A Novel Approach to Identify The Effect of Lamp Spectrum on Sadness Emotion for Theatrical Performance

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SUBMITTED BY

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RECOMMENDATION CERTIFICATE

This is to certify that the thesis entitled "**A NOVEL APPROACH TO IDENTIFY THE EFFECT OF LAMP SPECTRUM ON SADNESS EMOTION FOR THEATRICAL PERFORMANCE**" submitted by **JOY DAS**, (Examination Roll No. **M4ILN22024**, Registration No.**136120 of 2016-2017**) of this University in partial fulfilment 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 **JOY DAS**, 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 does not necessarily endorse or approved the thesis only for the purpose for which it has been submitted.

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DECLARATION OF ORIGINALITY AND COMPLIANCE OF ACADEMIC ETHICS

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

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ABSTRACT

In this thesis, the major topic of discussion is how light spectrum may be used to evoke human emotion of theatre artists. Researchers have drawn a connection between the non-visual effects of light and mood and emotion since the discovery of the ipRGC cell in 2002. Humans are susceptible to the psychological and physiological effects of light. Additionally, this thesis contains an Electroencephalography (EEG) research for analysing the subject's emotional state.

The lighting on the stage may affect the performances in the theatre. The lighting is set up such that the audience can only view the performer and not the entire stage. Stage lighting should take this into consideration as well in order to improve the artist's performance because light has a significant non-visual influence on task performance. The actors in a play or musical captivate the audience with their emotional responses. A fixed lighting arrangement may not effectively convey every emotion that they act out. This experiment looks at how the spectrum of light affects the sadness emotion.

For this experiment, ten neurogolocally healthy theatre professionals (6 male and 4 female, mean age 23 with SD $\pm$ 2 years) were recruited. To convey sadness, they performed a screenplay from "Raktakarabi" under four monochromatic lighting conditions (Red, Blue, Yellow, and Green). Through the use of an EEG headset, their brain signals were recorded when they performed, and they used the Self Assessment Manikin rating system to assess their emotional state (Valence and Arousal ratings) in numeric scale.

The SAM data were normalised, displayed on a two-dimensional circumplex model, and the normalised valence and arousal ratings were subjected to statistical analysis using the ANOVA method. The third quadrant of the 2-D Valence and Arousal plane plot of the sadness data displays the results, which are consistent with the circumplex concept. Additionally, an ANOVA analysis showed that under Blue lighting, valence and arousal were both considerably greater ($F = 11.1892$, p-value < 0.001 and $F = 9.8540$, p-value < 0.001, respectively). The analysis of the EEG data indicated that compared to the other three lighting conditions, the brain was more active or engaged under red lights (peak amplitude: -12.4 μV) through scalp map. According to the measurement of the event-related potential, the Blue lighting condition's 57 μV maximum positive peak occurred at around the 50-second. When subjected to Blue light, the brain's power spectrum activity shows more intense voltage fluctuations between negative and positive peaks.

The conclusion of the thesis is that performers may easily convey their sadness emotions when the blue light spectrum is present. Through behavioural research, statistical analysis, and an EEG-based analysis, this hypothesis has been substantiated. Even Nevertheless, a human-based experiment completely depends on people's perceptions and nature.

OVERVIEW OF THE THESIS

Chapter 1 contains the fundamental definition of the term as well as information on light, colour, human-centric lighting, the visual and non-visual effects of light,, emotion, human brain, etc.

Chapter 2 discusses the literature reviews on relevant papers, articles, etc.

Chapter 3 describes background of the study, objective of work, experimental design, procedure and results.

Chapter 4 involves analysis of the experimental data. There were two separate methods used to collect the data: an electroencephalography study and a self-assessment manikin rating system. Plotting in 2-D valence and arousal plane is used for the SAM data analysis, and statistical significance is taken into account. From the EEG study, the scale map plot, ERP, and PSA analysis are considered. Later a constructive discussion is added.

Chapter 5 covers the successful conclusion of the thesis study and suggests some potential areas for further research.

Chapter 6 References.

Chapter 7 is a section of the annexure. The software and technologies utilised for the thesis work have been covered. Details of all the pre-owned equipment were also discussed.

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CHAPTER-1

1 INTRODUCTION

1.1 What Is Light?

The Illuminating Engineering Society of North America (IESNA) defines Light as " The radiant energy that is capable of exciting the retina and producing a visual sensation." [1] Light is a small part of the Electromagnetic spectrum, sandwiched among Ultraviolet and Infrared radiation, that can excite the human retina so that humans can give a visual response. The visible portion of light extends from 380 nm to 780 nm, as shown in figure 1. What differentiates light from the rest of the electromagnetic spectrum is that radiation from 380 nm to 780 nm is absorbed by the human visual system's photoreceptor (Cone & Rod cells) and commences the process of seeing. Light can not be severally defined in terms of radiant energy or visual sensation but is a combination of both.

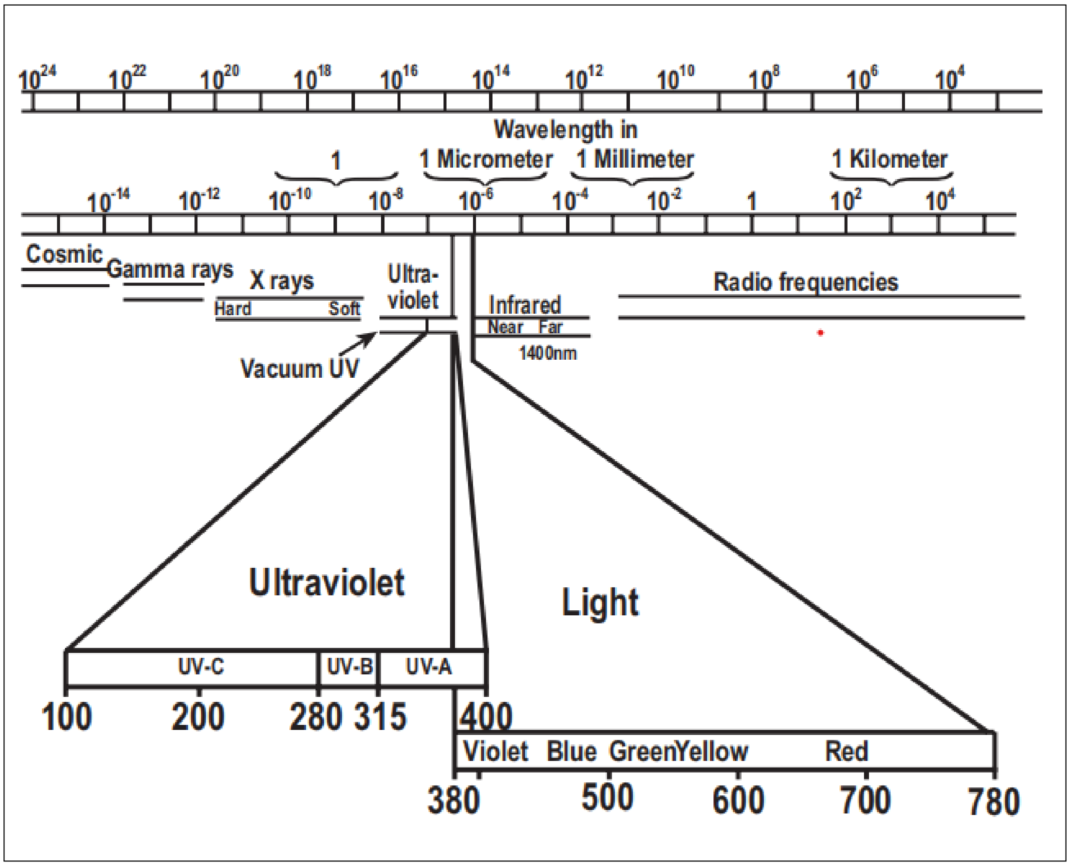


Figure 1: Figure of The Electromagnetic Spectrum

1.2 Relation between Spectrum and Colour

The human eye can perceive a small portion (380 nm to 780 nm) of the electromagnetic spectrum. Two types of photo-receptors inside the eye, i.e. cone cells and rod cells, convert radiation within this range into electrical signals to the brain. The cone photoreceptor additionally interprets light into colour depending on the light's wavelength. Colour is not an inherent attribute of light; alternatively, it is far from the brain's interpretation of the indicators from the cones. While human sees the light of shorter wavelengths (around 400 nm to 480 nm), the brain interprets it as "Blue". As wavelength increases, the associated colour constantly changes through the visible spectrum, from "Green" to "Yellow" to "Orange" to "Red". The perception of colour is due to the distinction in the wavelengths of light radiations.[1] Visible light can have a wavelength between 380 nm and 780 nm, and the colour changes in the way, as shown in Figure 2.

