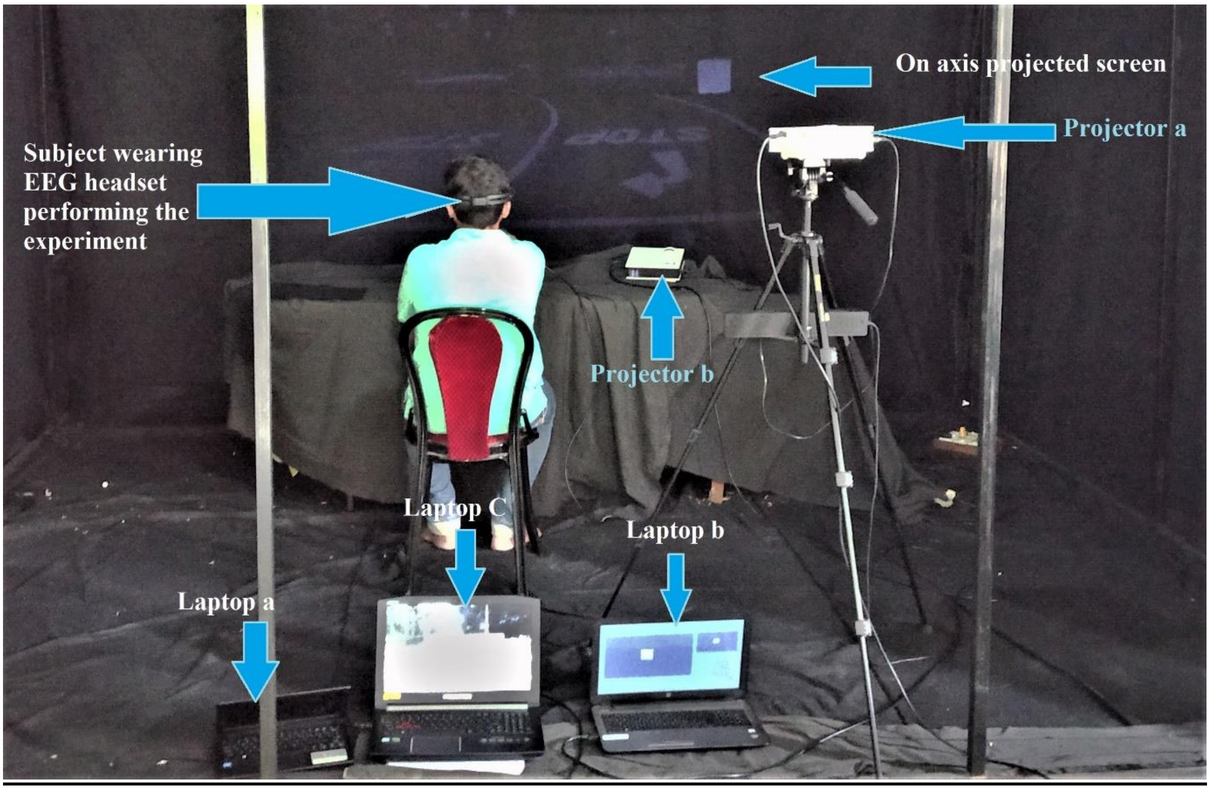


Figure 8: Experimental setup

4.1.c Behavioural Experiment

The word behavioural refers to the motor performance of the participants in this study. The reaction or response time of the participants/subjects has to be measured for further data analysis under the two trials (presence and absence of glare source). The behavioural data recording has been done with the help of a "Generic PC USB Pressure switch" input. It was connected with a laptop to record the subject's response in seconds up to 14 decimal points.

A python-based program was developed to simulate a real time road light scenario for 5 different background images as five "**Blocks**", each having a time span of 6 to 8 minutes. These background images are projected on the on-axis screen. The projection creates a well-lit simulated road in the mesopic photometry region covering a visual field of 110 degree with respect to the subject. The program generates an object as stimulus in certain predefined interval on the projected screen. These are termed as "**Events**". There were fifteen such events in each of the five blocks. Upon recognising the presence of the stimulus/events the subject has to press the switch at once. The response time generated from the switch would be stored in a laptop connected via USB. The python script used for this study is attached in the annexure.

4.1.d Cognitive Experiment

As object detection study encompasses complex mental processes hence cognitive data is also required to be stored at the time of the object detection events in this experiment. The cognitive data is gathered with the help of a potable 14 channel dynamic based EEG headset Emotiv Epoc+ which uses cap mounted Ag/AgCl type of electrodes. After putting the electrodes at the right position on the scalp of the subject, the participant was asked to start performing the task. The headset was connected wirelessly through a wifi enabled USB device connected to a recording device (Laptop) using EMOTIV PRO software. The recording was handled by one of the investigators of the experiment and the EEG data was recorded between the instant the stimulus was provided to the participant and the instant the participant detects the object. Inter-electrode impedances were kept low ($<20K\Omega$) by using a saline liquid which was used for cleansing the electrode points for proper conduction of signals. EEG recordings were then filtered using built in fifth order Sinc Filter. The data collected had a bandwidth of 0.2HZ – 45Hz and the device had notch filters at 50 Hz and 60 Hz.

4.2 Selection of Background and Stimulus

In both trials of the experiment (i.e. in presence and absence of glare source) five blocks or five projected background images were selected carefully so that these five images provide same simulated experience as driving through highway, conflict area, intersection of road etc. After selecting these five images, all images are made achromatic with the help of photoshop because in case of mesopic photometry, light level is much lower and mostly cone cells are contributing to the human vision. These cells do not mediate colour vision hence all projected background images are made achromatic (black and white). Figure 10 shows the five chosen blocks for each trial.

The stimulus or object generated by the python program at predefined interval is termed as events. The object is a standard cross-hair of 2° and appears on the road surfaces randomly on the projected background images. An example of such an event is shown in figure 9.

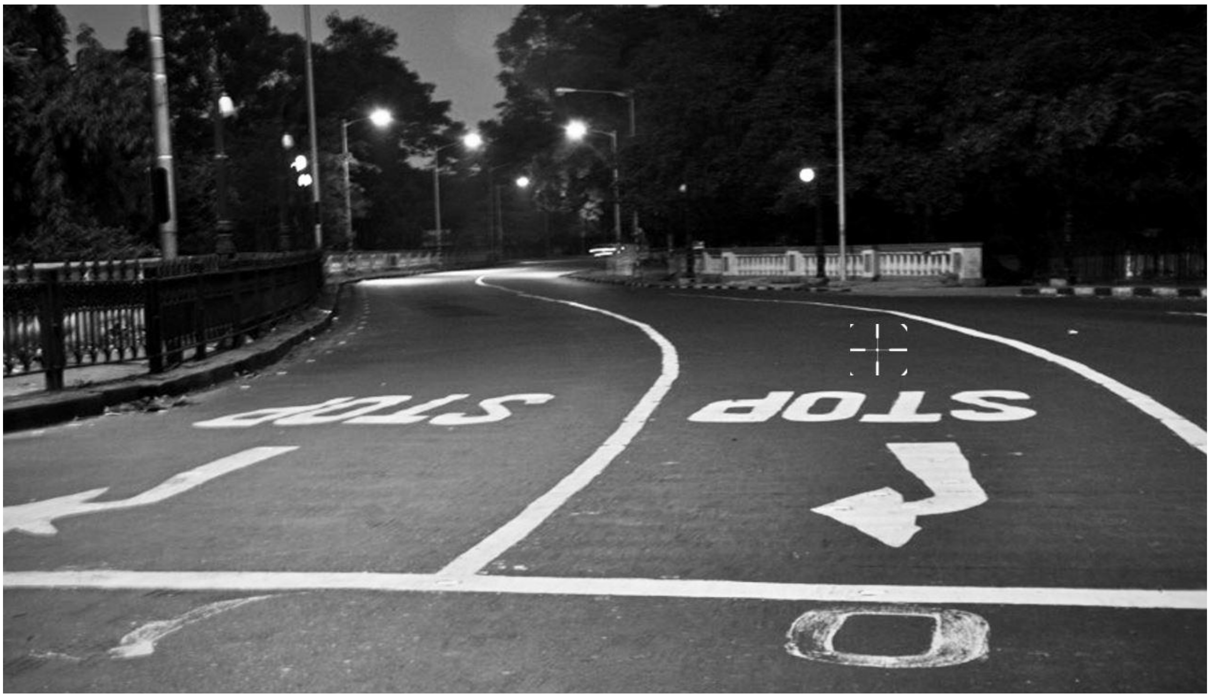


Figure 9: Sample event where object is appearing.

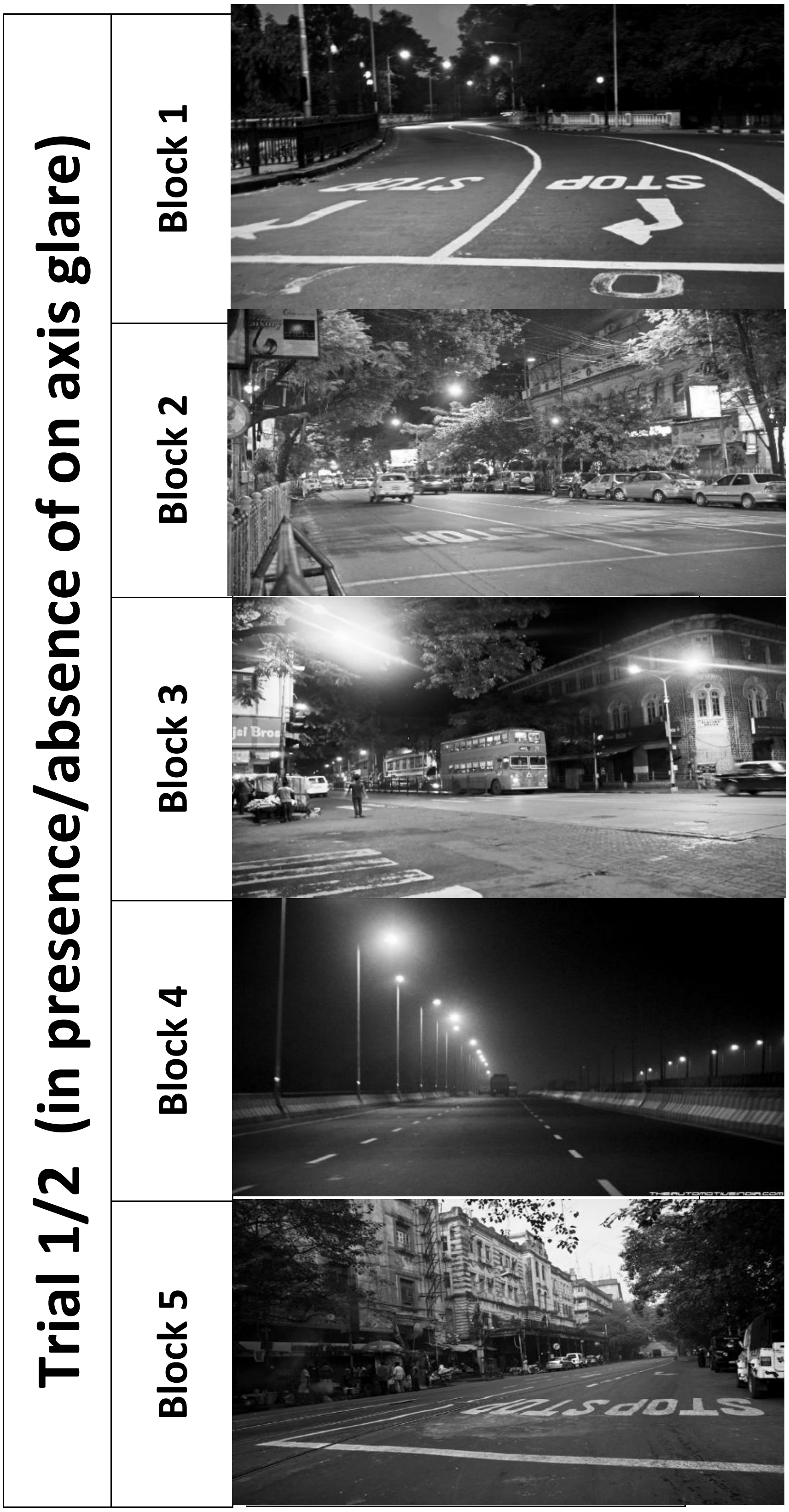


Figure 10: five blocks used in the both trials.

The fifteen events or stimulus are chosen such that their contrast levels are different and should vary at a maximum value 22 to minimum value 0.4 with respect to the background. The detail time frame of Stimulus for the five blocks is tabulated in table 3 for both trials.

Detail of stimulus

Table 3: Detailed time frame of the stimulus for both trials

Block 1

Event	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Time (in sec)	6-7	29-30	43-44	49-50	75-76	87-88	147-148	161-162	189-190	216-217	243-244	297-298	303-304	339-340	385-386

Block 2

Event	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Time (in sec)	31-32	37-38	93-94	149-150	185-186	261-262	267-268	293-294	329-330	355-356	391-392	397-398	423-424	459-460	485-486

Block 3

Event	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Time (in sec)	15-16	37-38	43-44	49-50	97-98	114-115	167-168	187-188	204-205	245-246	291-292	297-298	313-314	339-340	365-366

Block 4

Event	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Time (in sec)	27-28	47-48	63-64	74-75	95-96	110-112	137-138	153-154	179-180	205-206	267-268	317-318	354-355	389-390	427-428

Block 5

Event	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Time (in sec)	8-9	17-18	21-22	58-59	75-76	101-102	163-164	197-198	255-256	307-308	319-320	373-374	402-403	447-448	471-472

4.3 Subjects or participants for the experiment: -

Ten very healthy neurologically intact participants (Seven males and three females, age: mean ± S.D. 21.3±1.45 yrs.) were recruited for this study. All the participants recruited had normal or corrected to normal vision. Upon arrival, participants were made comfortable and provided refreshments before they were assigned to perform the required task. Prior to the experimental procedure, all the participants were made conscious about the entire experimental procedure and signed an informed consent before participating in the experiment. The above protocol was cleared by Institutional Ethics Committee.

Following is the details of the participants: -

Serial Number	List of Participants	Age
1	Subject A	23
2	Subject B	25
3	Subject C	22
4	Subject D	21
5	Subject E	22
6	Subject F	22
7	Subject G	23
8	Subject H	26
9	Subject I	22
10	Subject J	24

Table 4: Details of the participants

CHAPTER- 5

5.1 Data Recording

As discussed in chapter 4, behavioural data is recorded with the help of a pressure switch connected to a laptop via USB. The data is tabulated further as per trial and block for each of the participant for data analysis purpose. One example of such tabulated data for a participant for trial 1 is given below:

Event no	**Delay in Block 1**	**Delay in Block 2**	**Delay in Block 3**	**Delay in Block 4**	**Delay in Block 5**
1	NR	NR	NR	0.802080631	0.892321348
2	NR	NR	NR	0.770926714	0.770922899
3	2.353535414	1.656951427	2.353535414	0.716996431	0.813251972
4	1.003063202	NR	1.003063202	0.783389091	0.968881845
5	0.922573328	NR	0.922573328	0.765442848	0.755380392
6	NR	1.955662966	NR	1.0038414	0.78887701
7	0.89540267	NR	0.89540267	1.943936348	0.936892509
8	0.851495266	2.29137373	0.851495266	0.722940445	0.79522872
9	1.137474775	1.653850555	1.137474775	0.670671225	0.750113487
10	0.779115677	NR	0.779115677	0.833659172	0.788252354
11	0.912500381	NR	0.912500381	0.935678482	0.81282711
12	1.774691582	NR	1.774691582	0.704304934	0.876060724
13	0.851992846	1.147389174	0.851992846	1.858906507	0.730592489
14	NR	NR	NR	0.773140192	0.845314264
15	0.774423599	NR	0.774423599	0.709157705	0.784054995

Table 5: Sample Tabulated data (All values are in seconds. NR: Non-Responsive.)

While recording the data, delay for each event are calculated by simple excel subtraction formula, i.e. (Actual event time) - (Response time) = Delay. If the subject fails to provide any response then it is taken as non-responsive, NR. If any of the delay value is greater than 5 seconds, meaning the subject's response is delayed by more than 5 seconds, that value is also taken as non-responsive.

The cognitive data is recorded with the help of an EEG headset. The headset is a 14 channel dynamic EEG headset, manufactured by Emotiv Epoc+.

In order to collect the event related potential of the scalp, the electrodes along with the headset are set at the right position on the scalp of the subject. The headset was connected wirelessly through a wifi enabled USB device connected to a recording device (Laptop) using EMOTIV PRO software. The recording was handled by one of the investigators of the experiment and the EEG data was recorded between the instant the stimulus was provided to the participant and the instant the participant detects the object. The subject is then asked to perform the object detection task.

The data obtained from the Emotiv Epoc+ software is in .csv and in .edf format for each block of each subjects. For further data analysis (like data averaging, removing mean of channels, Epoch extraction etc) of the scalp EEG recordings of each subjects, MATLAB is used, preferably the EEGLAB toolbox where the .edf file was used as input.

5.2 Data Analysis

The data analysis part in this research work is divided in two domain, one behavioural data analysis and second, cognitive data analysis. The behavioural data obtained from the pressure switch is an excel file (.xlsx format) containing reaction/response time of the subjects. With the help of this file further statistical analysis has been done using R statistical software.

Cognitive data or the event related potential of the scalp obtained from the EEG headset, Emotiv Epoc+ connected to a laptop. The data obtained from the licensed software is in .edf and .csv format. For further analysis, MATLAB eeglab toolbox is used.

Following flow chart (Figure 11) gives an overview of the data analysis process.

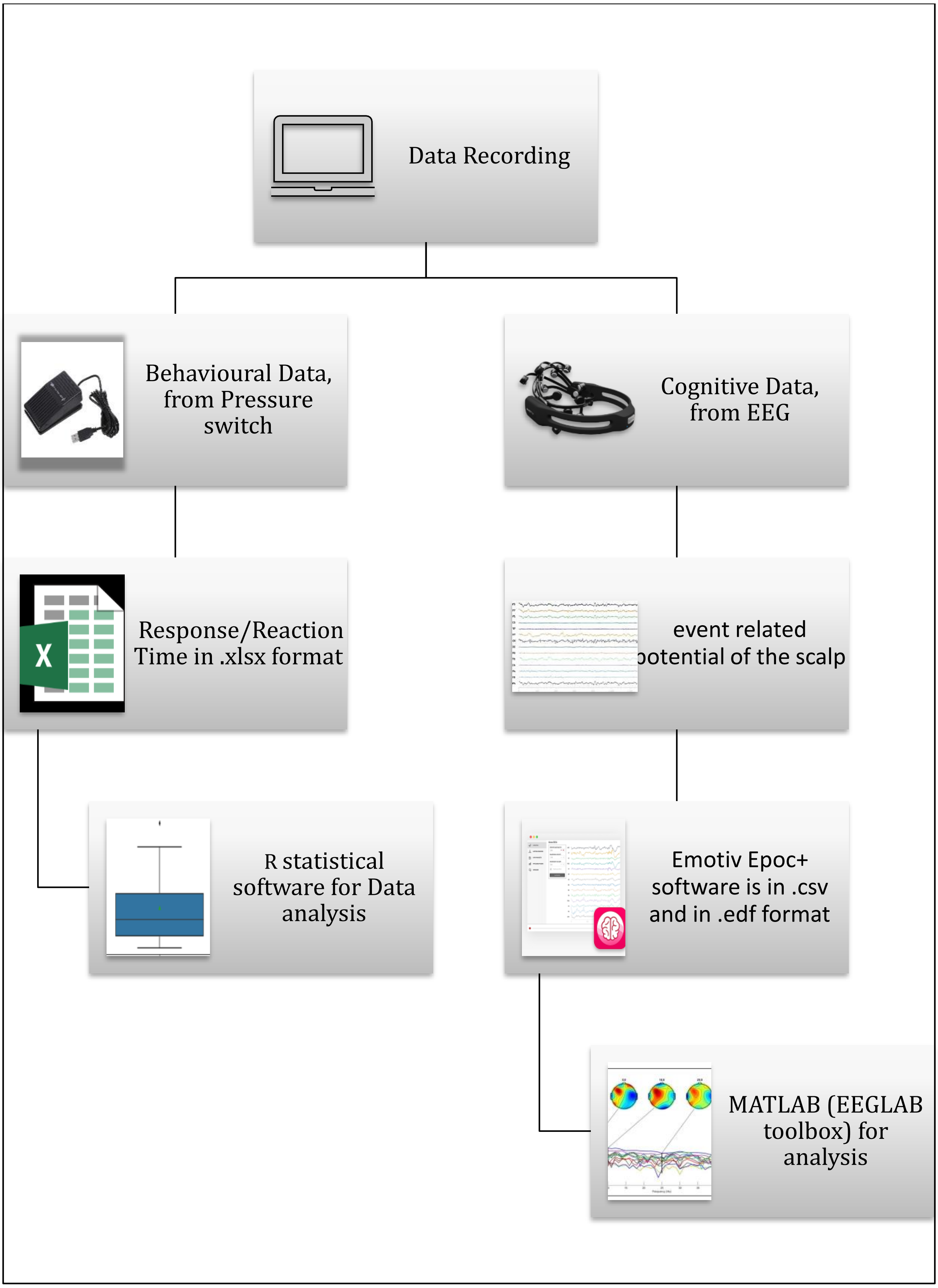


Figure 11: Flowchart of the data analysis process

The detailed description on the data analysis is given in the following subsections.

5.2.a Behavioural Data Analysis

The behavioural data is tabulated in .xlsx format for the response time of each event of each bock of a particular subject performing under a particular trial. The delay is calculated in the excel file itself. Hence, for each trial (Trial 1 and Trial 2) there exist one excel file containing the response time of all the subjects. From which the delay time and number of misses can be found. In order to compare the behavioural performance in the two trials, scatterplot of delay time in each block per trial is shown in figure 12 to 16.

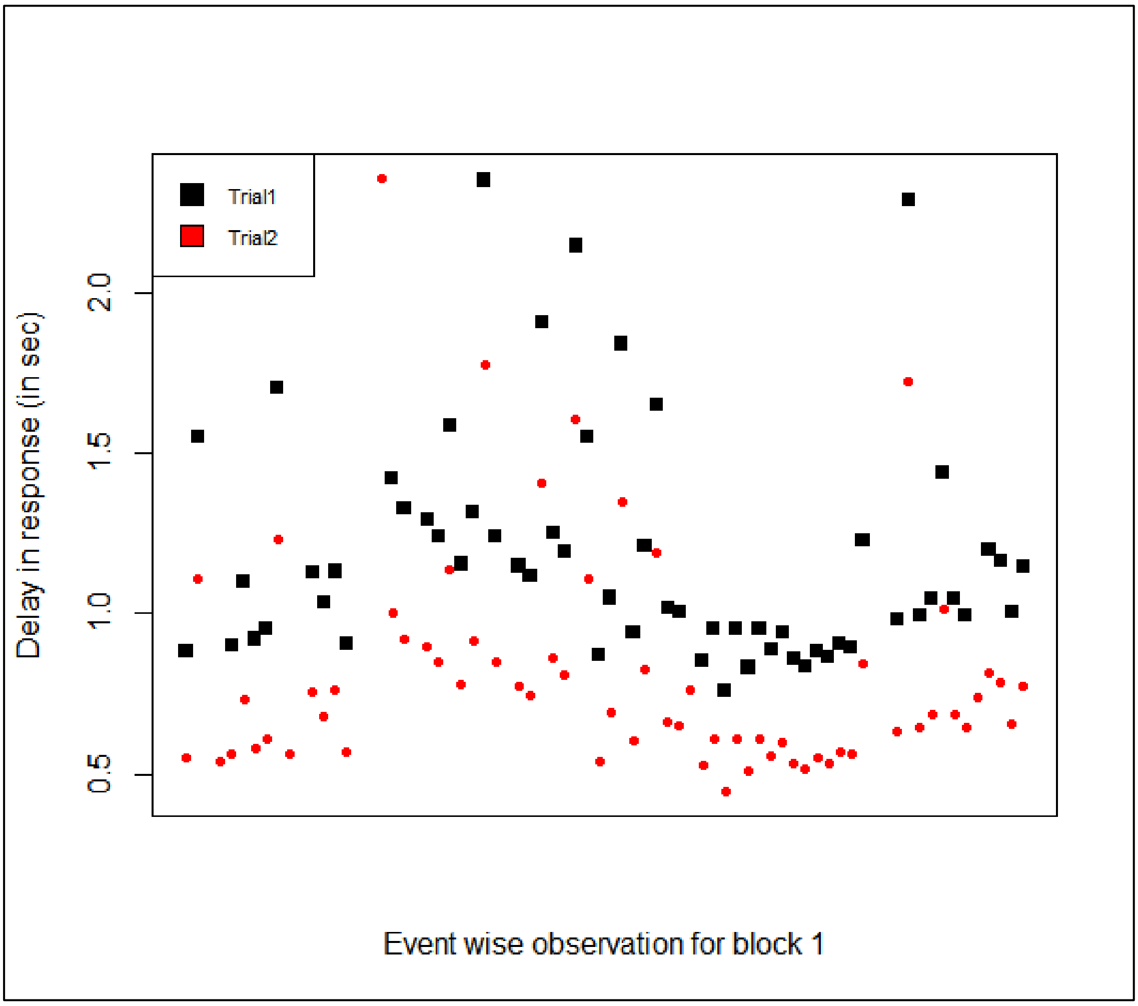


Figure 12: Delay time comparison of trial 1 and trial 2 for Block 1

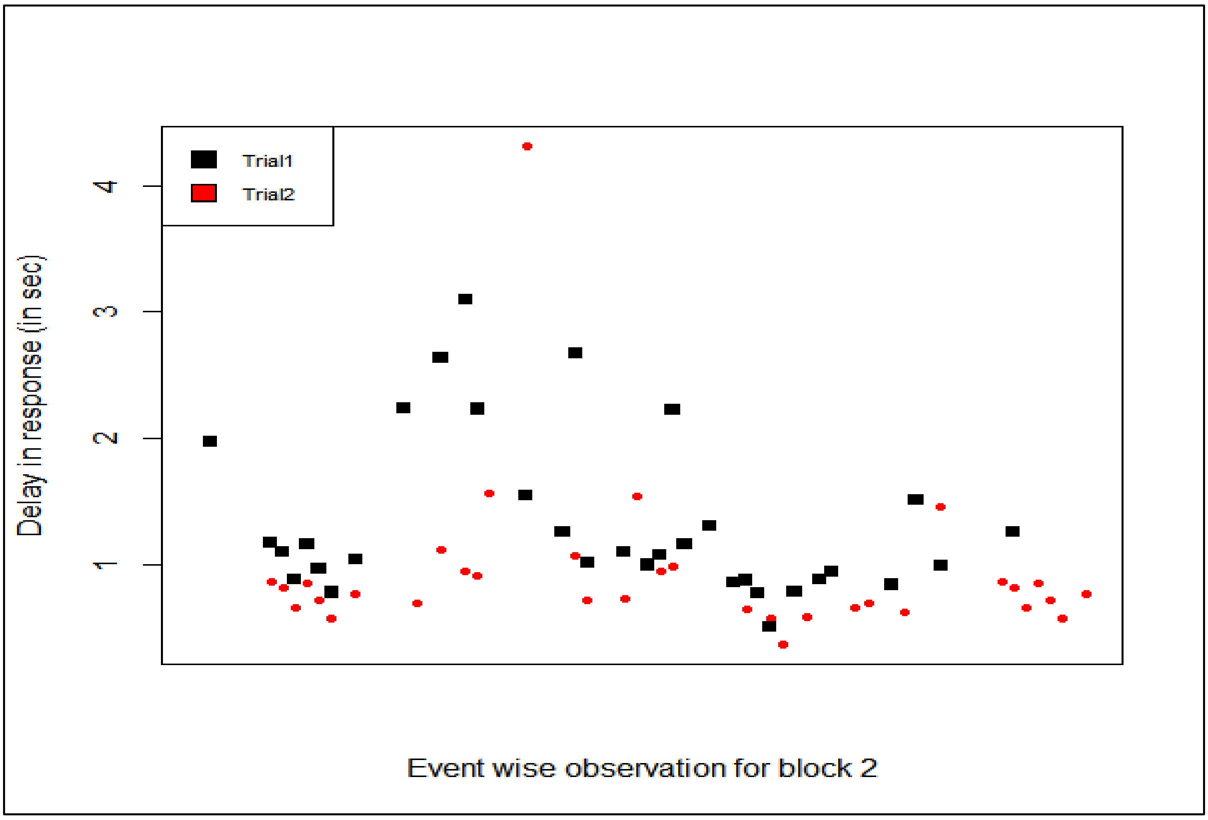


Figure 13: Delay time comparison of trial 1 and trial 2 for Block 2

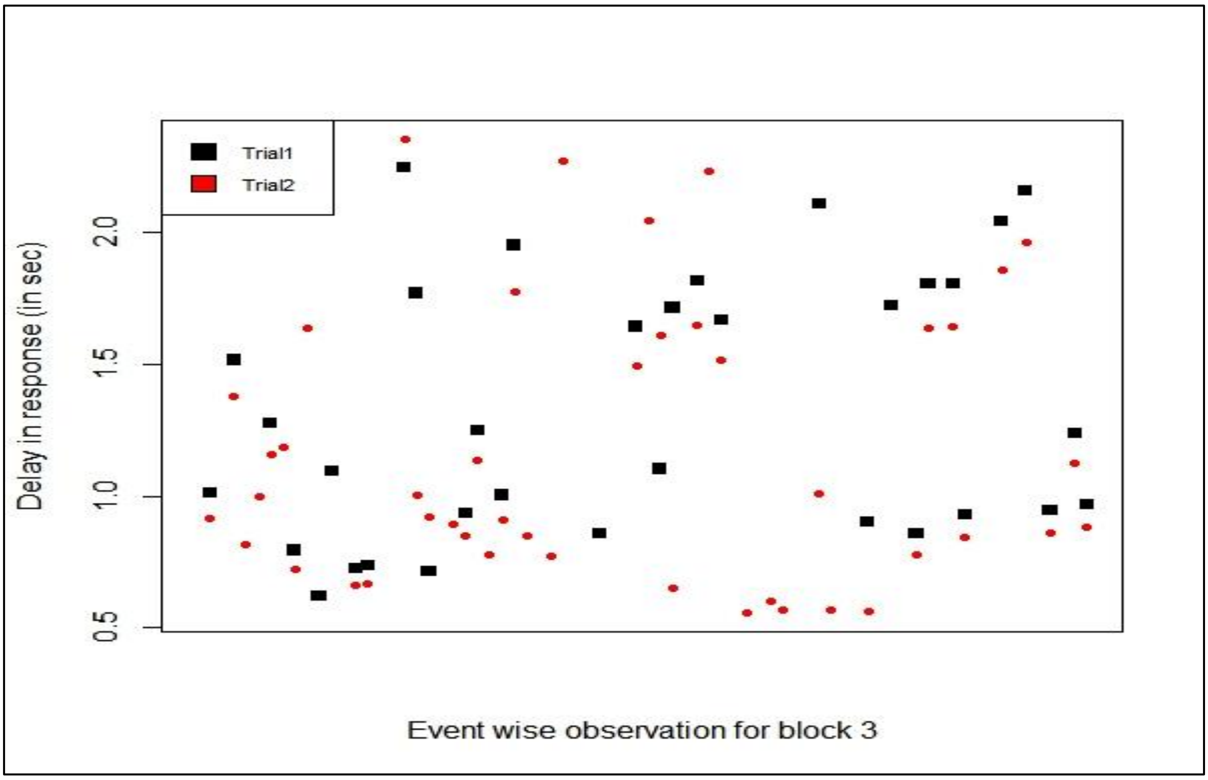


Figure 14: Delay time comparison of trial 1 and trial 2 for Block 3

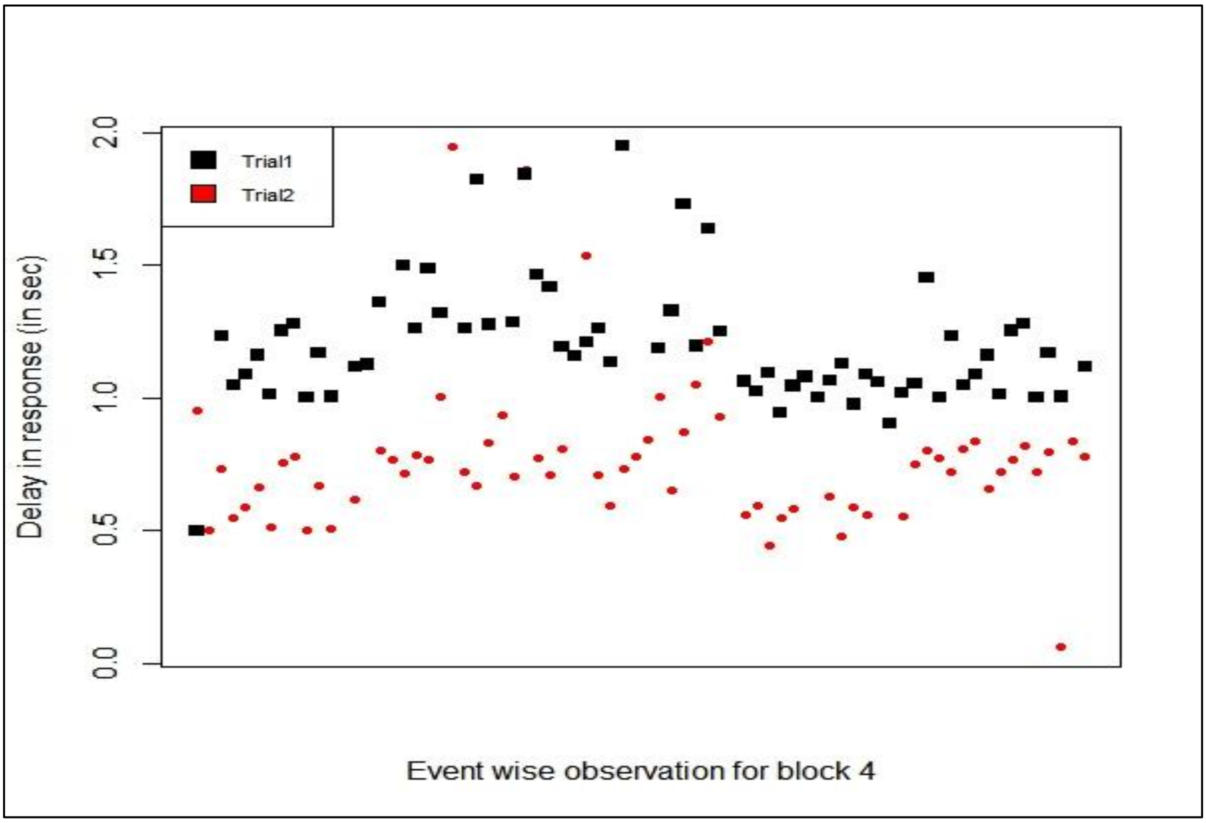


Figure 15: Delay time comparison of trial 1 and trial 2 for Block 4

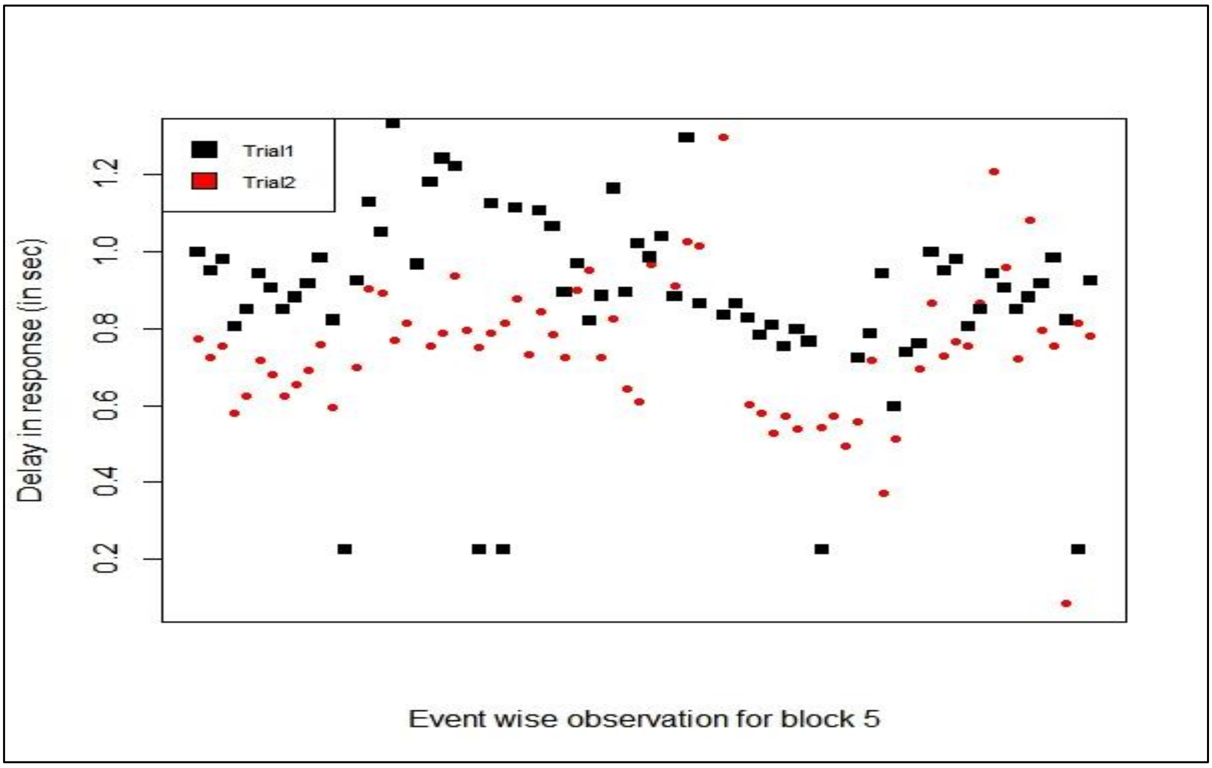


Figure 16: Delay time comparison of trial 1 and trial 2 for Block 5

The overall average delay for each trial is also calculated and plotted with the help of line diagram (figure 18) and boxplot (figure 17). To compare the delay in response time in the two trials, i.e. in presence and in absence of on axis glare source, categorical boxplot is used as shown in figure 17. Boxplot is a standardized way of descriptive statistics to find five-point summary (i.e. Median, 1st quartile, 3rd quartile, Maximum, Minimum). Between the interquartile range of the boxplot, (shown in grey area of the boxplot) lies 50 percent of the observed data and between upper/lower quartile and upper/lower whisker lies 25 percent of the observed data. With these knowledge, one can divide the observed data in four options ranging