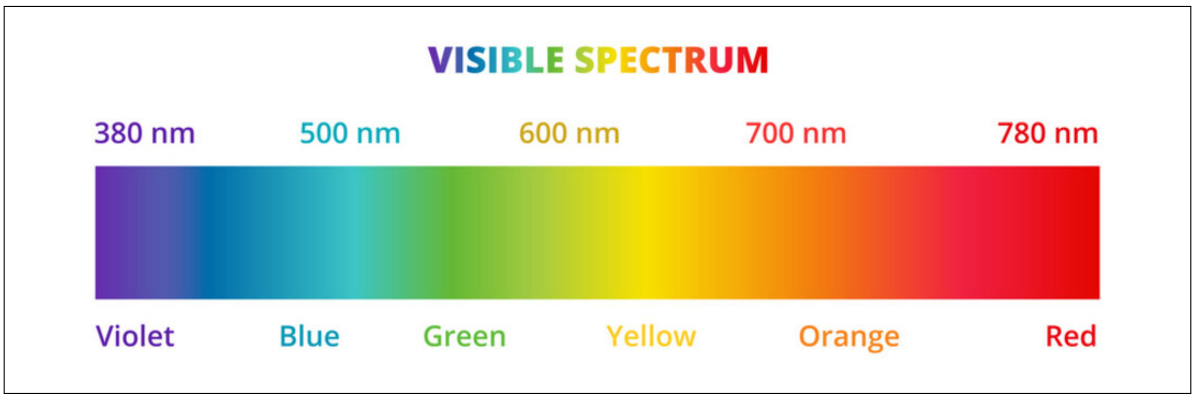


Figure 2: Figure of Colour Variation According to Wavelength

1.3 Spectral Sensitivity

The sensitivity of the human visual system is not the same at all wavelengths in the range of 380 nm to 780 nm. Also, the eyes' spectral sensitivity varies from person to person and with age, the strength of the eyes' vision also reduces. Human eyes have two different photo-receptors, i.e. cone cells and rod cells, so both have different spectral sensitivity at different luminance levels.[2] Cone cells are activated when the luminance/brightness level is more than 3 cd/m^2, this type of vision is called photopic vision. Rod cells are activated when the luminance/brightness level is less than 0.1 cd/m^2, which is called scotopic vision. And the state between photopic and scotopic vision is called mesopic vision and the luminance / brightness level is between 0.1 cd/m^2 to 3 cd/m^2. The peak sensitivity of cone cells (photopic vision) is 683 lm/W at 555 nm in yellowish-green. In contrast, rod cells (scotopic vision) have a peak sensitivity of 1700 lm/w at 507 nm in the bluish-green region of the colour spectrum shown in figure 3.

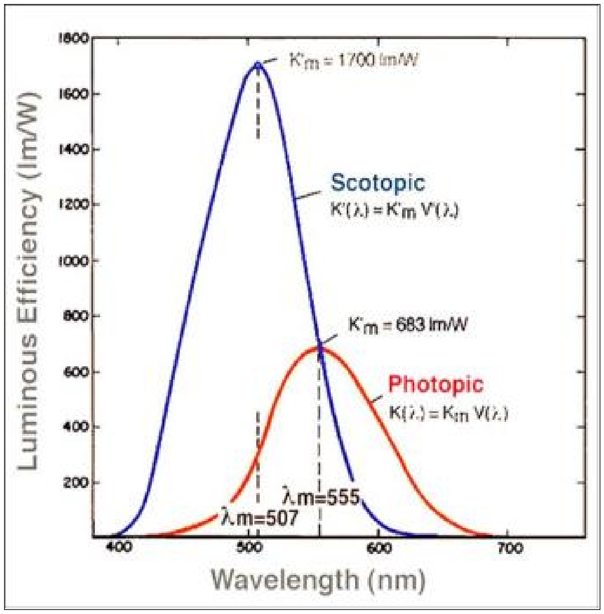


Figure 3: Figure of Photopic Vision and Scotopic Vision

The CIE (Commission Internationale de l'Eclairage) has introduced a standard photopic observer or luminous efficacy function and a scotopic observer or luminous efficacy function, defined by $V(\lambda)$ and $V'(\lambda)$ respectively. These efficacy functions are normalised to a 1 or 100% to their maximum. Figure 7 shows the relative sensitivities of CIE standard observers.

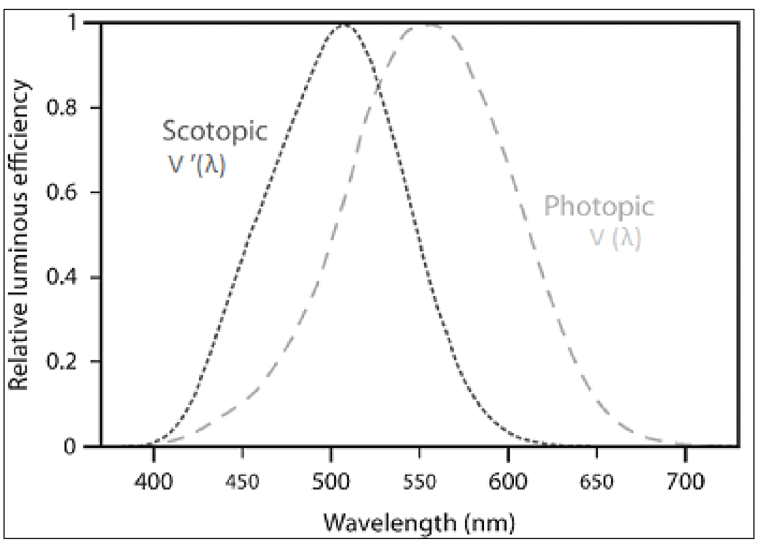


Figure 4: Relative CIE standard Photopic and Scotopic Luminous Efficacy Functions

1.4 CIE Colour Space & Chromaticity Diagram

The earliest established quantitative relationships between the distributions of electromagnetic visible spectrum wavelengths and physiologically perceived colours in human colour vision are found in the CIE 1931 colour spaces. When working with colour inks, illuminated displays, and recording equipment like digital cameras, the mathematical connections that characterise these colour spaces are important colour management tools. The "CIE", created the system in 1931.[3]

Colour matching is the cornerstone of the CIE colorimetry system. Another type of standard observer is represented by the CIE Colour Matching Functions, which are the relative spectral sensitivity curves of the human observer with normal colour vision. The CIE colour matching functions are mathematical constructions that represent the relative spectral sensitivity needed to guarantee that all wavelength combinations that are perceived as having the same colour occupy the same position in the CIE colorimetry system and that all wavelength combinations that are perceived as having a different colour occupy different positions. Two sets of colour matching functions are shown in figure 7. The spectral tristimulus values are the colour matching function values at various wavelengths.[4][5]