1. 1st quartile (lower whisker to lower quartile, 25 percent of the total observed data),
2. 2nd quartile (lower quartile to median, 25 percent of the total observed data),
3. 3rd quartile (median to upper quartile, 25 percent of the total observed data),
4. 4th quartile (upper quartile to upper whisker, 25 percent of the total data),

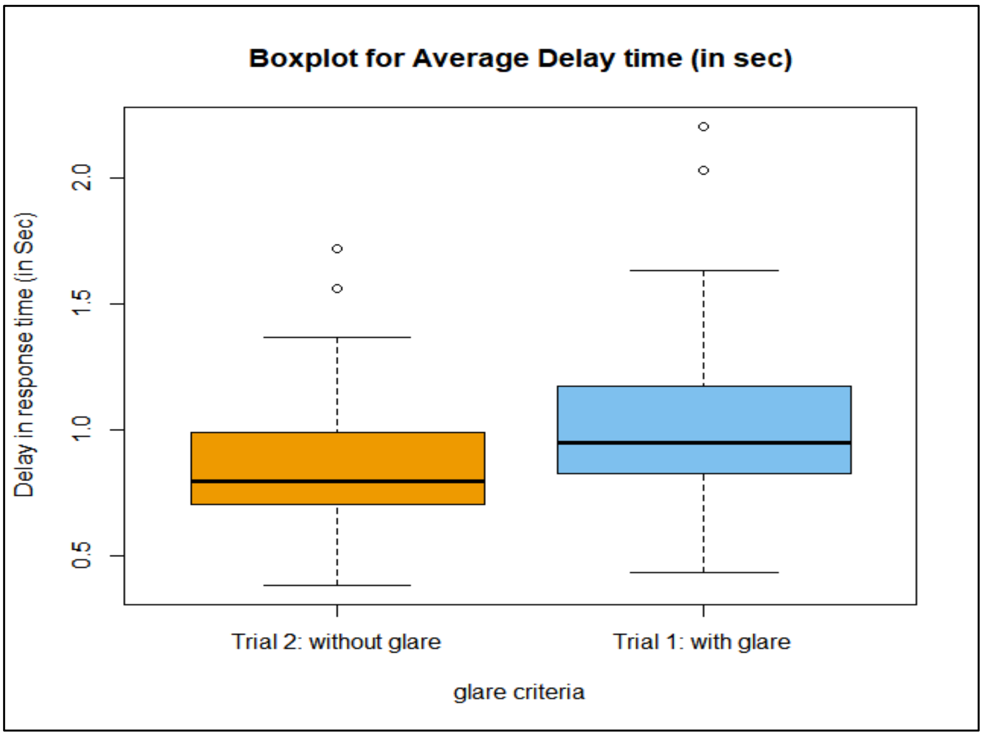


Figure 17: Boxplot for Average Delay time

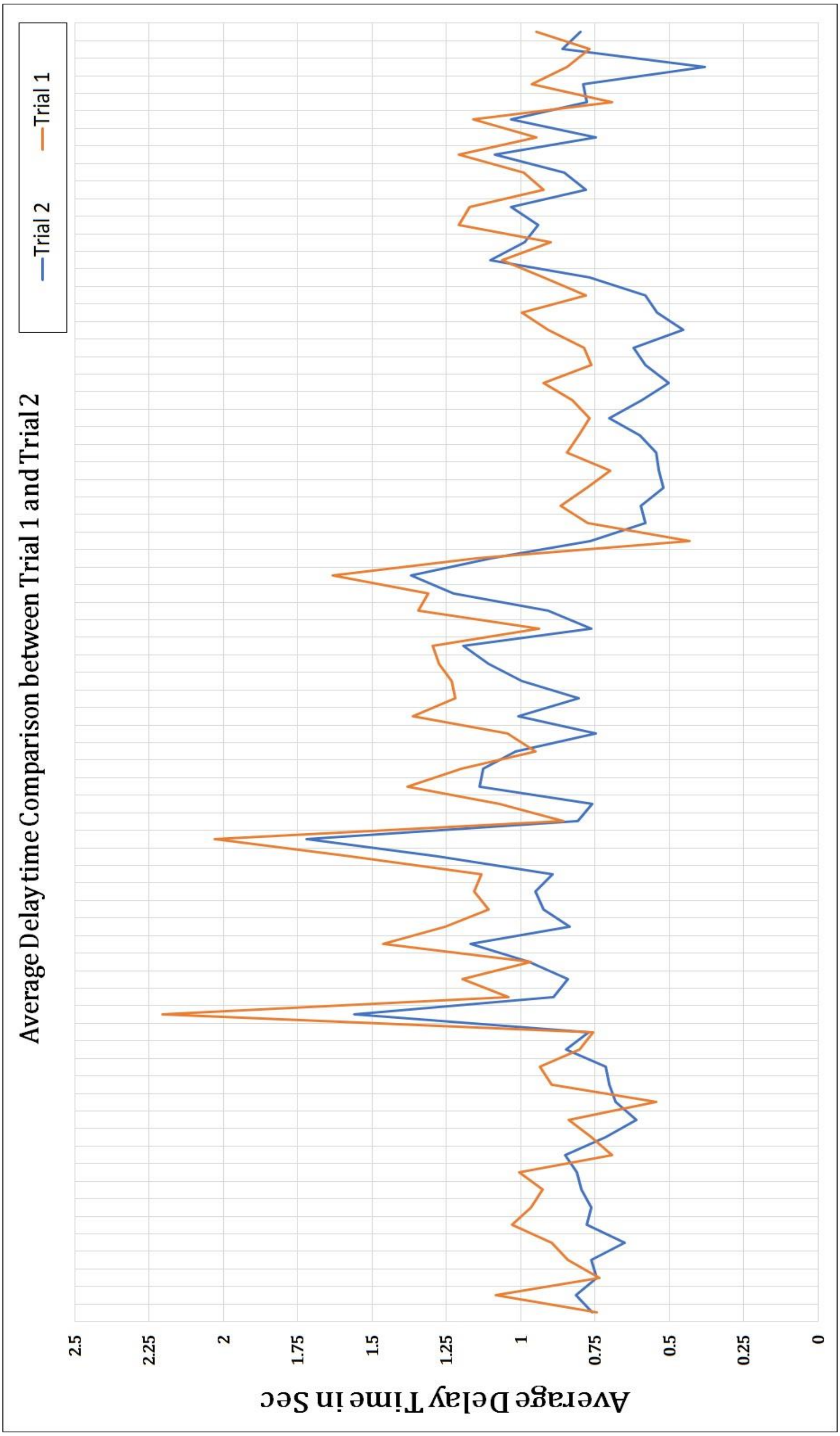


Figure 18: Line diagram of Average Delay time

5.2.b Cognitive Data Analysis

Cognitive data obtained from the 14 channel dynamic EEG Emotiv Epoc+ is in .edf format. These files contains event related potential data of the scalp at various time instant. The data was then averaged across participants for the two trials. The average ERP for all 14 channels was then plotted together as scalp contours in a time window between the instant the stimulus is provided to the instant the subject provides the response for object detection. These time window in which the event takes place is called Epoch. Further analysis was conducted to find out which frequency of brain waves have more contribution in the neural signals collected. Of the different types of brain waves discussed in chapter 3, the Alpha and Beta waves should be the point of interest as alpha waves gives the overall mental coordination, mind/body integration and beta contribute in judgement, decision making activity. To analyze the contribution of these two brain waves scalp topographic plot of the component spectra at 10Hz (as Alpha: 8 to 12Hz) and at 25 Hz (as Beta: 12 to 38Hz) are also plotted for the two trials. These plots the two trials are compared in between to find a conclusion on the brain engagement of the subjects under two lighting condition. The complete flowchart of the EEG data analysis is shown in figure 19.

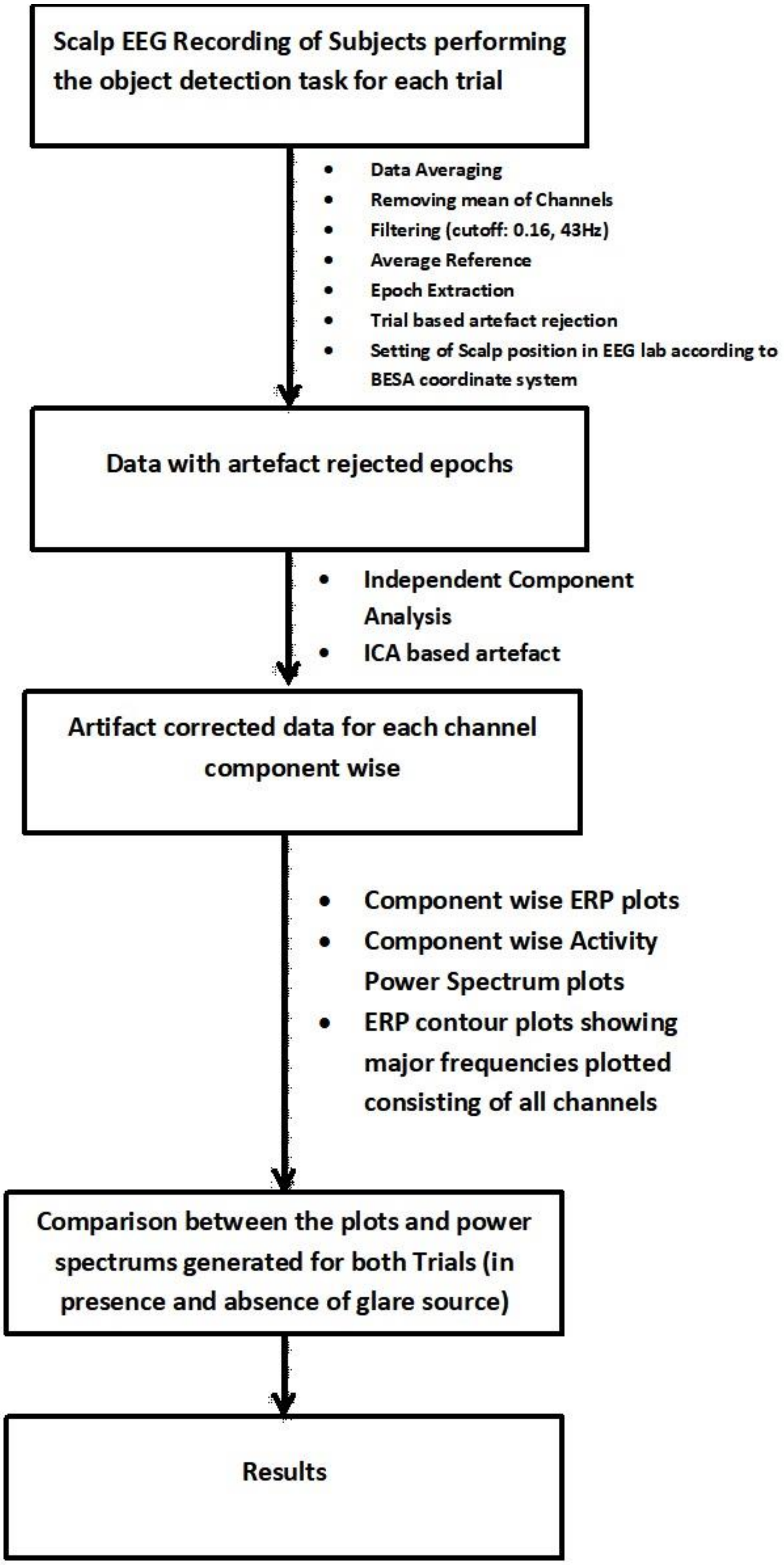


Figure 19: Flowchart of the cognitive analysis process

One example of the comparison between the Scalp Topographic plot obtained from the averaged scalp EEG recording of all the subjects is shown in figure 20. In the context of this research work, a comparison of the two most influential brain waves; alpha (10 Hz) and Beta (25 Hz) has been also found out (figure 21 and 22).

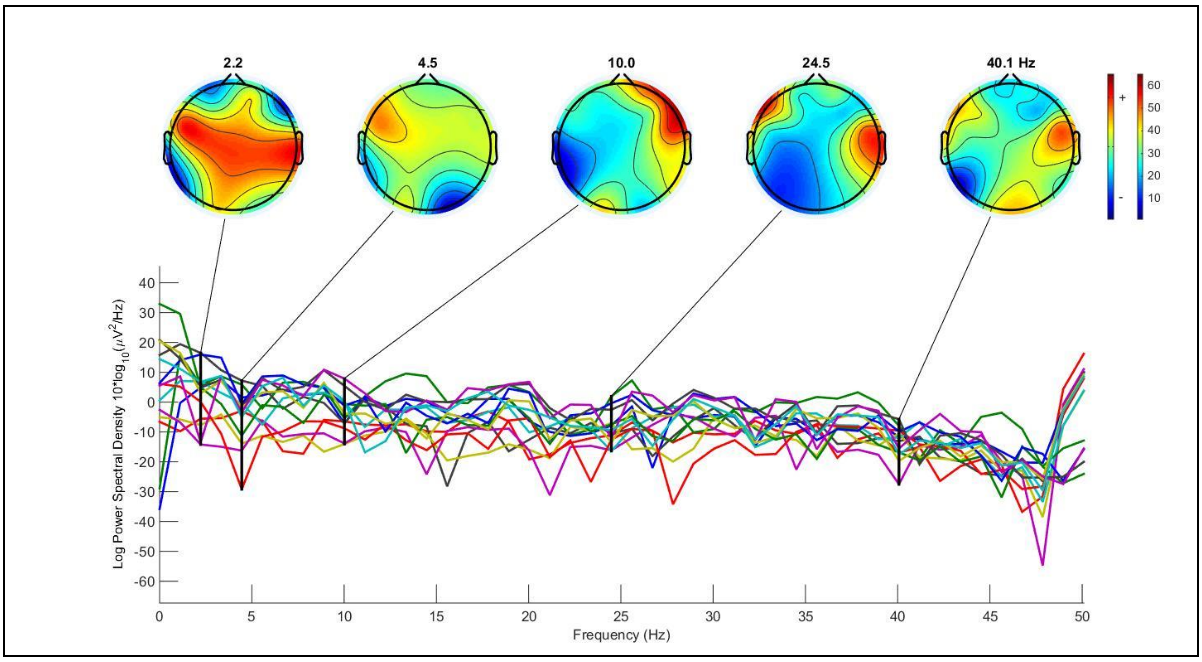


Figure 20.a: Scalp Map for Trial 1 (Channel Spectra)

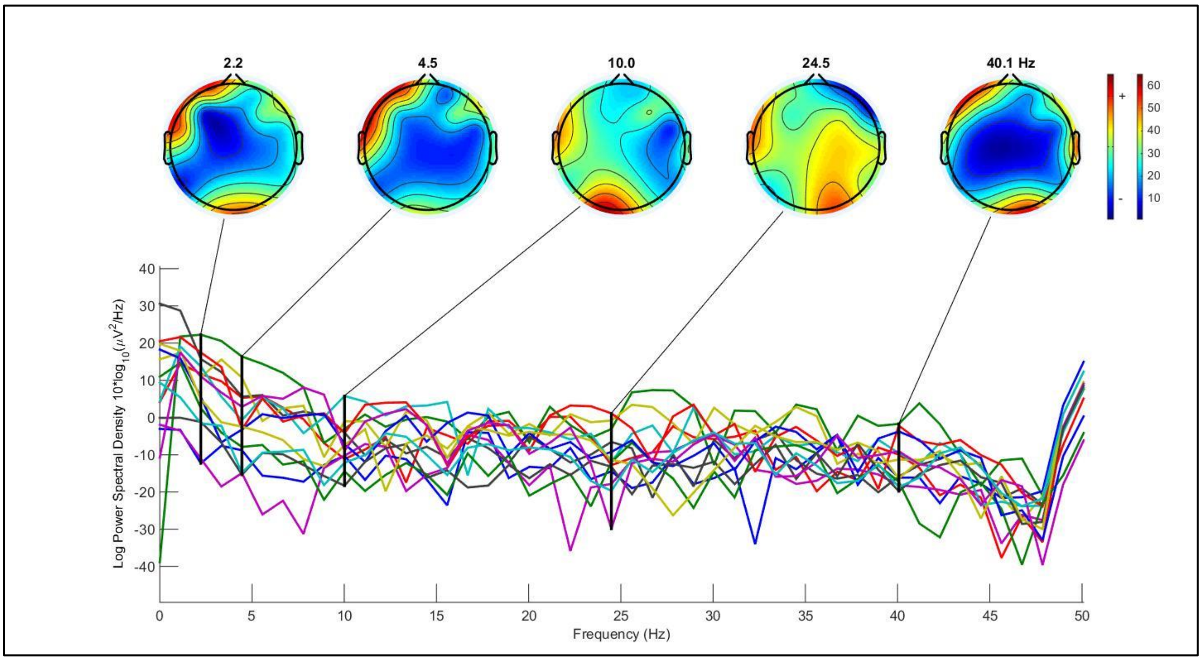


Figure 20.b: Scalp Map for Trial 2 (Channel Spectra)

Both the plot has same epoch time: 26 to 32 sec

Figure 21: Comparison of component spectra of Alpha waves between Trial 1 and Trial 2

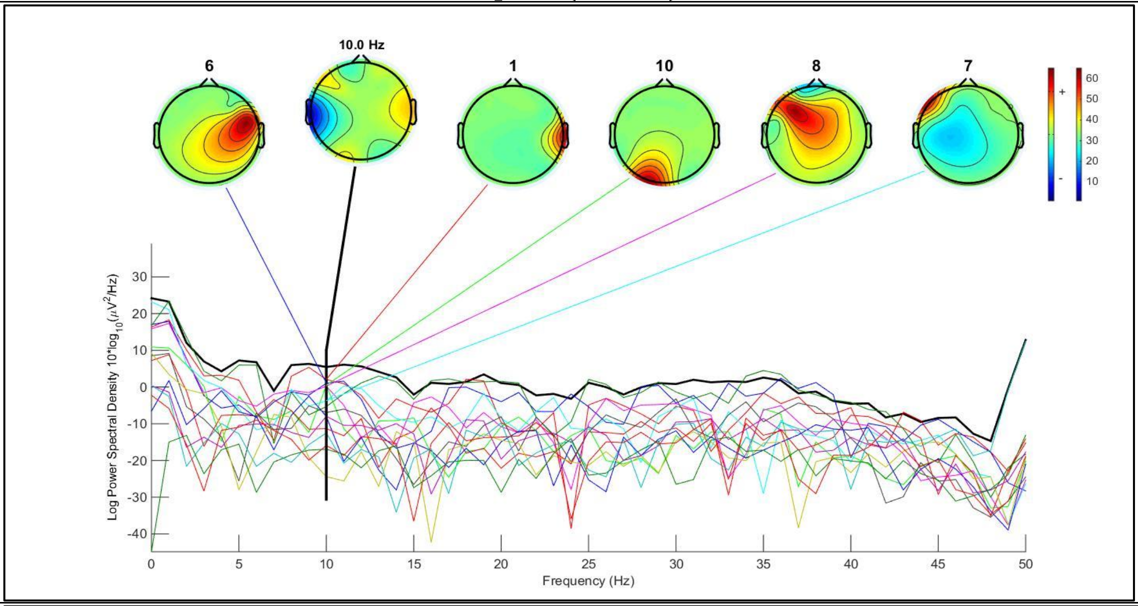
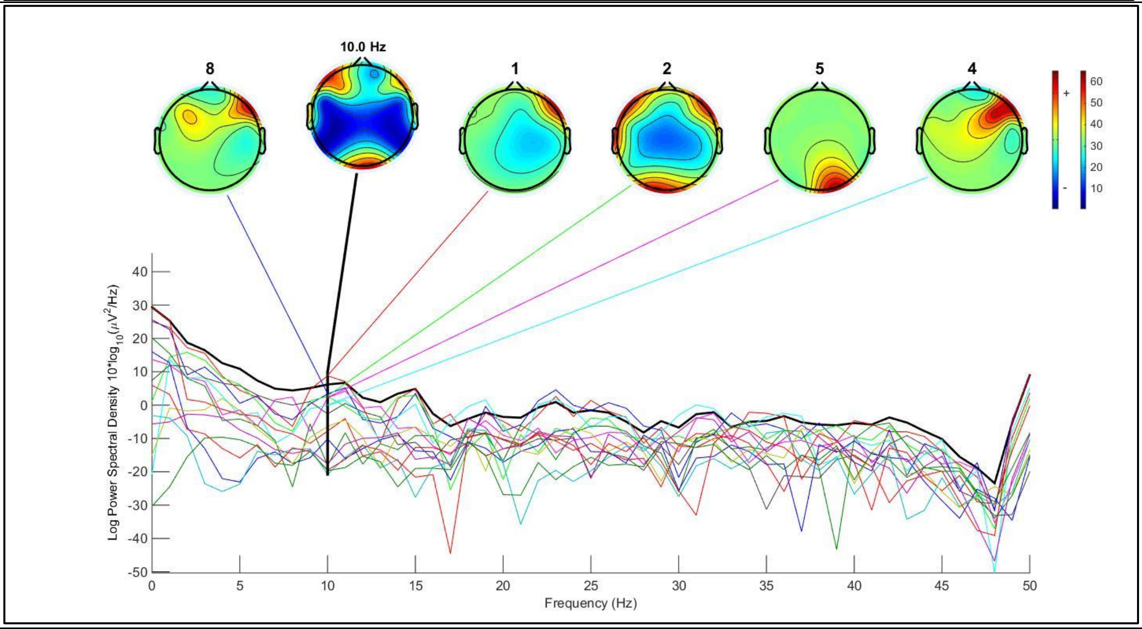
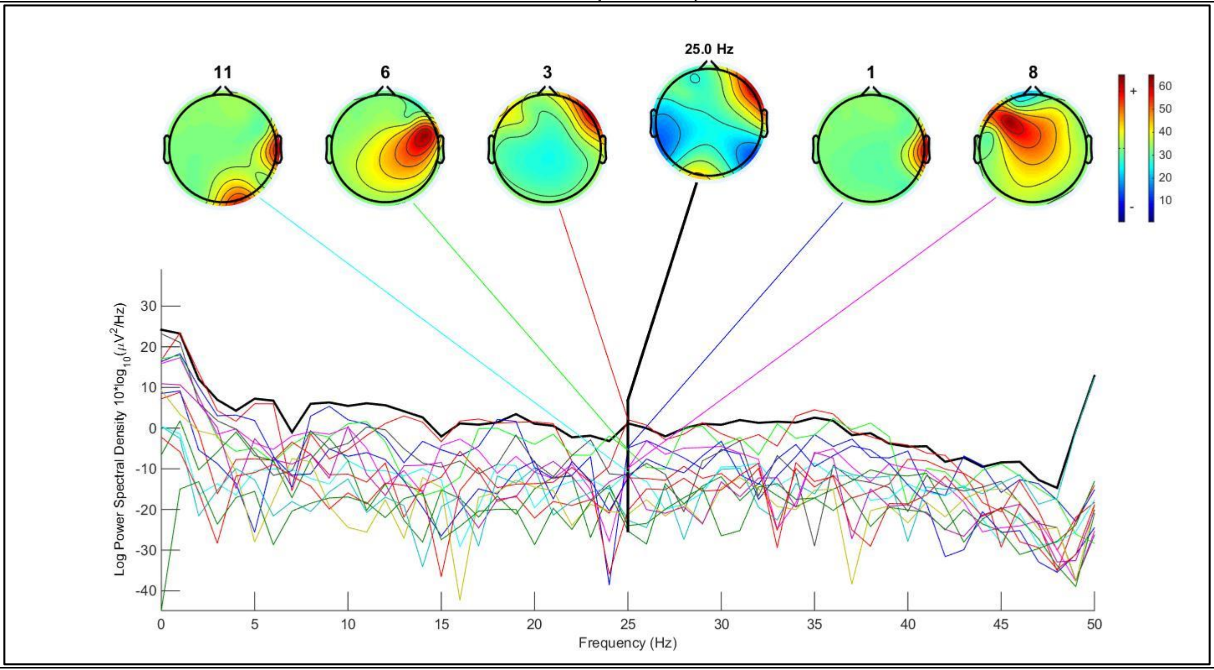
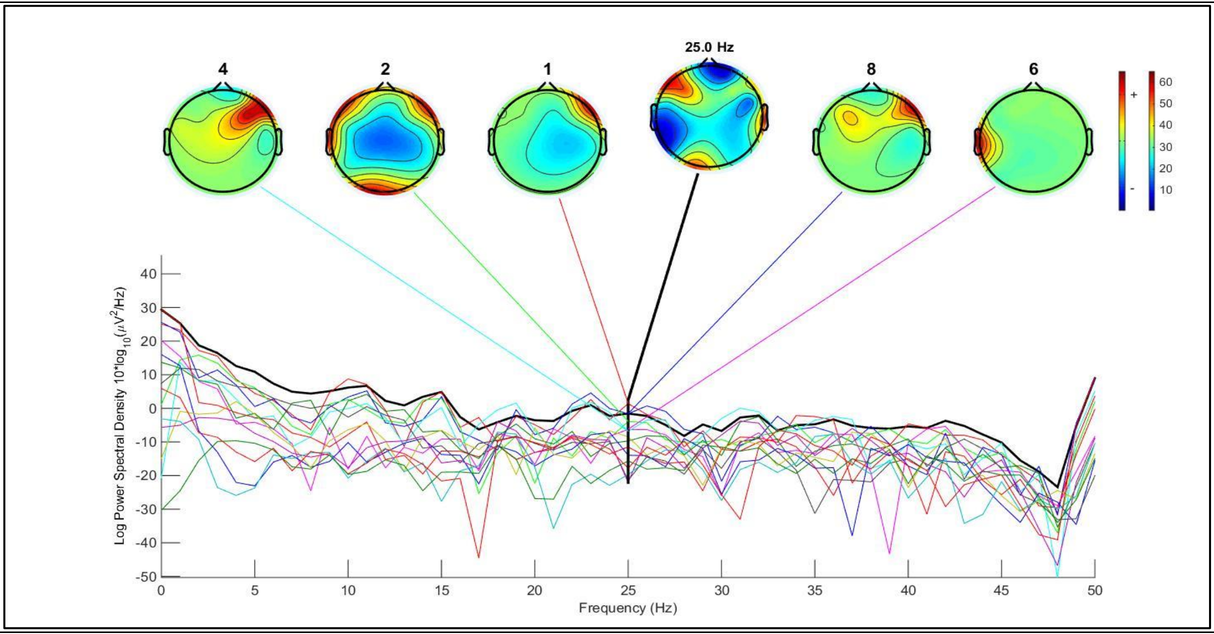
<table>
<tr><th></th><th>Alpha (10 Hz)</th></tr>
<tr><td>Trial 1</td><td>
</td></tr>
<tr><td>Trial 2</td><td>
</td></tr>
</table>

Figure 22: Comparison of component spectra of Beta waves between Trial 1 and Trial 2

	Beta (25 Hz)
Trial 1	
Trial 2	

CHAPTER- 6

6.1 Result and Discussion

From the data analysis, it is clear that the performance of the subjects changes in the two trials. Scatter diagram of the delay time comparison of trial 1 and trial 2 for each block clearly depicts that, in trial 1, i.e. in presence of on axis glare source, the delay time increases significantly. Increase of delay time denotes increasement of response time, which is undesirable as a driver's point of view.

The average delay time obtained in the each block for both the trials are tabulated below:

Trial 1 (In Presence of glare)	
Block No	Average delay in response of all Subjects (in sec)
1	1.149716171
2	1.33248777
3	1.435907026
4	1.22660477
5	0.908999045
Average	**1.210742956**

Trial 2 (In absence of glare)	
Block No	Average delay in response of all Subjects (in sec)
1	0.814577988
2	0.936865418
3	1.167009001
4	0.764694382
5	0.756546249
Average	**0.887938608**

Table 6: Average delay time for trial 1 and trial 2

It has been found that the average delay in response in presence of glare is 36.4% higher than in absence of glare. Figure 16, "Boxplot for average delay time" also gives the same result. The median of the delay time of the glare data has higher value from without glare data.

The number of misses (non-responsive) data for the two trial are tabulated below:

Trial 1 (In Presence of glare)	
Block No	No of misses
1	8
2	41
3	34
4	7
5	4
Average	**18.8**

Trial 2 (In absence of glare)	
Block No	No of misses
1	8
2	39
3	30
4	8
5	5
Average	**18**

Table 7: Number of misses for trial 1 and trial 2

The number of misses increase in presence of glare source.

From the cognitive analysis, it has been found that brain engagement is higher in presence of glare source (figure 20,21,22). Which means the brain is more attentive or alerted, resulting higher brain activity. Driving is a long continuous task and if brain activity is high for a long time the brain would become tiresome, which is undesirable. The comparison of component spectra of alpha and beta waves for the two trials also depicts the same result.

From the above discussion, one can conclude the following result about this research work: -

1. From the behavioural data, it is found that reaction or response time increases significantly in presence of an on-axis glare source. Average delay in response in presence of glare is 36.4% higher than in absence of glare.
2. Number of misses increases in presence of an on-axis glare source.
3. Brain engagement is higher in presence of an on-axis glare source.

6.2 Future Scope

This research work has been conducted keeping in mind that all the external factors like ambient temperature, precipitation present in the atmosphere, mood of the participants, circadian timing etc, has no effect or near to null effect on the experimental result. Moreover, the whole experiment is done in ideal condition in a laboratory setup. The result thus obtained can be challenged in a real-time field experiment where a driver has to perform the same task in this specific lighting condition where external effects can be considered.

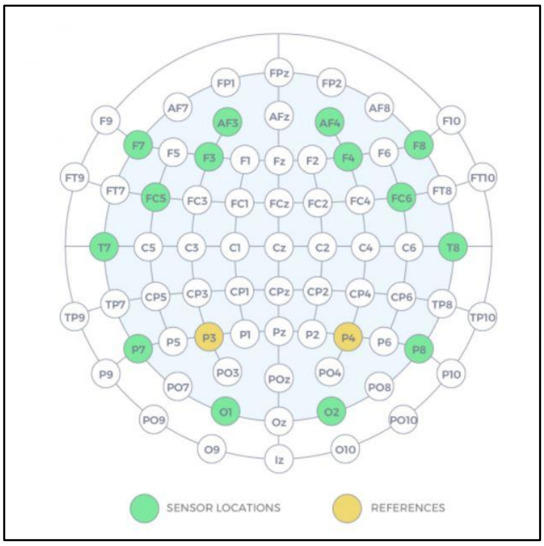
The EEG headset used in this experiment is a commercial 14 channel. With the use of higher number of channels (like 64 channel EEG) much higher informative cognitive data can be obtained and lastly with the advent of data science there is always some scope to use further data analysis.

CHAPTER- 7

Annexure

7.1 Apparatus Used

1. EMOTIV EPOC+ 14 Channel Mobile EEG



A commercial dynamic based EEG headset, Emotiv EPOC+ 14 channel mobile EEG, was used to collect the cognitive data.

Product Description

- 14 channels EEG, channel name: AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, AF4 (shown in the figure)
- 2 references: CMS/DRL references at P3/P4; left/right mastoid process alternative
- Sensor material: Saline soaked felt pads
- Connectivity: wireless
- Proprietary USB receiver: 2.4GHz band
- Sampling method: Sequential sampling, single ADC
- Sampling rate: 2048 internal down sampled to 128 SPS or 256 SPS (user configured)
- Resolution: 14 bits with 1 LSB = 0.51μV (16 bit ADC, 2 bits instrumental noise floor discarded), or 16 bits (user configured)
- Bandwidth: 0.16 – 43Hz, digital notch filters at 50Hz and 60Hz
- Filtering: Built in digital 5th order Sinc filter
- Internal Lithium Polymer battery 640mAh, rechargeable using USB.

2. UNIC UC40 projector 1080p

An UNIC UC 40 projector was used in the experiment to project the on-axis glare.

Product Description

- 20000 hours long LED lamp, the technology of projection is 0.24" LCD, LED tricolour (RGB) projection,
- 800 lumens brightness,
- 800:1 contrast ratio,
- Projection aspect ratio 16:9 and 4:3,
- Multi-function input: IP/IR/USB/SD/HDMI -Keystone correction supported (HDMI port is used as input for this research work),
- Power consumption 55W low power cost,
- Supported projection distance is from 0.3m to 3m,
- Electronics zoom function.

3. EGATE i9 LED HD Projector HD 1920 x 1080

An EGATE i9 LED HD projector was used in the experiment to project the background images and stimulus in front of the participants.

Product description

- 30000 hrs life long LED lamp
- HD 1920 X 1080 Support and 800X480 Native Resolution
- 1000 : 1 High Contrast Ratio
- 120-inch large screen display
- 1500 Lumen/120 Ansi
- Multiple Interface - HDMI/VGA/USB/AV/SD Card/Audio Out
- Direct play from USB

4. Generic PC USB Switch

Generic PC USB switch was used to take the response from the subjects. It was connected to the laptop for recording the responses of the subjects with the help of a python program. The subjects were asked to response by pressing the USB switch.

Product description

- Use USB switch to control your computer with any of your feet
- It is equivalent to a standard HID USB keyboard
- Pre-program key or key combinations functions on the foot pedal by software
- Allow connecting more than one switch to your computer by USB ports, you can achieve multi-key shortcuts function
- Compatible with Dos / Windows 2000 / XP / Vista/Win 7, MAC, Linux
- Dimension (L x W x H): Approx. 4 x 2.5 x 1.5 inch / 10 x 6 x 4 cm
- Cable Length: Approx. 67 inch / 170 cm
- Material: Plastic

5. Laptop

Three dedicated Laptop was used.

- First one was used to project the on-axis background and stimulus.
- Second one was used for projecting the on-axis glare.
- Third one used dedicatedly for data recording, it is connected with the generic PC USB switch using USB port and EEG EPOC+ headset with the help of wireless connectivity.

7.2 Response of Subjects

1. Behavioural response

The calculated delay in the response for the five blocks in each trial are for some of the subjects are tabulated below. All values are in seconds and NR represents non responsive.

Subject A: Trial 1

Event No	Delay in Block 1	Delay in Block 2	Delay in Block 3	Delay in Block 4	Delay in Block 5
1	0.883296638	NR	NR	0.498746856	0.997983106
2	1.550433403	1.976047218	1.010314274	NR	0.948915608
3	NR	NR	NR	1.231200918	0.979505904
4	NR	NR	1.516435218	1.049533351	0.803902753
5	0.899741226	NR	NR	1.087606414	0.850766309
6	1.099388557	NR	NR	1.160387977	0.942649968
7	0.920754295	1.178219962	1.276114178	1.015575393	0.905412801
8	0.952749401	1.09909426	NR	1.25253342	0.848896153
9	1.700365025	0.886647213	0.794622111	1.27954696	0.881209739
10	NR	1.159451365	NR	1.00071667	0.916788705
11	0.219648319	0.971720016	0.621665549	1.168485864	0.98224128
12	1.130944782	0.783909166	1.096308422	1.004878028	0.821243651
13	1.037221676	NR	NR	NR	0.22548569
14	1.131934124	1.04733417	0.727566838	1.115024074	0.924177535
15	0.906669193	NR	0.737437534	1.125958427	1.129446395

Subject A: Trial 2

Event No	Delay in Block 1	Delay in Block 2	Delay in Block 3	Delay in Block 4	Delay in Block 5
1	0.553040266	NR	NR	0.952972174	0.772497416
2	1.10898757	NR	0.918467522	0.501122475	0.723429918
3	NR	NR	NR	0.732454062	0.754020214
4	0.542826414	NR	1.378577471	0.550786495	0.578417063
5	0.566744089	NR	0.818573475	0.588859558	0.625280619
6	0.733116865	NR	0.99664402	0.661641121	0.717164278
7	0.58425498	0.872755527	1.160103798	0.516828537	0.679927111
8	0.610917568	0.814143896	1.185835361	0.753786564	0.623410463
9	1.233930588	0.656775713	0.722383738	0.780800104	0.655724049
10	0.561016083	0.858852863	1.640197277	0.501969814	0.691303015
11	NR	0.719792604	NR	0.669739008	0.75675559
12	0.759413719	0.580673456	NR	0.506131172	0.595757961
13	0.681311131	NR	NR	NR	NR
14	0.760238171	0.775803089	0.661424398	0.616277218	0.698691845
15	0.572517395	NR	0.670397758	NR	0.903960705

Subject B: Trial 1

Event No	Delay in Block 1	Delay in Block 2	Delay in Block 3	Delay in Block 4	Delay in Block 5
1	NR	NR	NR	1.357704623	1.048912413
2	0.219648319	NR	NR	NR	1.331263192
3	3.043890816	2.236884427	2.248609185	1.496967538	NR
4	1.423324161	NR	1.769996214	1.262596591	0.966273435
5	1.326736313	NR	0.716728401	1.485253318	1.181453593
6	0.219648319	2.640145004	NR	1.317269548	1.241312631
7	1.294131523	NR	NR	2.093409045	1.221676
8	1.241442638	3.093354535	0.936644793	1.263210281	2.081680425
9	1.58461805	2.23269825	1.251222253	1.823062642	0.22548569
10	1.154587131	NR	NR	1.276053651	1.125677951
11	1.314648777	NR	1.00375042	2.201007589	0.22548569
12	2.349278217	NR	1.95216074	1.284270032	1.112281211
13	1.242039734	1.548975384	0.371921301	1.841730817	NR
14	NR	NR	NR	1.462927326	1.107082971
15	1.148956638	NR	NR	1.419295057	1.065114148