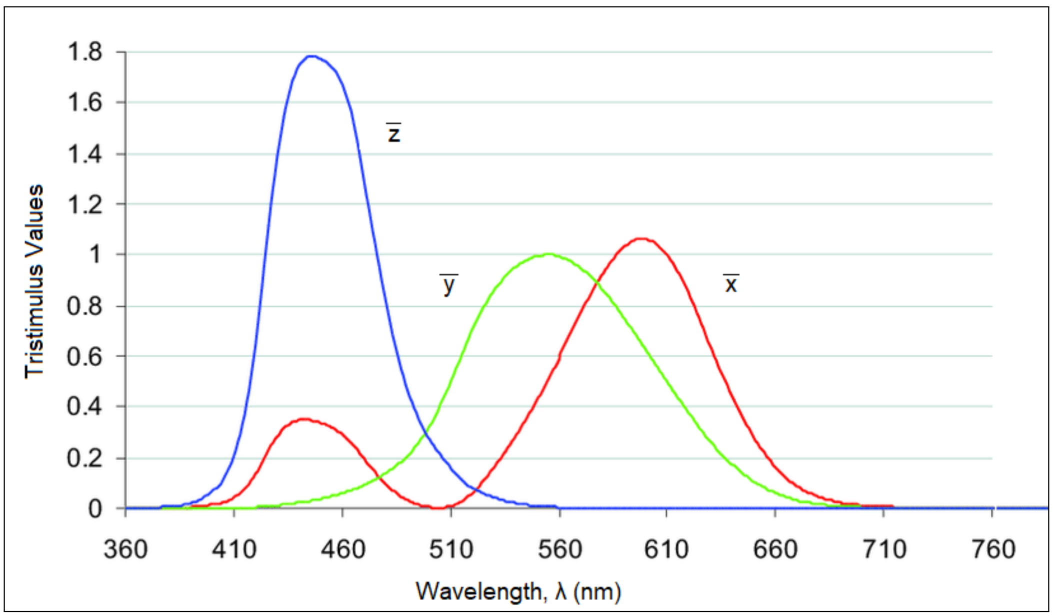


Figure 5: The CIE Colour Matching or Tristimulus Value of CIE 1931 Standard Observer

The quantities of the three fictitious primary colours X, Y, and Z needed to match the colour of the light source may be calculated by multiplying the spectral power distribution of the light source by each of the three colour matching functions x(λ), yλ), and zλ) wavelength by wavelength, as shown in the equation below. X, Y, and Z are expressed as equations by:

$$X = h \sum S(\lambda) x(\lambda) \lambda \tag{1}$$

$$Y = h \sum S(\lambda) y(\lambda) \lambda \tag{2}$$

$$Z = h \sum S(\lambda) z(\lambda) \lambda \tag{3}$$

where:-

$S(\lambda)$ = spectral radiant flux of the light source (W/nm)

$x(\lambda), y(\lambda), z(\lambda)$ = spectral tristimulus values from the appropriate colour matching function.

λ = wavelength interval(nm)

h = arbitrary constant.

Once the X, Y, and Z values have been determined, the next step is to express each value as a percentage of the total, i.e.

$$x = \frac{X}{(X+Y+Z)} \tag{4}$$

$$y = \frac{Y}{(X+Y+Z)} \tag{5}$$

$$z = \frac{Z}{(X+Y+Z)} \tag{6}$$

The CIE chromaticity coordinates are defined as the three values x, y, and z. Only two of the coordinates are necessary to describe the chromaticity of a colour since x + y + z = 1. The x and y coordinates are employed by convention. All colours can be represented on a two-dimensional surface since a colour may be described by two coordinates. The CIE 1931 chromaticity diagram is seen in figure 18. The outer curved boundary of the CIE 1931 chromaticity diagram is called the spectrum locus. This curve corresponds to all wavelength-only colours, or pure colours. The purple boundary, which is a straight line connecting the ends of the spectrum, is where it is possible to find the most intense purples. A colourless surface will be found at the equal energy point, which is the centre of the figure. The Planckian locus is a curve that is close to the equal energy point. This curve runs over the chromaticity coordinates of objects that behave as black bodies, meaning that the temperature of the light source alone determines its spectral power distribution. One may think of the CIE 1931 chromaticity diagram as a map showing where various colours are in relation to one another.[6] As the chromaticity coordinates move away from the equal energy point and toward the spectrum locus, the saturation of a colour rises. The direction in which the chromaticity coordinates travel affects the color's hue. Indicating roughly how a colour would seem, the CIE 1931 chromaticity diagram is a valuable tool (CIE Publication 107:1994). It provides chromaticity coordinate boundaries for signal lights and surfaces such that they will be recognised as red, green, yellow, and blue. Perceptually, the CIE 1931 chromaticity diagram is not uniform. Red colours are condensed in the bottom right corner whereas green colours are spread out across a vast region. Any effort to measure significant colour variances using the CIE 1931 chromaticity diagram is fruitless due to this perceived non-uniformity.

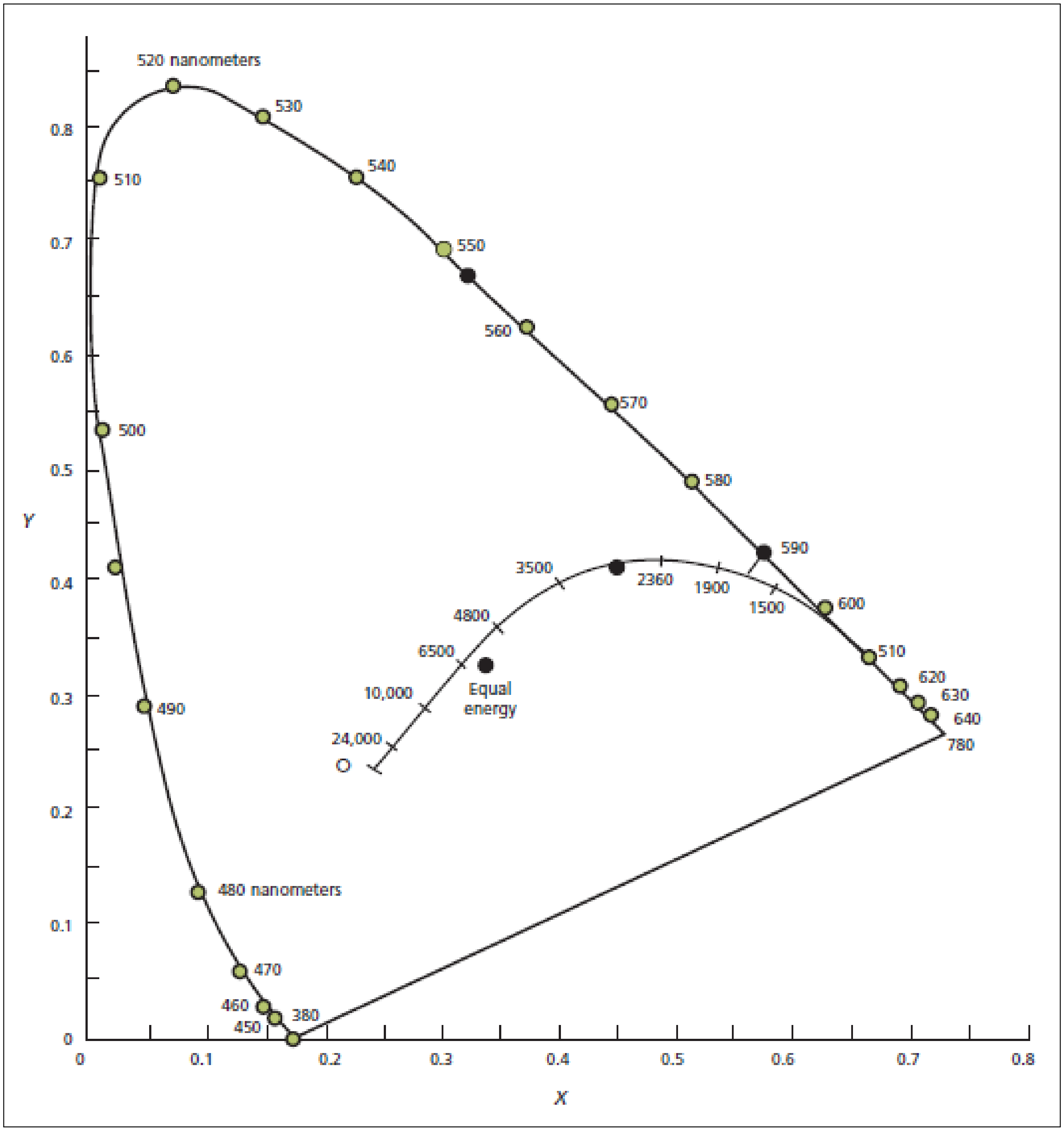


Figure 6: The CIE 1931 Chromaticity Diagram Showing The Spectrum Locus, The Planckian Locus

The CIE originally introduced the CIE 1960 Uniform Chromaticity Scale (UCS) diagram and then, in 1976, advocated the adoption of the CIE 1976 UCS diagram in an effort to remedy this problem. The CIE 1931 chromaticity diagram is only transformed linearly in both figures.[7] The CIE 1976 UCS diagram has axes with the formulas

$$u' = \frac{4x}{(-2x + 12y + 3)} \tag{7}$$

and

$$v' = \frac{9y}{(-2x + 12y + 3)} \tag{8}$$

where x and y are the chromaticity coordinates from CIE 1931. The CIE 1976 UCS diagram is shown in figure 16.