Subject B: Trial 2

Event No	Delay in Block 1	Delay in Block 2	Delay in Block 3	Delay in Block 4	Delay in Block 5
1	NR	NR	NR	0.802080631	0.892321348
2	NR	NR	NR	0.770926714	0.770922899
3	2.353535414	NR	2.353535414	0.716996431	0.813251972
4	1.003063202	0.693044901	1.003063202	0.783389091	0.968881845
5	0.922573328	NR	0.922573328	0.765442848	0.755380392
6	NR	1.125011921	NR	1.0038414	0.78887701
7	0.89540267	NR	0.89540267	1.943936348	0.936892509
8	0.851495266	0.958276272	0.851495266	0.722940445	0.79522872
9	1.137474775	0.919954538	1.137474775	0.670671225	0.750113487
10	0.779115677	1.567611694	0.779115677	0.833659172	0.788252354
11	0.912500381	NR	0.912500381	0.935678482	0.81282711
12	1.774691582	NR	1.774691582	0.704304934	0.876060724
13	0.851992846	4.307159901	0.851992846	1.858906507	0.730592489
14	NR	NR	NR	0.773140192	0.845314264
15	0.774423599	NR	0.774423599	0.709157705	0.784054995

Subject C: Trial 1

Event No	Delay in Block 1	Delay in Block 2	Delay in Block 3	Delay in Block 4	Delay in Block 5
1	1.116783577	1.258622503	2.501159692	1.193644985	0.894604571
2	1.909010273	2.677593684	NR	1.159313186	0.969638236
3	1.253911262	1.016253591	NR	1.211529477	0.819418319
4	1.191080337	NR	0.857027245	1.26028703	0.88488806
5	2.143697697	NR	NR	1.135640128	1.163197883
6	1.549300438	1.107460177	NR	1.949113115	0.895334609
7	0.869097954	NR	1.643704438	NR	1.020765431
8	1.049244839	1.001929629	2.588888955	NR	0.984998353
9	1.839309746	1.080764043	1.103369522	1.185879215	1.037645467
10	0.943550354	2.229626369	1.714830661	1.327438339	0.881424315
11	1.209189754	1.165059543	NR	1.728958591	1.294397958
12	1.649146992	NR	1.815064621	1.194770082	0.862856038
13	1.017569309	1.308829272	2.454131937	1.636308177	1.598074801
14	1.004117924	NR	1.667289257	1.250252469	0.834650405
15	NR	0.864698911	NR	NR	0.86561879

Subject C: Trial 2

Event No	Delay in Block 1	Delay in Block 2	Delay in Block 3	Delay in Block 4	Delay in Block 5
1	0.747612715	NR	2.273781538	0.80695796	0.723660707
2	1.407801628	1.07429266	NR	NR	0.901076078
3	0.861885786	0.724997759	NR	1.535430193	0.953066587
4	0.809526682	NR	NR	0.708243847	0.725640059
5	1.603374481	NR	NR	0.592106581	0.826387405
6	1.108043432	0.741113901	NR	0.731359959	0.642274141
7	0.541208029	1.54823494	1.494276762	0.780873537	0.60998559
8	0.691330433	0.996101141	2.044190168	0.840790987	0.965959311
9	1.349717855	0.954918385	1.609087467	1.003299952	1.045674801
10	0.603251696	0.985170364	0.651571274	0.655307293	0.91179347
11	0.824617863	NR	NR	0.873938322	1.025178194
12	1.191248894	NR	1.650058746	1.048608065	1.013324499
13	0.664934158	NR	2.231029034	1.211604023	NR
14	0.65372467	NR	1.515717506	0.93159461	1.296286345
15	0.765492439	NR	NR	NR	NR

Subject D: Trial 1

Event No	Delay in Block 1	Delay in Block 2	Delay in Block 3	Delay in Block 4	Delay in Block 5
1	0.853427273	0.879169643	2.615764427	1.061928972	0.827315219
2	0.953009754	0.775647211	NR	1.024184926	0.783092626
3	0.758934265	0.510544646	NR	1.096020444	0.807308801
4	0.953574234	NR	2.622483802	0.945658191	0.75167907
5	0.833160931	0.792977071	NR	1.045540317	0.798049815
6	0.951910835	NR	NR	1.080206617	0.765593655
7	0.889446407	0.887325382	2.11004169	1.000553354	0.22548569
8	0.941639763	0.944863594	0.327032971	1.067312225	NR
9	0.860824734	NR	NR	1.129663451	NR
10	0.837183815	NR	NR	0.976028665	0.721730836
11	0.881273895	NR	0.900430822	1.088968976	0.784879096
12	0.863047749	NR	NR	1.061530097	0.941454776
13	0.905032116	0.843114638	1.72454977	0.905143722	0.597438462
14	0.894333893	NR	NR	1.021195634	0.737239488
15	1.230266911	1.516909575	0.858451843	1.053419336	0.759648211

Subject D: Trial 2

Event No	Delay in Block 1	Delay in Block 2	Delay in Block 3	Delay in Block 4	Delay in Block 5
1	0.528149128	0.651236773	0.559785843	0.563182116	0.601829529
2	0.611134529	NR	NR	0.597273588	0.581823111
3	0.449404955	0.57455349	0.600717068	0.446911335	0.52619338
4	0.611604929	0.378181219	0.565894365	0.546793461	0.572564125
5	0.511260509	NR	NR	0.581459761	0.540107965
6	0.610218763	0.587390423	NR	NR	NR
7	0.558165073	NR	1.009128809	NR	0.541469097
8	0.601659536	NR	0.570029974	0.630916595	0.57303977
9	0.534313679	NR	NR	0.477281809	0.496245146
10	0.514612913	0.657278061	NR	0.59022212	0.559393406
11	0.551354647	0.699898958	0.565150499	0.562783241	0.715969086
12	0.536166191	NR	NR	NR	0.371952772
13	0.571153164	NR	NR	NR	0.511753798
14	0.562237978	0.624529362	NR	0.55467248	NR
15	0.528149128	0.651236773	0.559785843	0.563182116	0.601829529

Subject E: Trial 1

Event No	Delay in Block 1	Delay in Block 2	Delay in Block 3	Delay in Block 4	Delay in Block 5
1	NR	NR	1.804611444	1.45171903	0.997983106
2	0.219648319	0.993154299	NR	0.999869331	0.948915608
3	0.983810383	NR	1.806875014	1.231200918	0.979505904
4	2.289108044	NR	0.930791926	1.049533351	0.803902753
5	0.99536491	NR	NR	1.087606414	0.850766309
6	1.045315224	NR	NR	1.160387977	0.942649968
7	1.440623337	NR	2.043187928	1.015575393	0.905412801
8	1.047183472	1.263071644	NR	1.25253342	0.848896153
9	0.99295364	NR	2.160806227	1.27954696	0.881209739
10	NR	NR	NR	1.00071667	0.916788705
11	1.200605827	NR	0.947535419	1.168485864	0.98224128
12	1.164996105	NR	NR	1.004878028	0.821243651
13	1.007744842	NR	1.23746984	NR	0.22548569
14	1.145738846	NR	0.969284153	1.115024074	0.924177535
15	NR	NR	1.804611444	1.45171903	0.997983106

Subject E: Trial 2

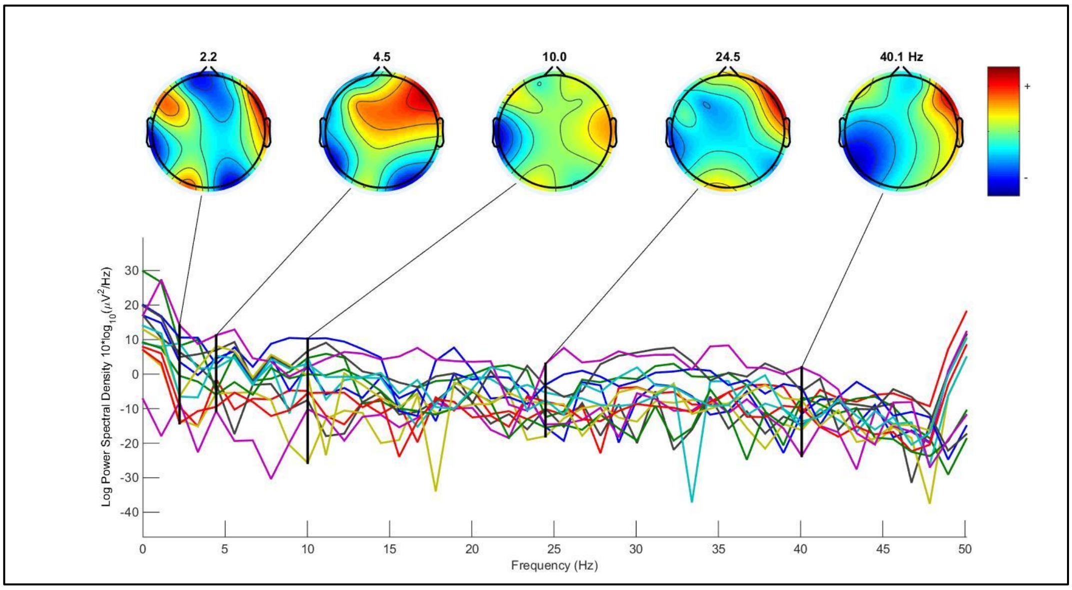
Event No	Delay in Block 1	Delay in Block 2	Delay in Block 3	Delay in Block 4	Delay in Block 5
1	0.842182159	NR	0.780410767	0.752771378	0.694999933
2	NR	NR	1.640555859	0.801245213	0.86709404
3	NR	1.46373868	NR	0.771784544	0.726949215
4	0.63680172	NR	1.642613649	0.72299099	0.765047073
5	1.72454977	NR	0.846174479	0.809466362	0.756043911
6	0.646430492	NR	NR	0.834633827	0.864678144
7	0.688055754	NR	NR	0.660791159	1.208417654
8	1.017479181	0.872755527	1.857443571	0.724541426	0.960324287
9	0.689612627	0.814143896	NR	0.768445015	0.723061323
10	0.644421101	0.656775713	1.964369297	0.817189455	1.081068277
11	0.739080429	0.858852863	NR	0.724266291	0.794881582
12	0.81746459	0.719792604	0.861395836	0.796621561	0.756082296
13	0.787789822	0.580673456	NR	0.06652236	0.087494135
14	0.656747103	NR	1.124972582	0.839161158	0.815942526
15	0.771742105	0.775803089	0.881167412	0.779346228	0.781646013

2 Cognitive Response

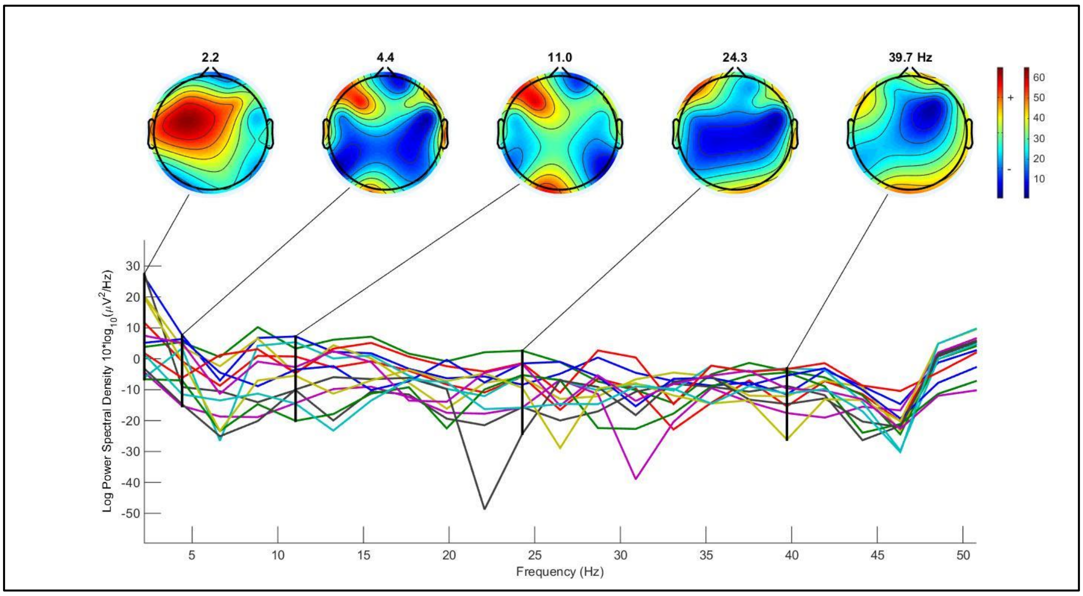
The topographic scalp plot comparison for both the trials for one subject is given below:

Subject G:

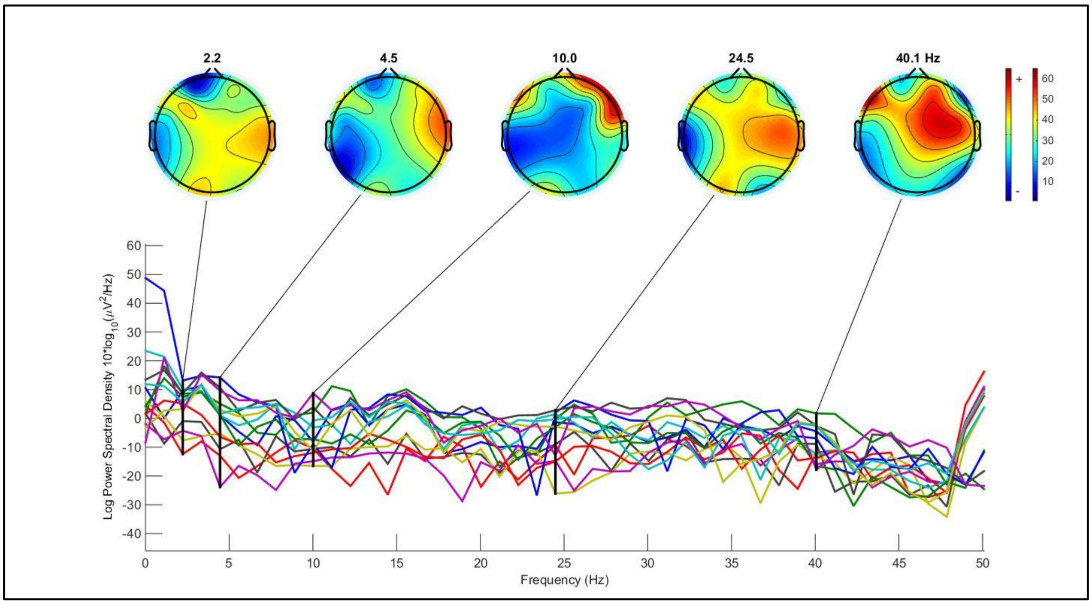
Trial 1: (Response time: 6.570766687 sec) Epoch time range to analyse 3 to 9 sec



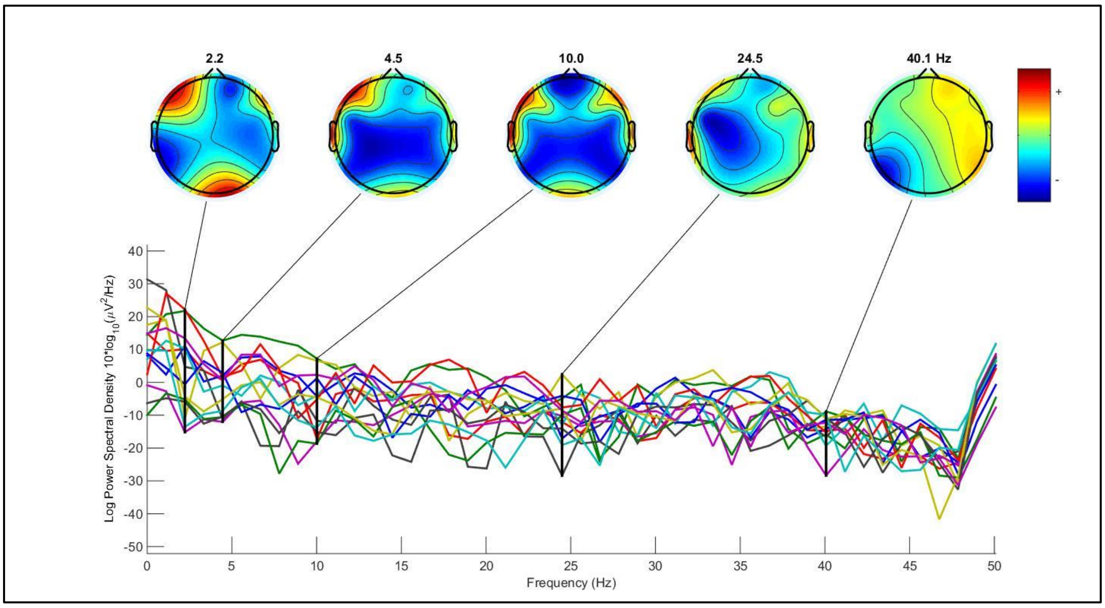
Trial 2: (Response time: 6.5281491279602 sec) Epoch time range to analyse 3 to 9 sec



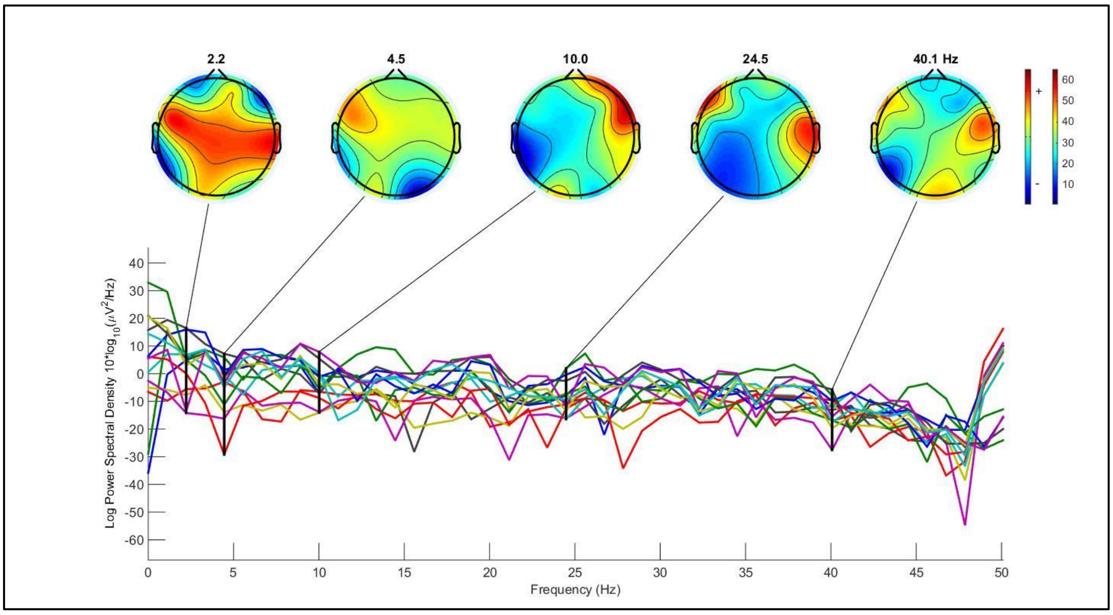
Trial 1: (Response time: 15.59390783 sec) Epoch time range to analyse 12 to 18 sec



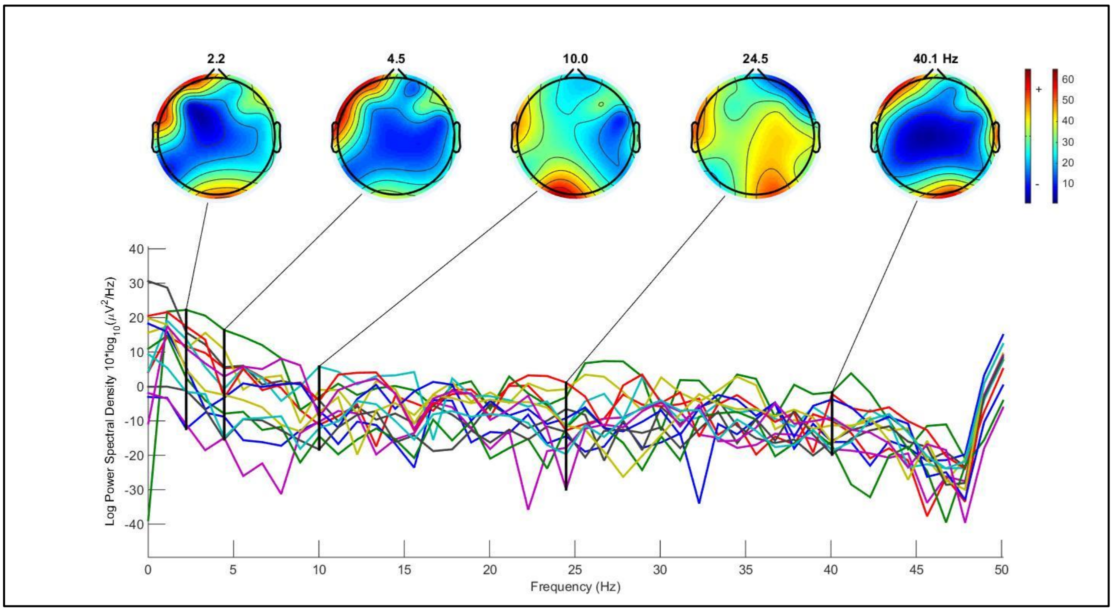
Trial 2: (Response time: 15.4742624759674 sec) Epoch time range to analyse 12 to 18 sec



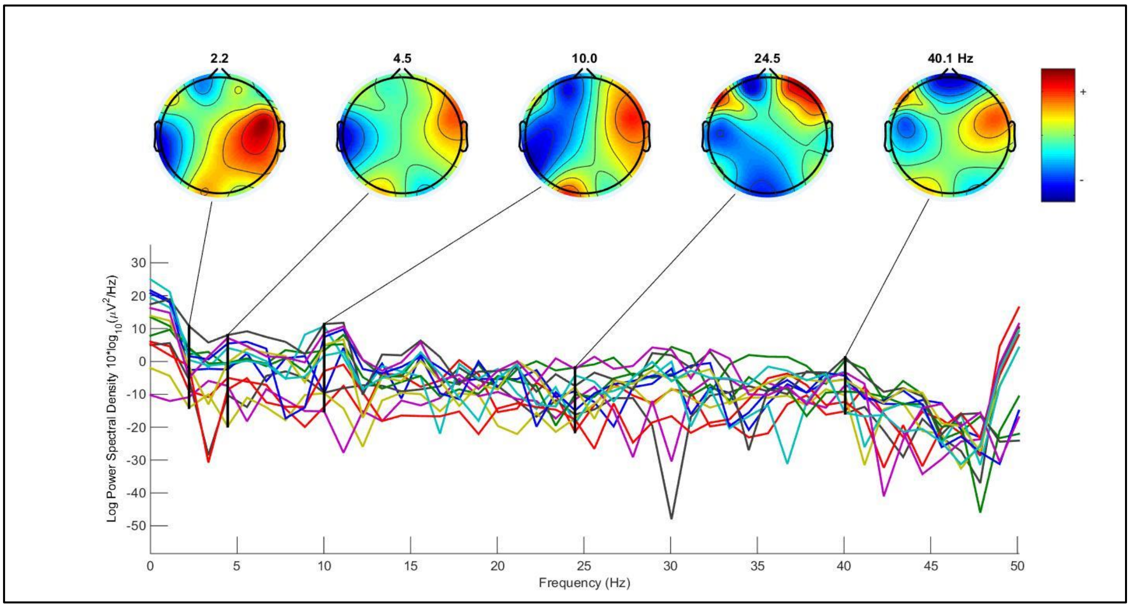
Trial 1: (Response time: 29.62044549 sec) Epoch time range to analyse 26 to 32 sec



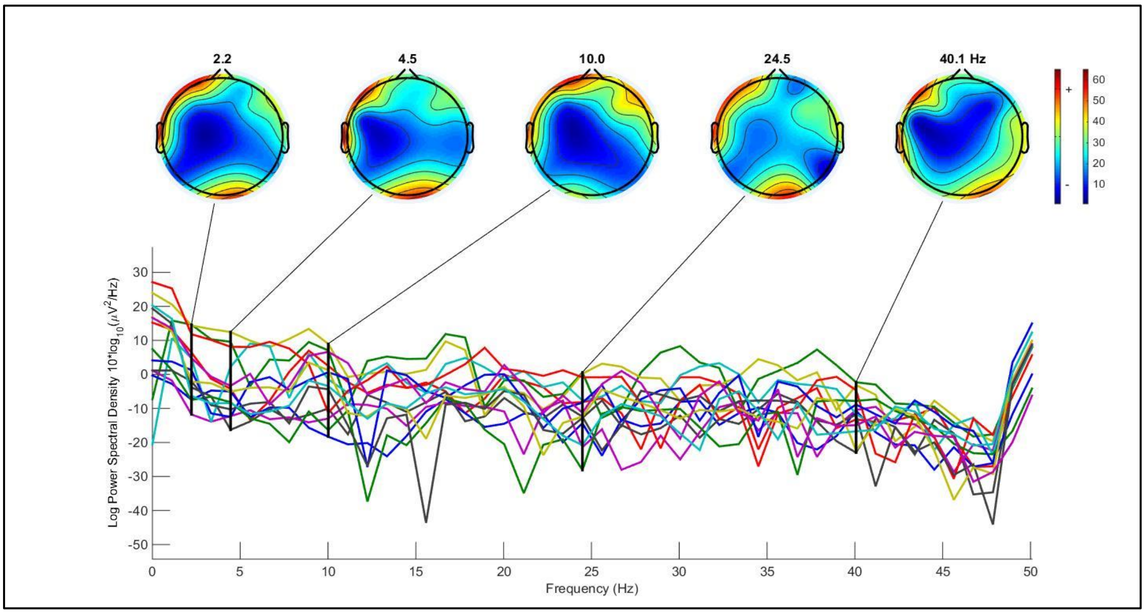
Trial 2: (Response time: 29.6111345291137 sec) Epoch time range to analyse 26 to 32 sec



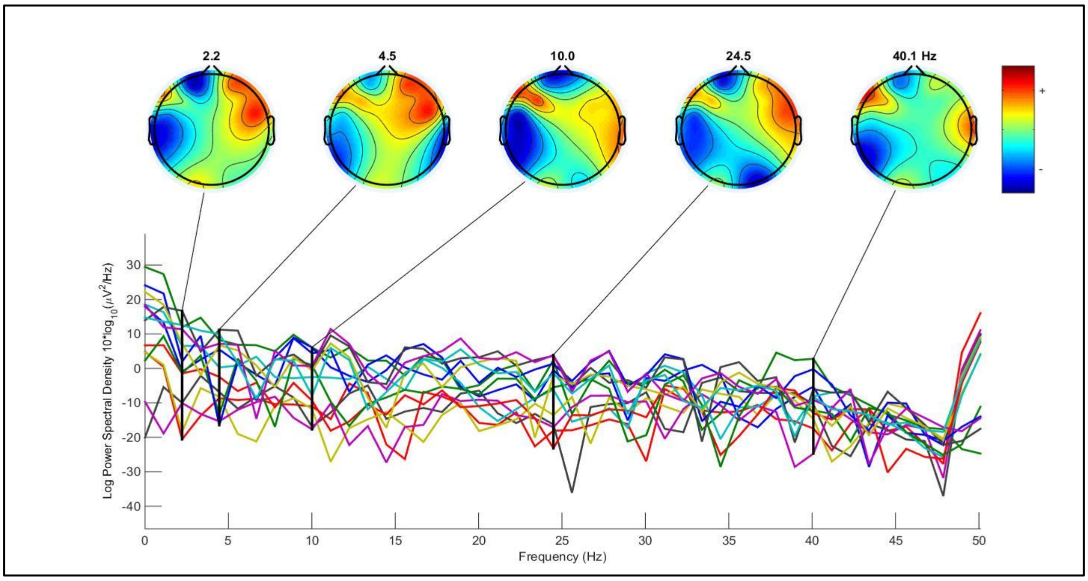
Trial 1: (Response time: 43.53436613 sec) Epoch time range to analyse 40 to 46 sec



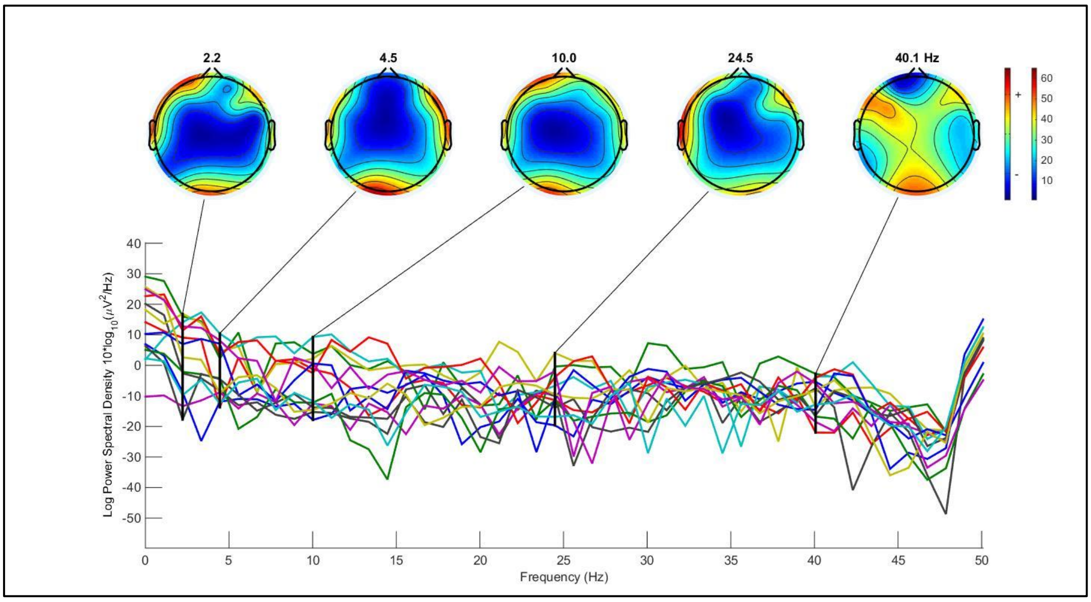
Trial 2: (Response time: 43.4494049549102 sec) Epoch time range to analyse 40 to 46 sec



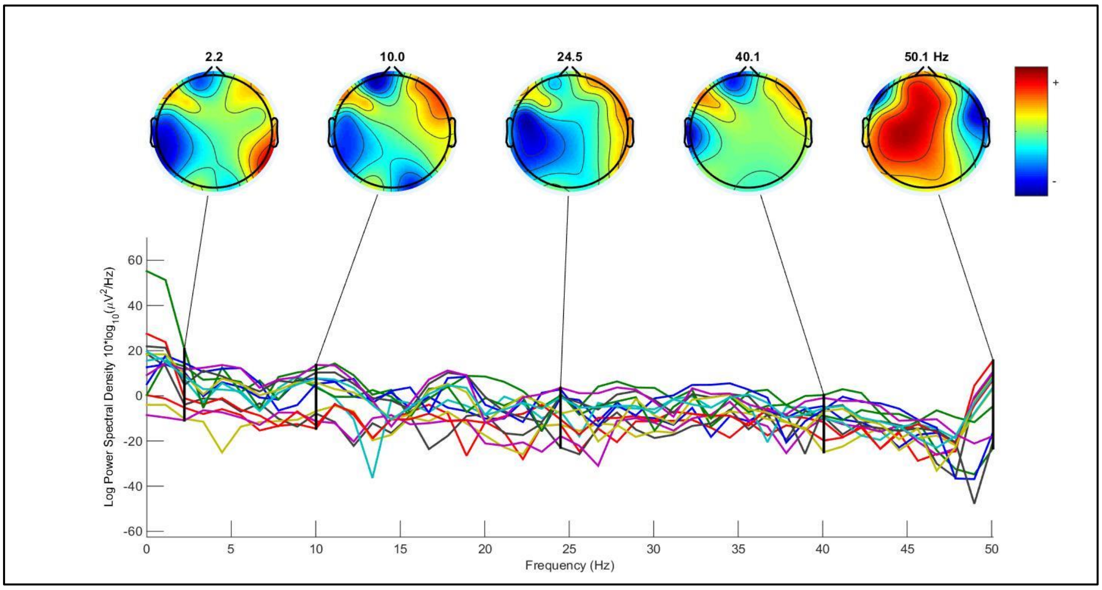
Trial 1: (Response time: 75.61160493sec) Epoch time range to analyse 72 to 78 sec



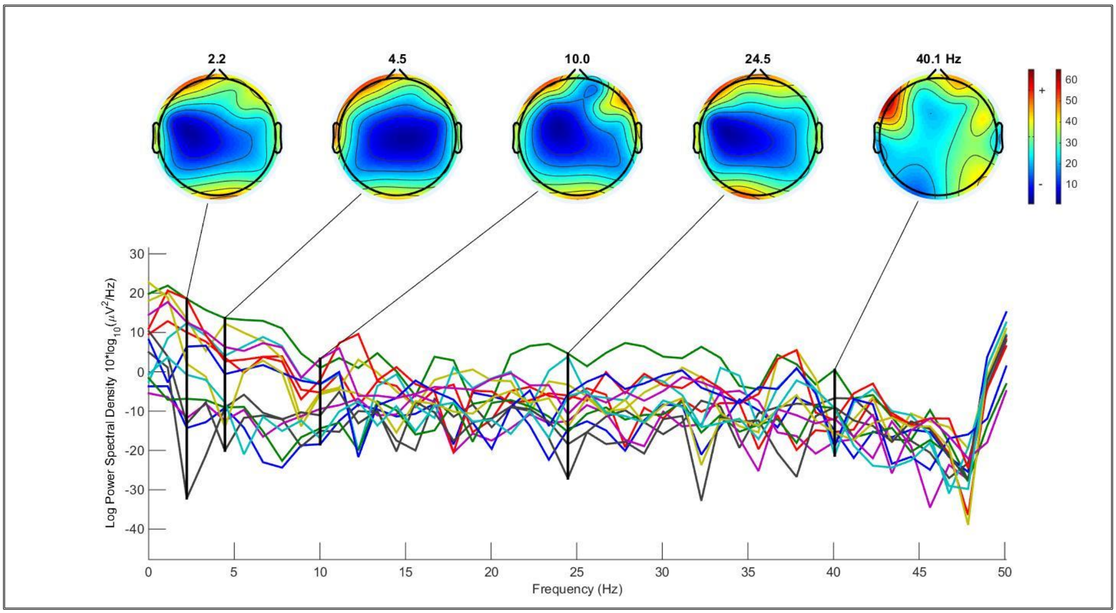
Trial 2: (Response time: 75.58806014 sec) Epoch time range to analyse 72 to 78 sec



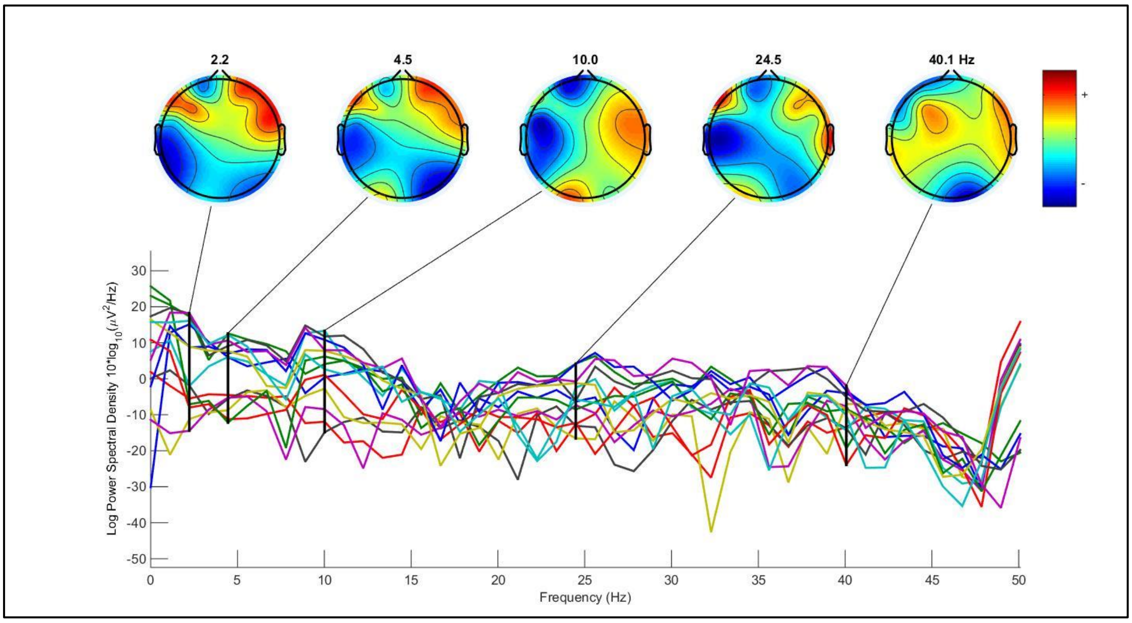
Trial 1: (Response time: 99.8313727378845 sec) Epoch time range to analyse 96 to 102 sec