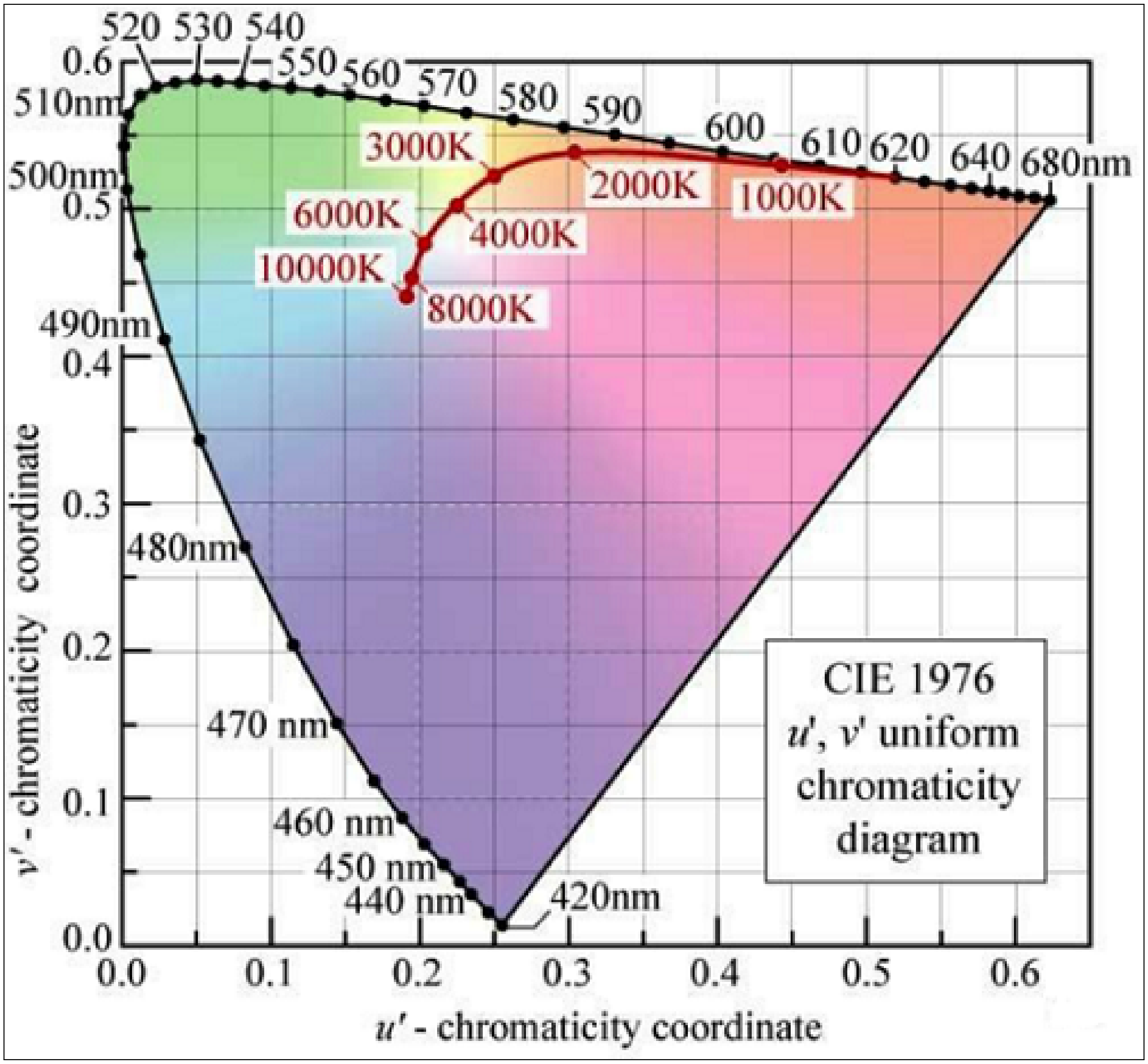


Figure 7: The CIE 1976 Uniform Chromaticity Scale Diagram

1.5 Light Emitting Diode (LED)

A current as well as substrate material are supplied through the semiconductor that makes up an LED to cause it to emit light. The materials used to create the semiconductor have an impact on the spectrum emission of the LED. Indium gallium nitride (IGN) and aluminium indium gallium phosphide (AlInGaP) are now the most used LED material combinations for lighting (InGaN). The wavelength at which the maximum emission occurs (peak wavelength) and the full width half maximum (FWHM) bandwidth, the difference in wavelengths at which the radiant flux is half the maximum radiant flux are used to describe the spectral emission of LEDs, which typically emit radiation in a narrow, Gaussian-shaped band. Peak wavelengths for AlInGaP LEDs are 626 nm, 615 nm, 605 nm, and 590 nm, respectively, which correspond to the perceptions of red, red-orange, orange, and amber. Peak wavelengths of inGaN LEDs are 525 nm, 505 nm, 498 nm, and 450 nm, which correspond to the perception of green, green-blue, blue, and blue-green, respectively. LEDs generally have an FWHM of around 25 nm. The current flowing through the semiconductor and its temperature control how much light an LED emits.[8] In general, the light output increases as the current increases and the temperature decreases. A driver is a piece of control equipment that manages current flow. When utilising LEDs, care should be taken not to use more current than the manufacturer's maximum recommendation. LEDs may last up to 60,000 hours if this care is followed, which is a lengthy lifespan. The newest high-flux LEDs have luminous efficacies up to 100 lm/W in terms of light output and it rapidly increases.[9]

It may be assumed that the usage of LED would be prohibited because it is a narrowband source of light. However, this is not the case with general lighting, except from the entertainment sector. There are two ways to use LEDs to create white light. One approach is to use a luminaire that combines the outputs of three, four, or more distinct LEDs. Then, any colour that falls within the boundaries of the shape made by the lines linking the chromaticity coordinates of the individual LEDs on the CIE chromaticity diagram may be created. The amount of distinct LEDs utilised reflects a trade-off between luminous efficacy and colour qualities; the more different LEDs used, the worse the luminous efficacy but the better the colour qualities. The issue with this method is that light output from LEDs with various peak wavelengths declines at different rates, which causes the colour characteristics to either fluctuate over time or need the use of a complex feedback mechanism to stabilise.[10] The second way that LEDs can produce white light is by illuminating one or more phosphors that produce light in the rest of the visible spectrum with an LED that emits UV or short-wavelength visible radiation.This method has the benefit that it averages out any colour variances between the individual LEDs when enough LEDs are utilised to produce enough light output for practical application.

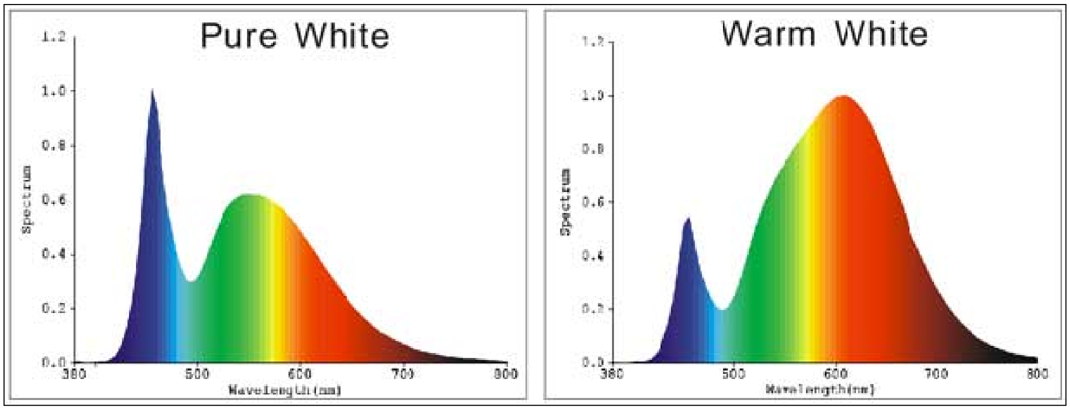


Figure 8: Spectral Composition of Light Emitting Diode for Pure White and Warm White

The spectrum emissions of both approaches to produce purportedly white light are depicted in Figure 11. The LED has already overtaken all other conventional light sources.

1.6 Human Centric Lighting

Modern lighting technologies that imitate the natural daylighting pattern that drives human body systems are known as "Human centric lighting". It is a technique for bringing indoors, using artificial light to mimic natural light, the variations in light intensity, colour temperature, and colour quality that occur naturally. Evidence-based lighting solutions optimized for vision, performance, concentration, alertness, mood, and general human health and well-being. Human Centric Lighting balances visual, emotional, and biological benefits of lighting for humans, recognizing the role of light on human vision, psychology, and physiology.[11] The advancement of time Light Emitting Diode boosts human productivity, comfort, health, and happiness. Human vision is the most evident consequence of light. It allows us to distinguish between brightness, forms, colours, and images and detect information and contrast. On the other hand, light impacts human biology, influencing hormones, alertness, attentiveness, and exhaustion, as well as determining human biological clock and circadian rhythm. Human-centric lighting considers these factors to create a comprehensive and application-oriented approach to human lighting.

Figure 9: Human Centric Lighting

1.7 Relation Between Light Stimulus And Human Responses

An overview of the correlation between light as a stimulus (top) and human reactions (bottom), with a schematic distinction of the visual and non-visual responses. At the top level, the light spectrum refers to the spectral power distribution (SPD) that determines colour qualities, the temporal pattern relates to the timing and duration of exposure to a light stimulus, the spatial pattern refers to the spatial distribution of light in the three-dimensional light field, and the light level refers to the amount of light in radiometric or photometric units. The biological efficacy of the light stimulation is influenced by these four elements. Age and chronotype, two non-lighting variables that are not depicted but are significant in actuality, modify the effects of light on humans. The effects of optical radiation on or via the skin are not taken into account in this figure; only the effects of light through the eyes a re. The retina in the eye serves as the visual pathway leading to the visual cortex, while the ipRGC in the eye serves as the nonvisual channel leading to the pineal gland. Both are connected. No visual route has an impact on acute reaction, circadian rhythm, or long-term responses, but the visual route affects visual performance, visual experience, and visual comfort. The visual, circadian, neuroendocrine, and neurobehavioral responses are all affected by these.[12] The schematic 10 is illustrated the light stimulus and human responses.

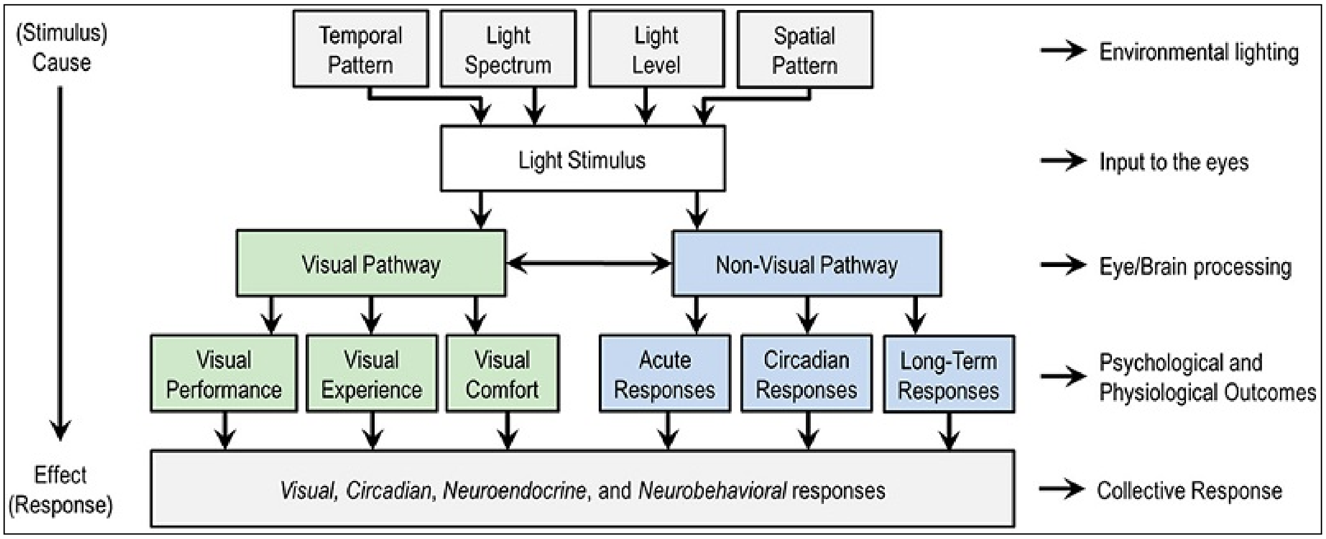


Figure 10: The Stimulus Response Relationship Between Light and Human Outcomes

1.8 Effect of Lighting on Human Performance

To find the relationship between Lighting and Human Performance, it is necessary to see by which specific lighting conditions might influence human performance. There are three such routes that directly or indirectly incorporate non-visual through the visual system, through circadian system, and through perceptual system.[13] The lower part of figure 11 depicts the first route through the visual system. It demonstrates how task performance is a combination of visual performance, cognitive performance, and motor performance, and how illumination and task parameters together produce the five metrics that define visual performance. The second route through circadian system is shown in the upper left of the figure 11. This demonstrates how the retinal illuminance, light spectrum, timing, and length of exposure to light all affect the circadian system's functioning, which in turn affects how well people perform in general by changing their circadian phase or being more alert at night. The third route through the perceptual system is shown in the upper right of figure 11. This method has two origins: one in visual discomfort and one in how humans generally perceive their surroundings, and hence the 'information' sent. Both modes of perception are correlated with expectations, which in turn are related to mood and motivation and ultimately to general human performance.[10]

1.8.1 Visual Effect of Light

Of the three routes outlined above, the impact of light on the visual system is a highly common and well-known phenomenon. To assess the extent to which a stimulus has an effect on the visual system, five separate factors must be taken into consideration. The visual size, luminance contrast, colour difference, retinal image quality, and retinal illuminance are some of these factors.[13]

Depending on the application, the visual size of an item is an angular quantity that may be portrayed in a variety of ways. It may be characterised as the solid angle that the item at the eye subtends for detecting reasons. However, the visual size should be defined as the angle subtended by the crucial dimension of the item at the eye if any minor details need to be detected. Therefore, the eyes can detect things and gather details more easily when the visual field is larger. [14]

The difference between an object's luminance and its background luminance is what is meant by luminance contrast. Therefore, the better the item can be detected, the stronger the contrast. However, it is important to keep in mind that lighting can alter the luminance contrast, which might cause the observer to experience glare or obscuring reflections.[15]

The combination of various wavelengths emitted from every item or light source determines its colour. Therefore, even if there is no luminance difference between the item and its background, the object can still be recognised due to the colour difference. Since each light source has a unique colour appearance, an object's colour appearance may alter if the lighting's wavelengths do not coincide with the object's wavelengths of emission.