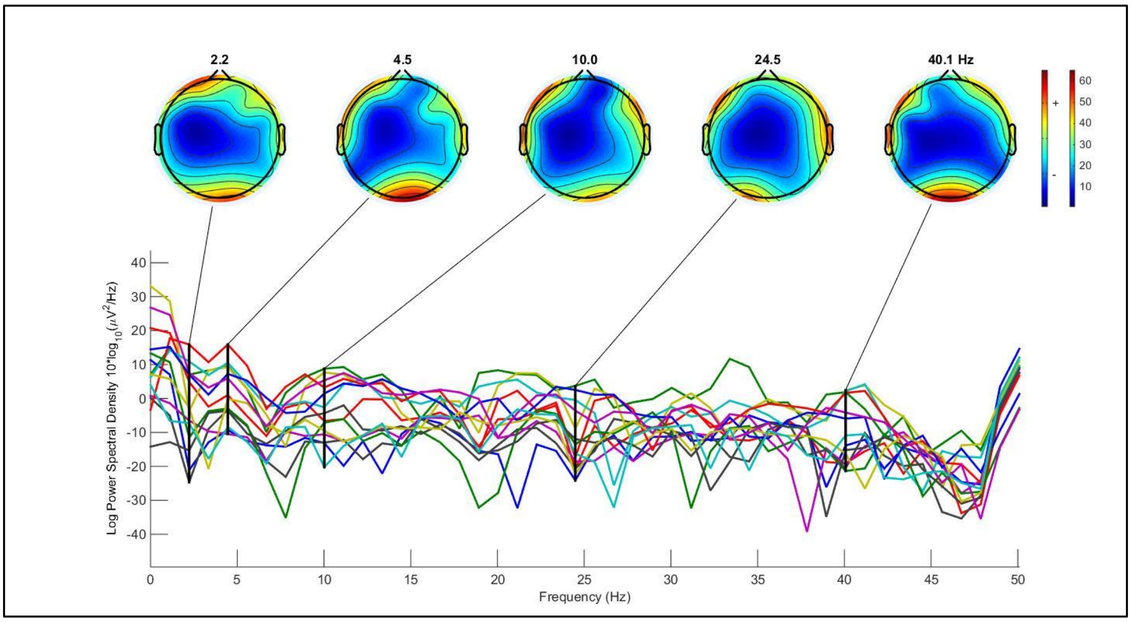
Trial 2: (Response time: 99.5112605094909 sec) Epoch time range to analyse 96 to 102 sec



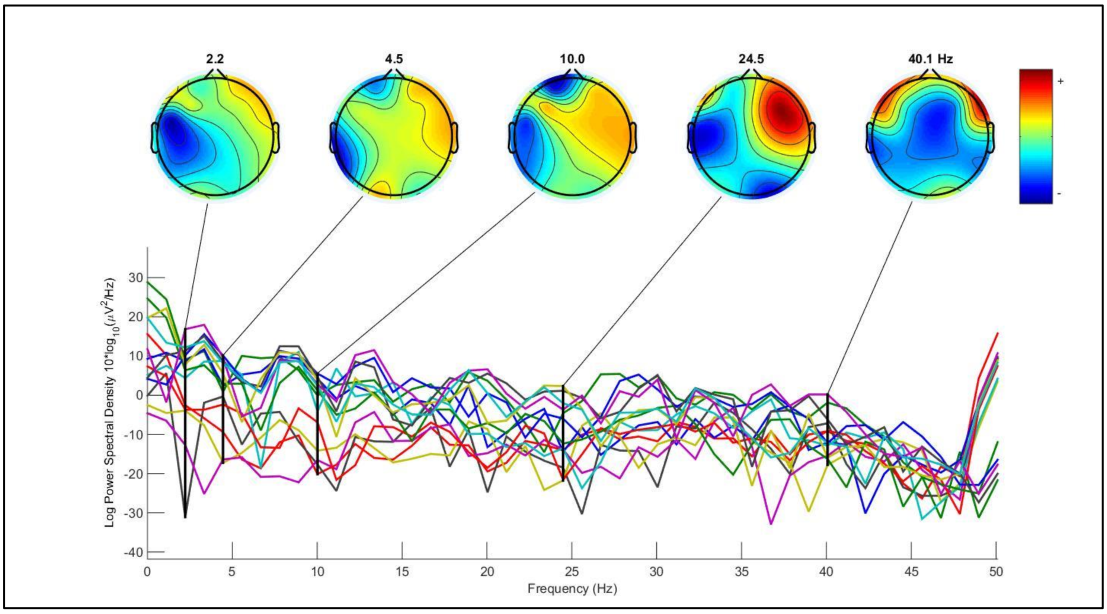
Trial 1: (Response time: 147.893925476074 sec) Epoch time range to analyse 144 to 150 sec



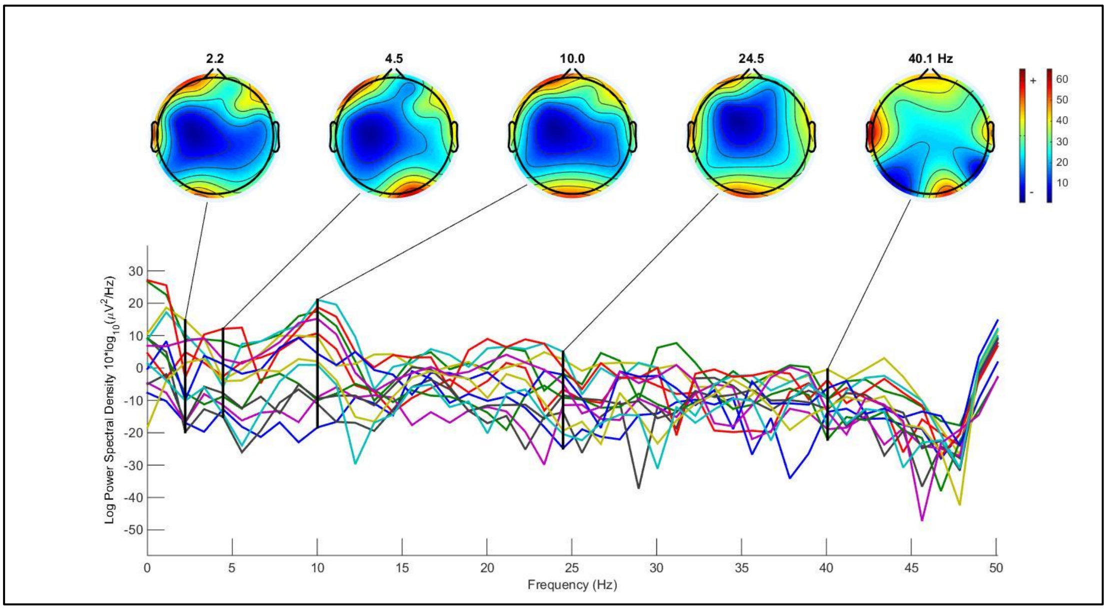
Trial 2: (Response time: 147.410218763351sec) Epoch time range to analyse 144 to 150 sec



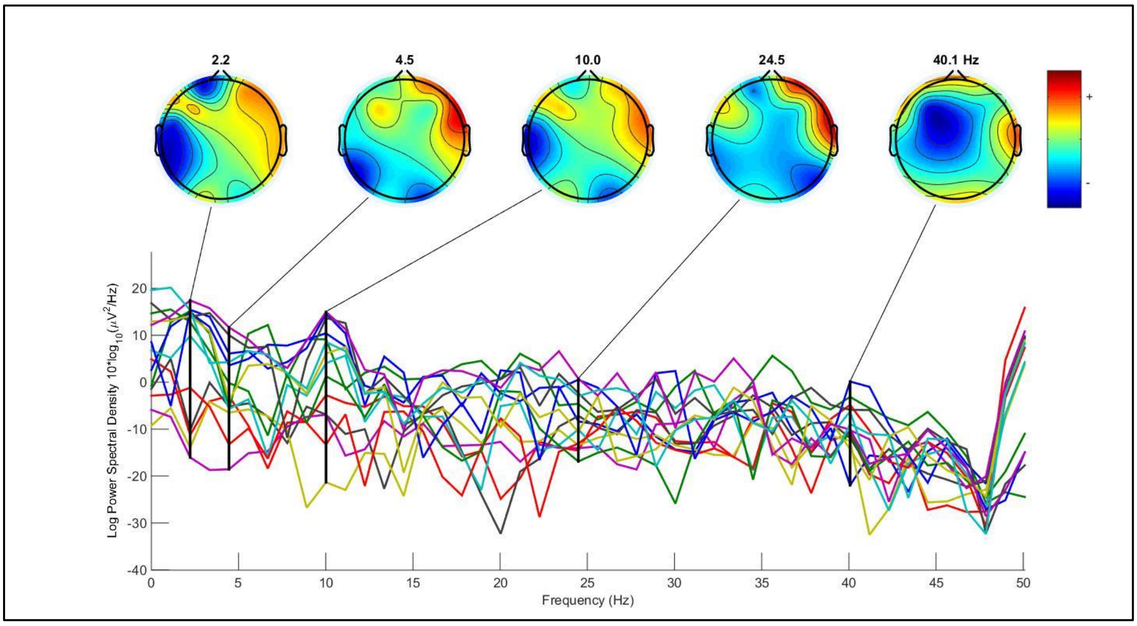
Trial 1: (Response time: 161.608954191207 sec) Epoch time range to analyse 158 to 164 sec



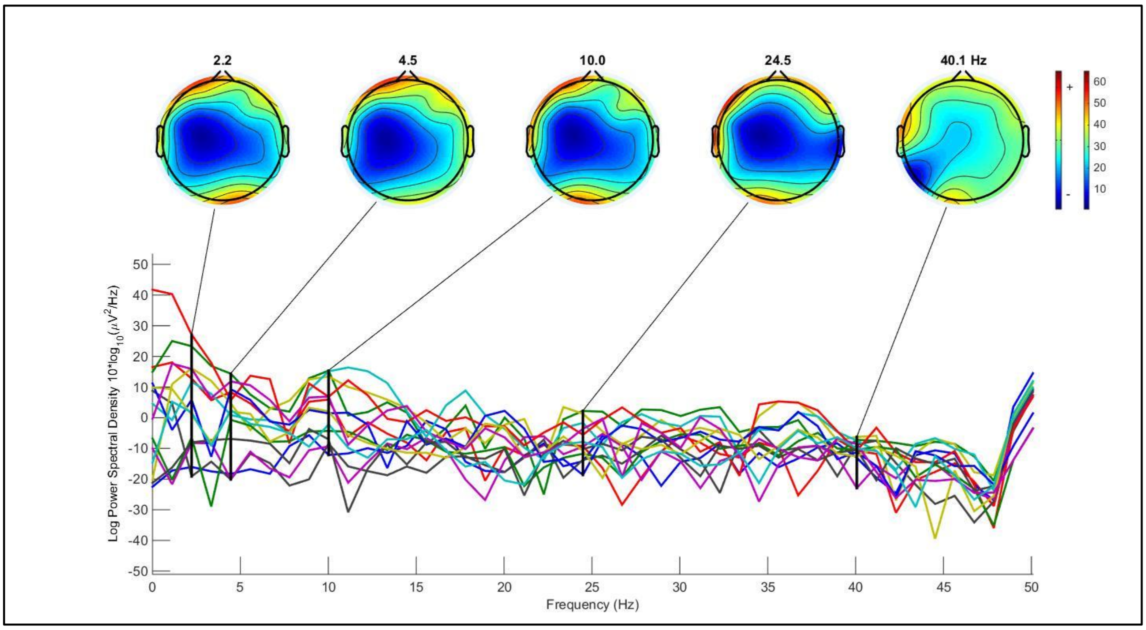
Trial 2: (Response time: 161.558165073394 sec) Epoch time range to analyse 158 to 164 sec



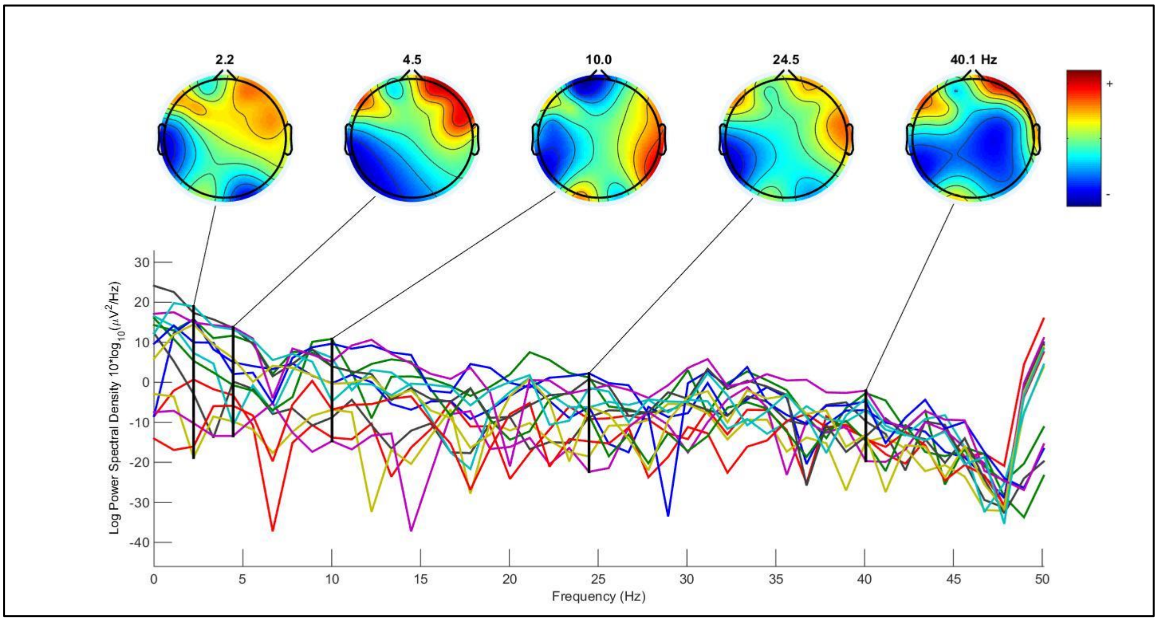
Trial 1: (Response time: 173.617569446563 sec) Epoch time range to analyse 170 to 176 sec



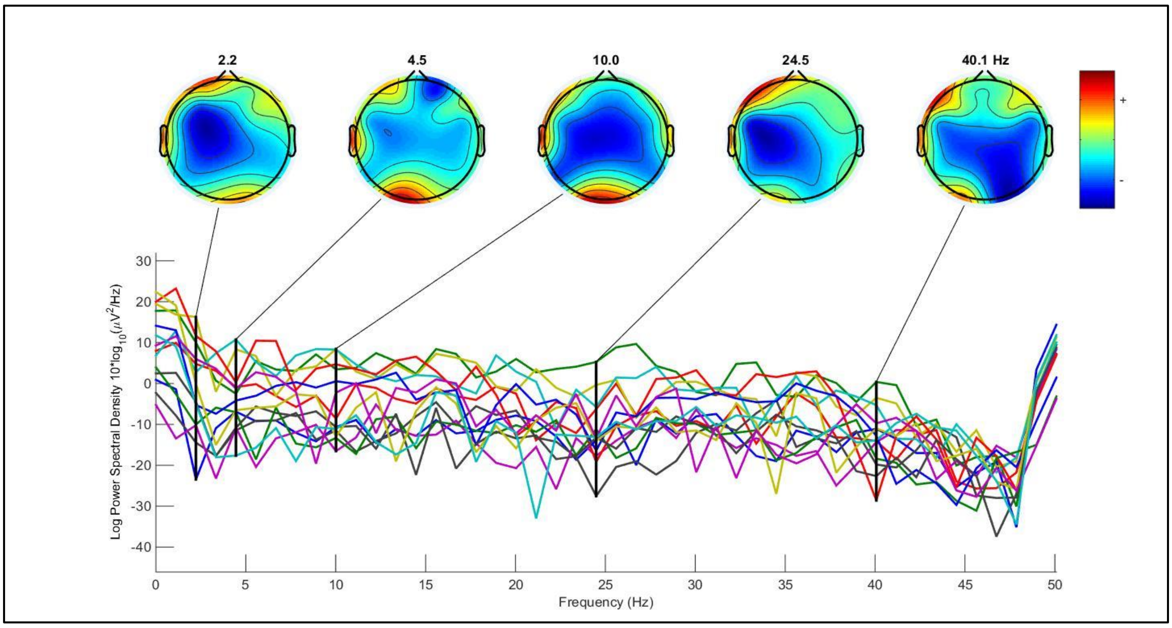
Trial 2: (Response time: 173.601659536361 sec) Epoch time range to analyse 170 to 176 sec



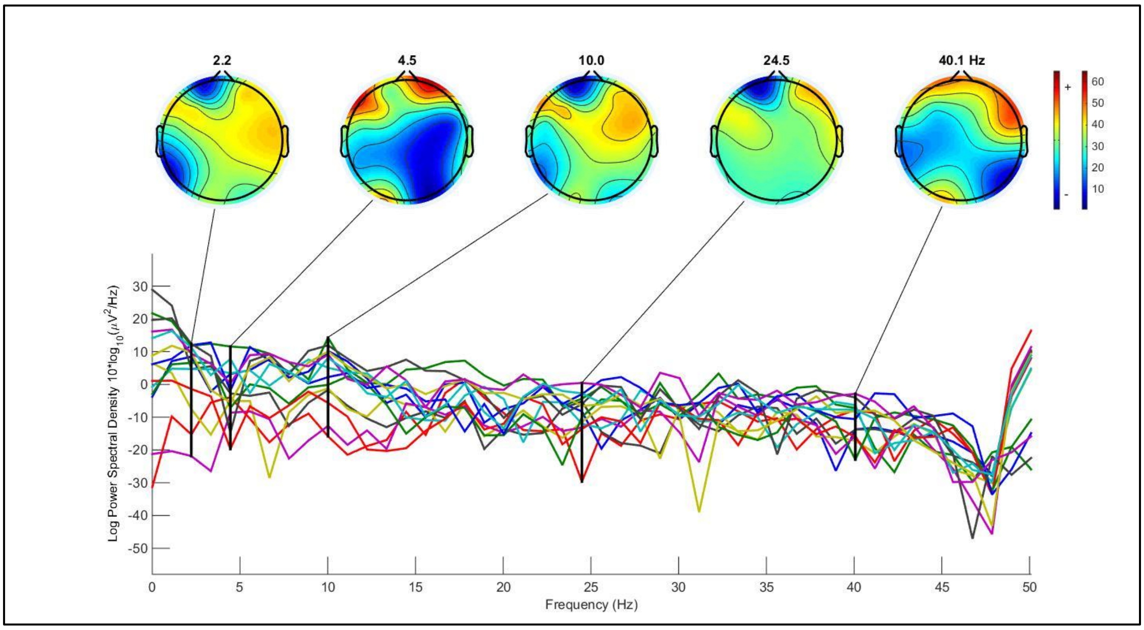
Trial 1: (Response time: 189.557830810546 sec) Epoch time range to analyse 186 to 192 sec