The sharpness of the picture affects the quality of the retinal image. As far as the sharpness of the picture is concerned, the medium through which the light after it has been reflected off the object has travelled is important since light is dispersed as it travels through a medium. Focusing the light on the retina becomes more difficult when scattering is significant. Shorter wavelength light has been discovered to contribute to smaller pupil diameters and clearer images in the retina. Additionally, it suggests a better comprehension of the depth of field increase and lesser chromatic and spherical distortions.

The retinal illuminance is determined by the quantity of light coming into the eye from the lighted surfaces in the field of view. It illustrates how the visual system changes based on the surfaces around it. Therefore, changing the retinal illuminance can affect how well the visual system functions.

The degree of visual performance for a lighting stimulus may be identified using these five characteristics. However, visual performance alone is insufficient to comprehend the physical changes a person's body makes when doing a visual activity. Visual, cognitive, and motor components make up the majority of visual tasks. First, the visual element indicates visual performance, which is attained by employing the eyes to see all the information required for the activity. The next stage of cognitive processing involves interpreting the facts and choosing the appropriate course of action. The process of carrying out the chosen tasks constitutes the motor component, in the end. Together, the three components result in task performance, which, depending on how important the visual component is, can be affected by lighting conditions.

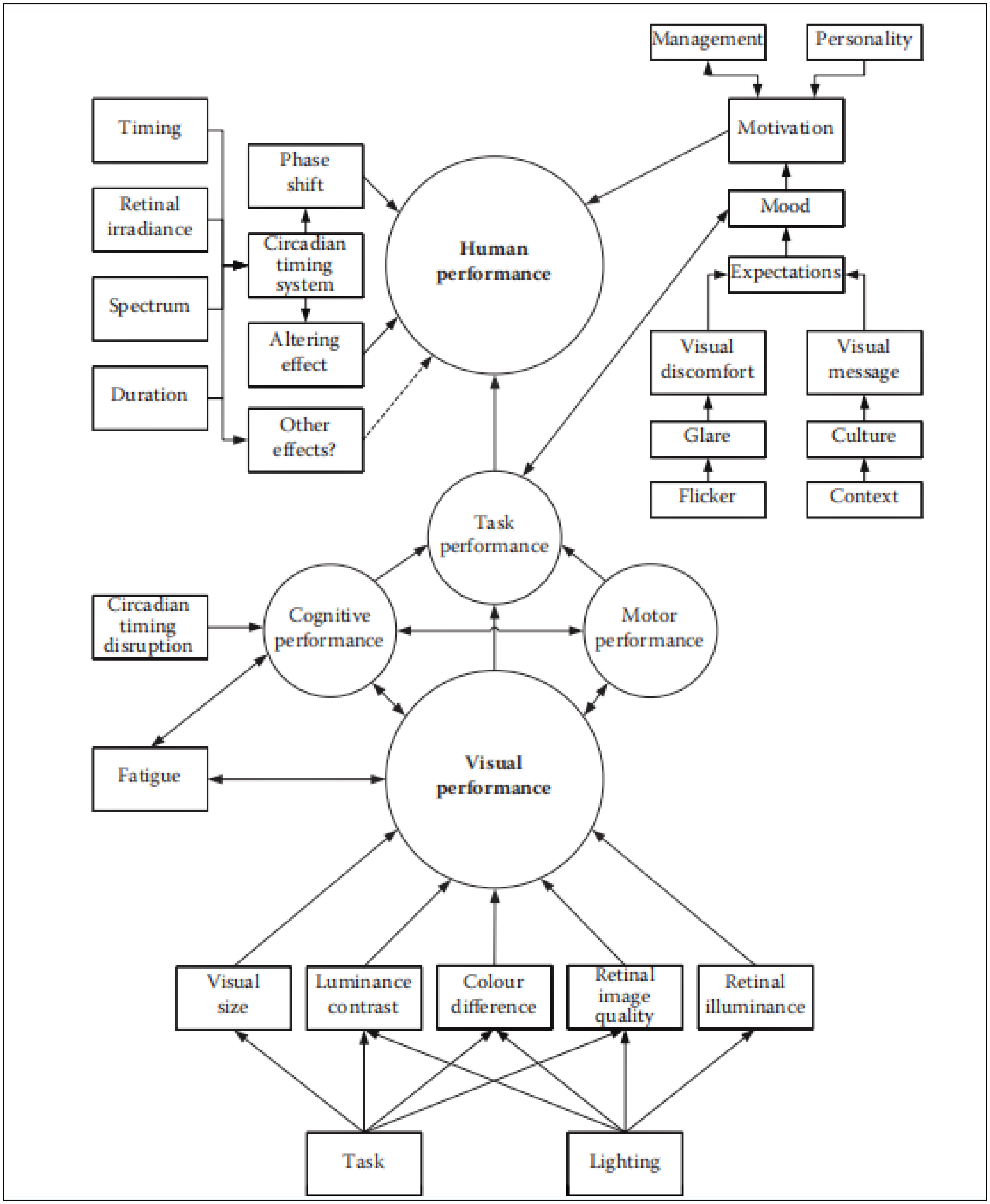


Figure 11: A Conceptual Framework Setting Out The Three Routes Whereby Lighting Conditions Can Influence Human Performance. The Arrows in The Diagram Indicate The Direction of Effect.

1.8.2 Non Visual Effect of Light

Additionally, light can have effects that are entirely or partially independent of the visual system. The biological effects of light, also known as the non-visual, non-image forming (NIF) effects of light, are connected to human circadian photo-reception.[16][17]

Intrinsically photo-receptive retinal ganglion cell (ipRGC), an unique third photoreceptor discovered in 2002, has sparked intense attention among researchers studying circadian biology and lighting.[18]

Rods and cones transmit light along the "Visual path". Electrochemical signals from incoming light information (electromagnetic rays) are converted and delivered to the visual cortex through polysynaptic pathways. Light via NIF pathways is conveyed by intrinsically photosensitive ipRGC via the retinohypothalamic tract to the Suprachiasmatic Nucleus (SCN) and other brain regions, such as the pineal gland which synthesises melatonin : Figure 12 schematically illustrates the pathways of visual and NIF effects in the brain.

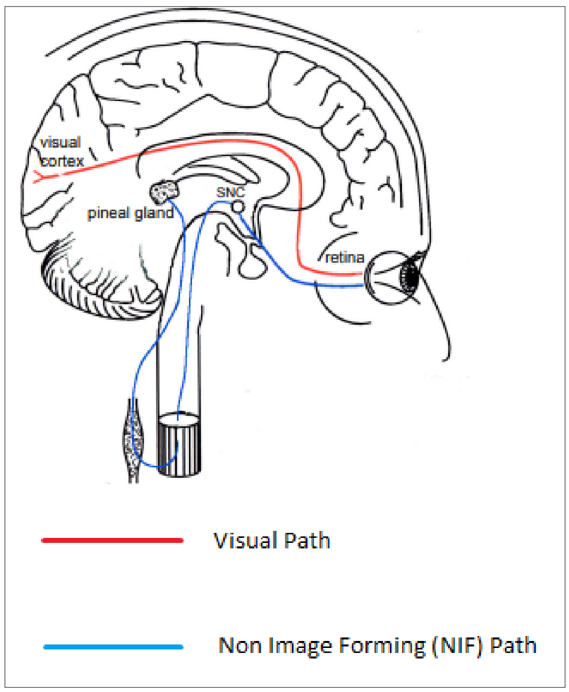


Figure 12: Schematic of visual (Red) and NIF (Blue) Pathways in The Human Brain.

It has been discovered that the ipRGC is the primary photoreceptor in charge of subjecting people to the ambient light/dark cycle as well as other biological impacts. It fills in a critical gap in the explanation of how light and dark affect biological processes. As a result, light might be considered an outside stimulus that instructs the body's internal clock to function properly. Most daily rhythms in physiology and behaviour are controlled by the human biological clock. These consist of hormone secretion, core body temperature, and sleep/wake pattern. It transmits information that controls the release of practically all hormones, including cortisol, the nocturnal pineal hormones melatonin and serotonin, and many more. Along with the endogenous clock's phase shifting in response to light, the pupillary reflex, alertness, mood, and human performance have all been linked to the ipRGCs.[19][20][21]

There is proof that the biological clock is most effectively regulated by short-wavelength light.[22][23][24] The prospect of using blue-enriched light to influence human reactions and behaviour, such as attentiveness and mood, is now the subject of extensive investigation.[25][26][27][28] the impact of light on alertness has been extensively studied, the mechanism underlying the observed reactions is still elusive.

The biological effects of light and how they affect human performance are not fully understood at this time. The non-visual impacts of light and take them into consideration in lighting practices, a significant amount of study is still needed. Research is required to produce a better knowledge of how various lighting effects interact with behavioural visual tasks and cerebral responses, as well as how the biological impacts of lighting may be connected to these responses.

The ipRGCs are most sensitive in the blue part of light between 460-480 nm, in comparison to rods (505 nm) and cones (555 nm).[24][29] Along with wavelength-dependent changes, additional visible electromagnetic spectrum physical characteristics, such as luminous intensity, timing, and exposure time to light, alter the strength of NIF effects. Recognizing the principles of the luminous qualities that affect NIF effects is necessary to optimise indoor lighting settings. Environmental light acts as a signal to control NIF effects, including circadian, circannual (seasonal), pupil light reaction, and hormone secretions.[30]

Through motivation and mood, light may also have an impact on how well a work is done. It has been discovered that the lighting in a workspace may cause an emotional reaction that reveals the mood and motivation of the task. For instance, if the light source in a workspace serves as a glare source, distracting from tasks, it results in visual discomfort. Discomfort may also be more psychological in nature and may result from disparate cultural norms and expectations. One of the simplest examples of how light affects mood and motivation is lighting serving as a glare source. Significant evidence of improved mood and visual comfort when an LED matching sunshine spectrum was utilised was observed in a research done by C Cajochen.[31] Visual effects of light affect visual performance; Non visual effects of light impact health and well-being.

1.9 Effect of Light on Productivity

The correct visual circumstances should be provided by lighting to enable individuals to carry out visual tasks effectively, securely, and comfortably. Through a series of methods, the light environment affects physiological and psychological aspects of people, which further affects their performance and productivity.[32]

It is questionable how lighting affects productivity. The fact that many other elements have an impact on productivity at the same time makes it challenging to establish a relationship between lighting and productivity. These elements include employee motivation, relationships with management, and the degree of individual influence over working circumstances.[10] The capacity to do visual activities can be enhanced, and discomfort from poor illumination can be avoided. Improvements in visual and task performance, as well as productivity, may result from this. The level of experimental control needed makes field studies in operational settings problematic. The impact of increased illumination on work performance has been investigated in several research. Illuminance is just one of many factors that make up the lighting conditions, though. It is important to control and analyse when changing the lighting what lighting aspects are changed (such as illuminance, spectrum, and luminance distribution) and if other factors in the working environment are also changed at the same time (such as working arrangements, people, and work supervision). Studies on the impact of the light spectrum on human performance and the potential for using blue-enriched light to enhance human performance through non-visual effects of light have been conducted recently.

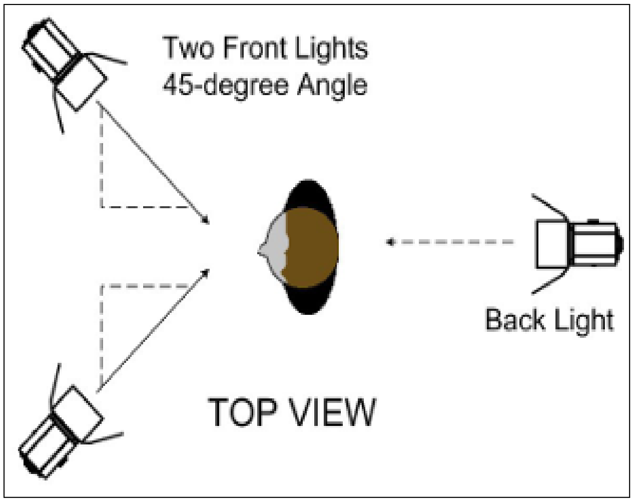
Different light colours have been discovered to influence emotions, heart rates, and circadian cycles in light treatment research.[33] Different hormones are released by the body in response to varying light intensity. Serotonin is released when a colour has a high colour temperature (greater than 6000 K), which affects people's mood and energy levels. This happens naturally during the day from the sun and is known as blue light or a cold temperature. Short blue wavelengths are ideal for boosting productivity and fostering a happy workplace. Melatonin is produced and released when the colour temperature is low(less than 4000 K), which helps relax and go asleep. Low colour temperature, which naturally happens at night, is sometimes known as warm, red light.[34]

Light always works and its effects not just visual and emotional but biological as well. Light solutions that control the colour and intensity of illumination guide humans throughout the day. improve people's efficiency, get the creative juices flowing and help people to keep calm in stressful situations.

1.10 Theatre Lighting

1.10.1 Theatre Lighting

Theatre stage lighting is intended to make the stage performance visible to the audience, but the technique utilised to illuminant the stage will have an affect on how the stage picture is perceived, and it should enhance the production's overall dramatic impact. The McCandless System is the most popular way to illuminant a theatre stage. In his book "A Method of Lighting the Stage," written in 1932, Stanley McCandless [35] discussed this technique. His approach is a helpful guide based on his experience, but it wasn't intended to be the only one. It is best characterised as a three-point system: There are two lighting luminaires in front of the subject and one in back. The front luminaires are positioned 45 degrees to the subject's left and right as well as 45 degrees above the subject. These angles guarantee that the subject's features are well-lit, seem natural, and have three-dimensional shape. The light's angles provide form definition without casting thick, heavy shadows under the chin, nose, or eyebrows. As the person rotates their head from side to side, vision is also made possible by the positioning and angle. Visibility and definition will be improved with the addition of colour and intensity to the front lights. McCandless advised utilising a cool colour in the other front light and a warm colour in the front lights. The colours clash with one another to add clarity while blending for a natural effect. The third light, sometimes known as the "Backlight" is positioned far above and behind the subject; it does not shine directly on the person or directly into the audience's eyes. By illuminating the back of the head and top of the shoulders, it makes the subject stand out against the background and further emphasises their shape. However, by utilising bright, warm backlight, a halo effect can be produced instead of the backlight's typical function of 'Colouring the shadows" formed by the front lights.