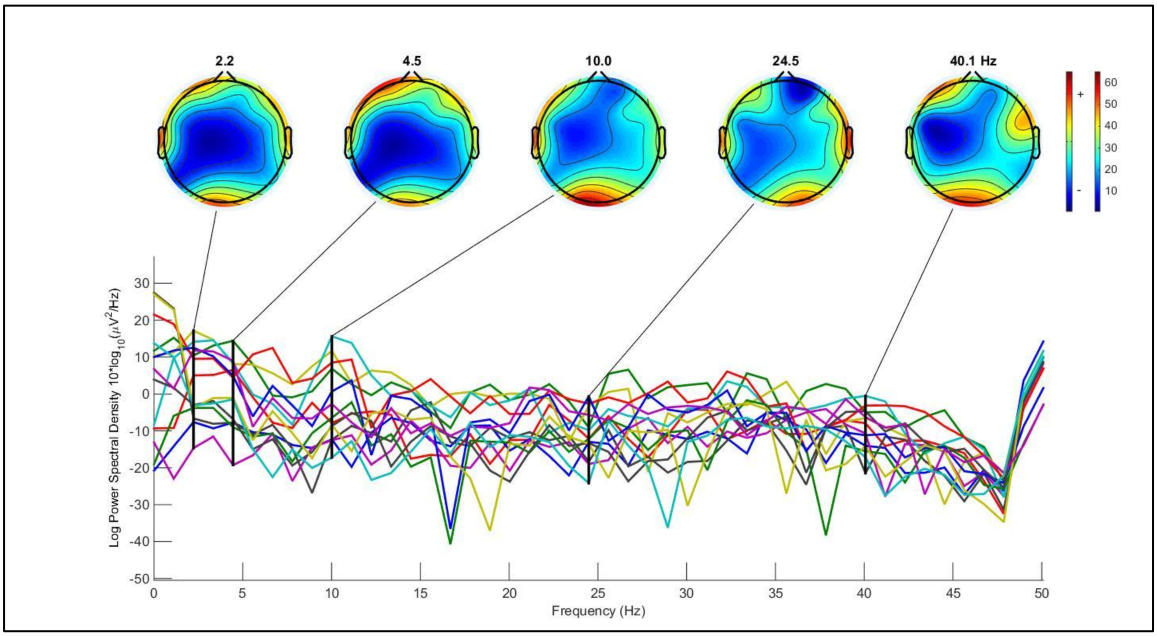
Trial 2: (Response time: 189.534313678741 sec) Epoch time range to analyse 186 to 192 sec



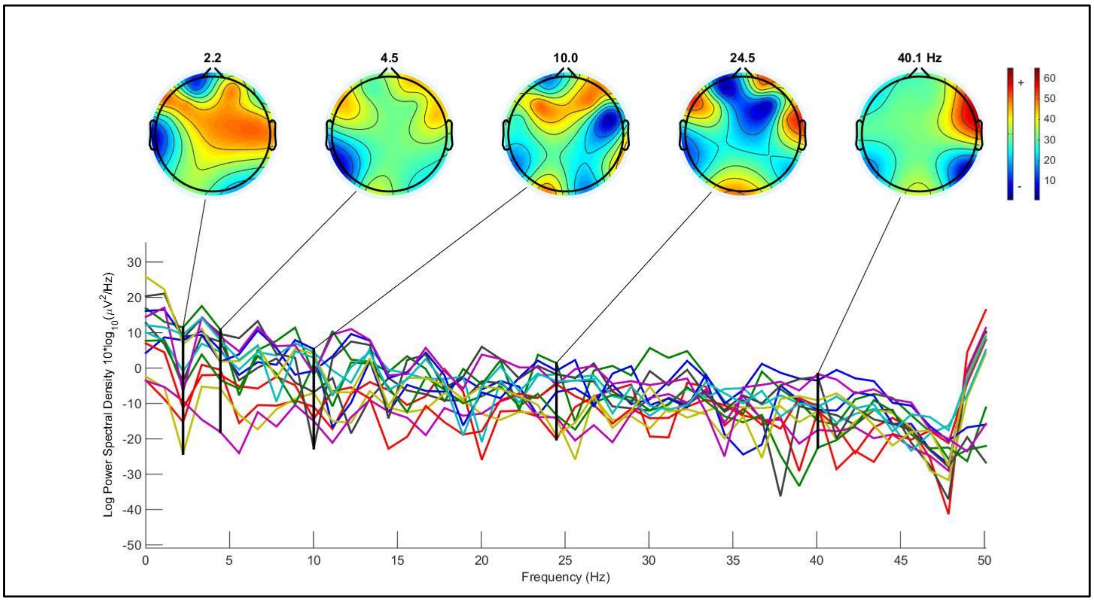
Trial 1: (Response time: 216.700616598129 sec) Epoch time range to analyse 213 to 219 sec



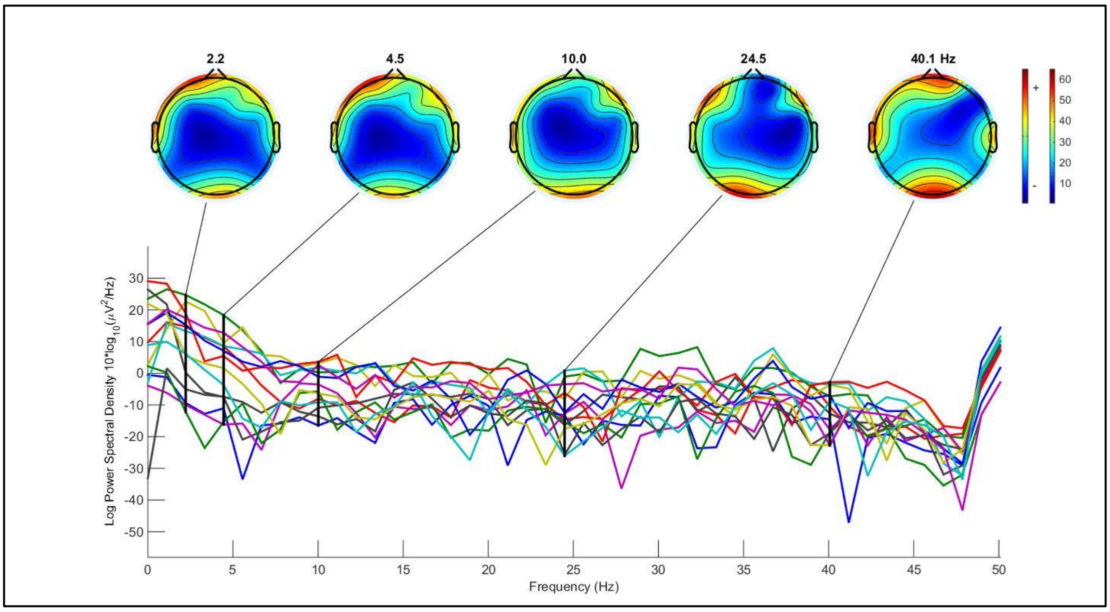
Trial 2: (Response time: 216.514612913131 sec) Epoch time range to analyse 213 to 219 sec



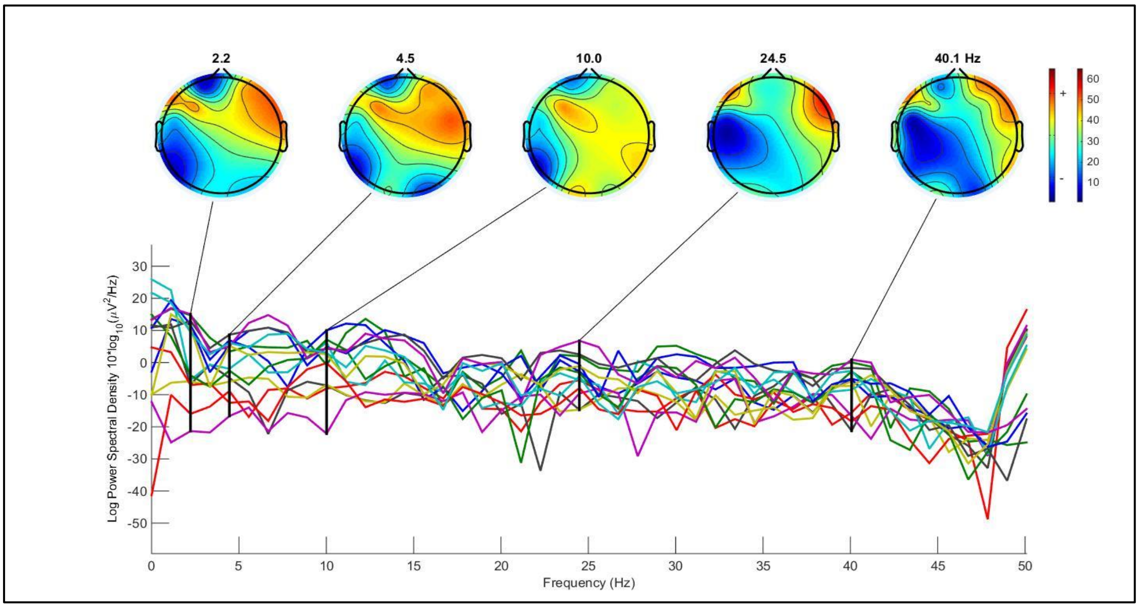
Trial 1: (Response time: 227.521649837493 sec) Epoch time range to analyse 224 to 230 sec



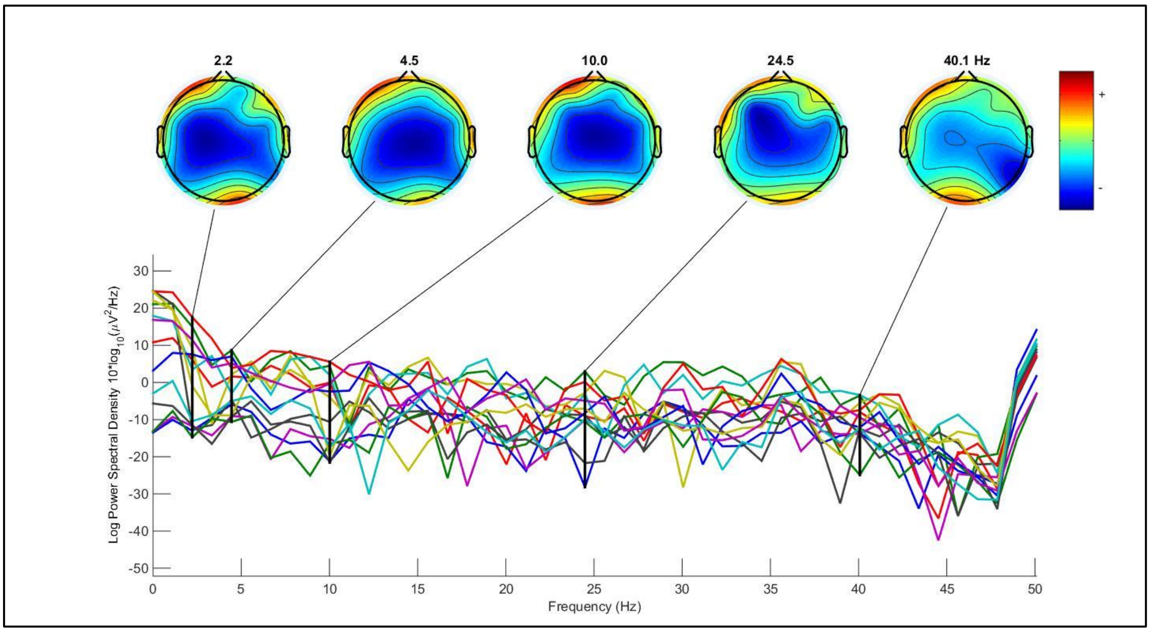
Trial 2: (Response time: 227.551354646682 sec) Epoch time range to analyse 224 to 230 sec



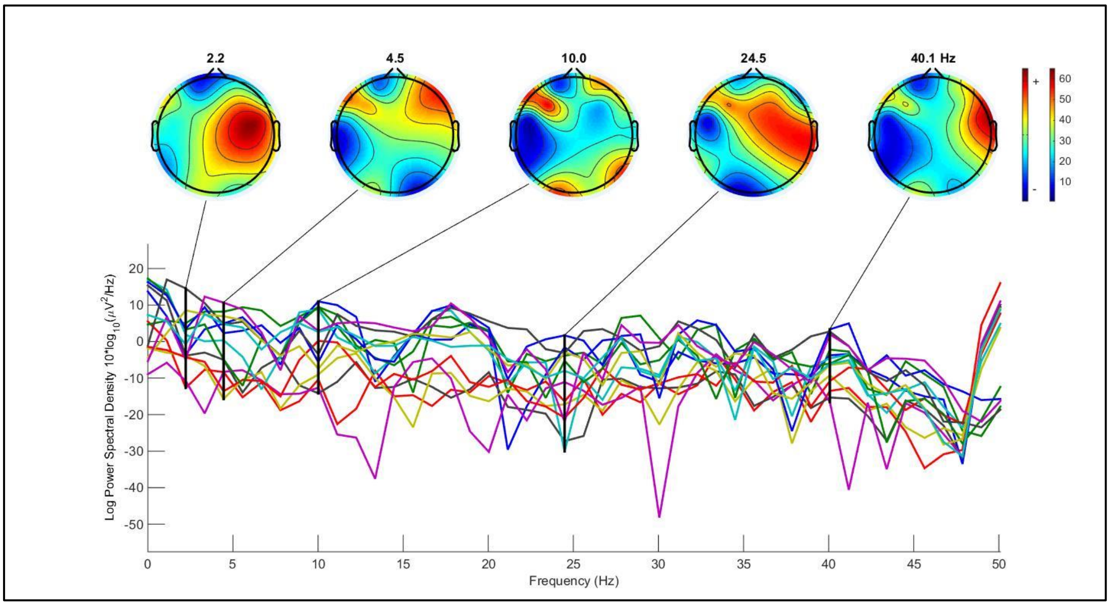
Trial 1: (Response time: 233.829511880874 sec) Epoch time range to analyse 230 to 236 sec



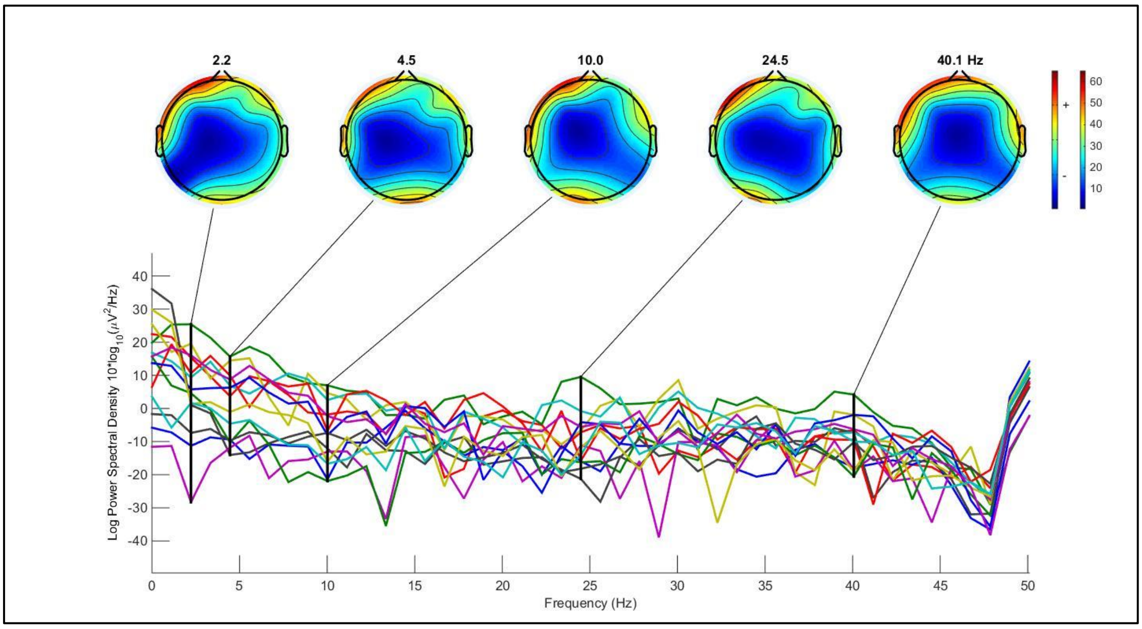
Trial 2: (Response time: 233.536166191101 sec) Epoch time range to analyse 230 to 236 sec



Trial 1: (Response time: 296.59017920494 sec) Epoch time range to analyse 293 to 299 sec



Trial 1: (Response time: 296.562237977981 sec) Epoch time range to analyse 293 to 299 sec



7.3 Python Script used to simulate the background and stimulus (Events)

```
__author__ = 'Debtanu'
from time import time
import pygame

# pygame.init()
# pygame.joystick.init()
# print pygame.joystick.get_count()
# wheel = pygame.joystick.Joystick(0)

#wheel.init()
_width_ = 1366
_height_ = 768
fullscreen = True
display = pygame.display.set_mode((_width_, _height_))  # ,pygame.FULLSCREEN)
if fullscreen: display = pygame.display.set_mode((_width_, _height_), pygame.FULLSCREEN)

background = pygame.image.load("image.jpg").convert()
def draw(img, x, y):
    display.blit(img, (x * _width_ - img.get_rect().size[0] / 2, y * _height_ - img.get_rect().size[1] / 2))



c0 = pygame.image.load('Blip.png')
#TODO: Add start and end time frame for each image. Name images from Blip0 to Blip<n-1>  for n times
timings = [(6, 7), (15, 16), (29, 30), (43, 44), (75, 76), (99, 100), (147, 148), (161, 163), (173, 175), (189, 191), (216, 217), (227, 228), (243, 244), (269, 270), (286, 287)]
timestamps = []

images = []
for x in range(len(timings)):
    c0 = pygame.image.load('Blip' + str(x) + '.png')
    #print 'Blip' + str(x) + '.png'
    images.append(c0)
pygame.display.set_caption('TIMER')
clock = pygame.time.Clock()
timer = time()
i = 0
```

```
quit = False
while not quit:
    for event in pygame.event.get():

        if event.type is pygame.QUIT:
            quit = True
        elif event.type == pygame.KEYDOWN:
            if event.key == pygame.K_ESCAPE:
                quit = True
            if event.key == 98:
                t = time() - timer
                print (t)
                timestamps.append(t)
        elif event.type == pygame.JOYBUTTONDOWN:
            print (event.key)

    t = time() - timer
    display.fill((0, 0, 0))
   # display.blit(background, (0, 0))

    if t > timings[0][0] and t < timings[0][1]:
        #c0 = pygame.image.load('Blip.png')#'+str(i)+'.png')
        #p = random.randint(1,9)*.1,

         if i== 0 :
           draw(images[i], .1, .6)
         elif i== 1:
           draw(images[i], .6, .8)
         elif i== 2:
           draw (images[i], .8, .7)
         elif i== 3:
           draw(images[i], .3, .8)
         elif i== 4:
           draw(images[i], .2, .5)
         elif i== 5:
           draw(images[i], .9, .6)
         elif i== 6:
           draw(images[i], .6, .7)
         elif i== 7:
           draw(images[i], .6, .8)
         elif i== 8:
          draw(images[i], .2, .8)
```

```
        elif i== 9:
         draw(images[i], .4, .7)
        elif i == 10:
         draw(images[i], .8, .5)
        elif i == 11:
            draw(images[i], .2, .6)
        elif i == 12:
            draw(images[i], .9, .7)
        elif i == 13:
            draw(images[i], .3, .6)
        elif i == 14:
            draw(images[i], .7, .8)
        #print i

    elif t > timings[0][0] and t > timings[0][1]:
        i += 1
        timings.pop(0)

    pygame.display.update()
    clock.tick(60)
    if len(timings) <= 0: break
print (timestamps)
```