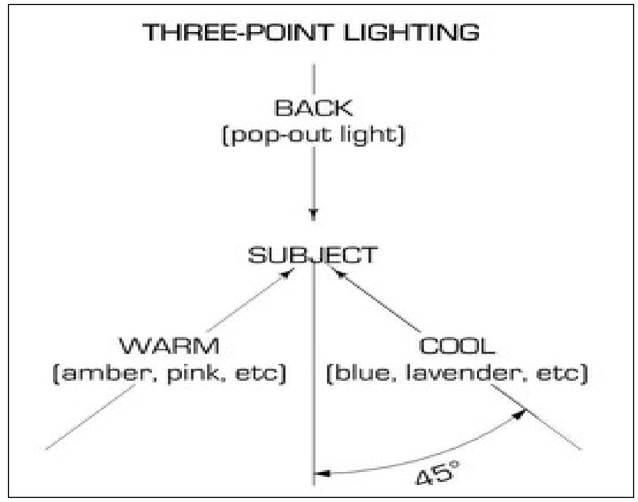


Figure 13: Theatre Lighting Design by McCandles

1.10.2 History of Theatre Lighting and Its Evolution

Stage lighting is the technique of using lighting to produce performing arts including opera, dance, and theatre. The concept of stage lighting was first established by ancient Greek (and later Roman) theatres. They frequently built their theatres from east to west while staging afternoon plays in order to take use of natural sunlight reaching the actors but avoiding the audience. Playhouses continued to benefit from natural illumination by including big circular openings at the top of the theatre. Early modern English theatres without roofs allowed for the use of daylight for stage lighting. When theatres moved inside, artificial lighting became necessary, which led to the start of research into artificial stage lighting. An unknown date candlelight was used in theatre lighting, and as a result, theatre lighting in Europe advanced further. Europe serves as the cradle of highly superior lighting schemes. Italian theatrical techniques witnessed by Charles II, was brought to England when he became a king of England. The "Main source of light in Restoration theatres to be chandeliers," which were "Concentrated toward the front of the house, and especially over the fore-stage". [36] During this time, dipped candles were used to light the chandeliers and sconces in English theatres. A wick was repeatedly dipped into hot wax to create dipped candles, which were cylindrical in shape. Candles needed frequent trimming and relighting regardless of what was happening on stage because "They dripped hot grease on both the audience and actors". Some patrons' views were also hindered by the chandeliers. The two primary types of Restoration theatres in England at the time were Restoration commercial theatres and Restoration court theatres. The two primary types of Restoration theatres in England at the time were Restoration commercial theatres and Restoration court theatres. Since commercial theatres had to be more "Conservative in their lighting, for economic reasons," they preferred using "Candle-burning Chandeliers" as their main lighting source. Court theatres had the resources necessary for their productions to "Use most of the Continental innovations". [36] At the end of the 17th century, there was a similarity between the French and English theatre stages. The earliest theatres to employ gas lighting were the Drury Lane and Covent Garden theatres in the early 1800s. In the 1820s, a brand-new type of artificial lighting was developed. In this kind of illumination, a gas flame is used to heat a cylinder of quicklime (calcium oxide). When the quicklime reached a particular temperature, it would begin to incandescence. Then, to direct this light, lenses and reflectors might be employed. It took some time for this new Limelight to begin being used for theatrical performances, which started about 1837. Limelight gained popularity in the 1860s and beyond until being supplanted by electrical illumination. After the gradual introduction of electric lighting in the late 19th and early 20th centuries, significant breakthroughs were achieved with the advent of LASER and other cutting-edge technologies in the middle and late 20th century, as well as today. There is proof that India performed outside using the sun throughout the day and the moon at night. Even Chaitanyadeva gave theatrical performances throughout the afternoon in public areas. For indoor performances, a variety of lights were used, including Deepa, Diyas, and Vilakku.[37] But it is widely acknowledged that British theatre, in particular, has significantly influenced Indian theatre as it is practised now. As a result, lighting design uses many of the same technologies or methods. Following the premiere of Gerasim Lebedev's first significant theatrical work in 1795, lighting occasionally followed European customs to keep up with changes in Europe. The current globalisation system means that strategies are practically the same everywhere.

1.10.3 Function of Theatre Lighting

Visibility, Motivation, Composition, and Mood are the four basic functions of theatrical stage lighting design.[35] Each of these functions is discussed in depth below.

Visibility: The fundamental idea of visibility is that the stage lighting has to spotlight elements on stage that the audience should be able to view and keep the lights off areas of the stage where the audience shouldn't be able see.

Motivation: It makes sure that the stage lighting seems to emanate from appropriate lighting luminaires on the stage, such as table lamps or chandeliers, for a realistic interior scenario at night, for instance.

Composition: The Lighting Designer's endeavour to improve the options the Scenic Designer and Director have presented is known as composition, which is also a component of scenic design.

Mood: Composition, motivation, and the amount and kind of light all contribute to mood, which is a component of all three other functions.

Stage lighting is used for many different things. Visibility, mood, creating the scene, modelling, focus, composition, staging the story, style, and rhythm are how Dunham [38] sums them up. The ability to observe what is occurring on stage is referred to as selective visibility. Any lighting scheme will be unsuccessful if viewers are unable to see the characters,

Figure 14: Lighting Scene of Theatre Lighting Depicting Emotional Scene

unless it is particularly intended. It also distinguishes how forms appear on stage, particularly those of three-dimensional stage elements. When a performance is focused, one area of the stage receives the audience's attention while another is ignored. The mood establishes the scene's tone. Stage lighting has a big influence on the mood. In order to evoke the proper emotions from the audience, it is important to match the lighting to content of the show. In a play, this may imply a gentle, warm light for a joyous moment, or dim, chilly tones for a sombre song at a performance. Distinct emotions are associated with various colours. Different effects result from soft lavender light to harsh red light. For instance, the colour red is frequently associated with strong emotions like love or violence, but the colour blue is frequently associated with melancholy. Indicating a place and the time of day is another important purpose of lighting. It could specify the time and place of the on-stage action. Blue can indicate night time, whilst orange and red may indicate dawn or dusk. On stage scenery can be made or projected using lighting, mechanical filters (sometimes known as "Gobos") that project skyscapes, the moon, etc. Theatre projection is a Brechtian method that properly carries the form. Lighting may be used to "Paint a picture" and draw the audience's attention to certain areas of the stage that the set designer wants them to see. [39] [40]

Lighting design is an art, thus there is no one "Right" way to achieve it. According to a contemporary theory, the lighting design contributes to the aesthetic of piece while also helping to establish the scene's environment. Although the surroundings is important, "Mood" is in question.[40]

1.11 Emotion

As per the Collins English Dictionary, **"Emotion is a strong feeling that is derived from one's circumstances, mood, or relationships with others."** The Merriam-Webster Dictionary states emotions as **"A conscious mental reaction (such as anger or**

fear)subjectively experienced as a strong feeling, usually directed toward a specific object; and typically accompanied by physiological and behavioural changes in the body." Hockenbury and Hockenbury stated **" Emotion as a composite psychological state that engages subjective experience, a physiological response, and an expressive reaction"**.[41] Emotions are such thing that helps people to interact with one another. A significant factor in influencing how people behave is emotion. Understanding the emotional state of another human-human can improve their emotional communication at that moment. This is so that words, voice intonation, facial expressions, body language, and emotions may all be identified. Science fields including physiology, psychology, speech science, neurology, psychiatry, and communication have all researched emotions in some depth. There are several theories for emotions. One of these theories is the **Darwinian Theory** that says that " Emotions are evolved phenomena with important survival functions that have been selected for because they have solved certain problems we have faced as species". [42] According to the **Jamesian Theory**, " Bodily changes follow directly the perception of the exciting fact and our feeling of the same changes as they occur is the emotion ".[43] Another theory that defines emotion is the **Cognitive Theory**.[42] It states that," Every emotion has associated with it a particular pattern of appraisal is that if the appraisal is changed, the emotion should change as well ". As a result, different viewpoints suited for the complexity and diversity of emotions have arisen about the idea of emotions. It is crucial to consider how these various viewpoints work in concert with one another. Physiological arousal, expressive actions, and cognitive experience are the three main components of human emotion. There are hence three perspectives on emotions in that regard. According to this theory, emotions may be predicted and, depending on the emotion evoked, settle in certain brain parts. The three main kinds of an emotional responses are behavioural, automatic, and hormonal.[44]

- Psychological (what one is thinking)
- Physiological (what one's body is doing)
- Expressive (how one reacts) in nature.

Psychology views emotional expression as a response to stimuli that entail unprecedented physiological changes. Psychology defines emotion as a disruption of the homeo-static equilibrium. The characteristics of emotions can be conceptualised as a three-dimensional entity based on these changes.

- **Arousal**: measured as an intensity.
- **Affect**: valence of pressure, measured as the positive or negative feeling after emotion perception.
- **Power (control)**: measured as dominance or submissiveness in emotion expression.

As a result, it is possible to think of the psychology of emotions as a complicated experience of consciousness (psychology), bodily sensation (physiology), and behaviour (active speech). The attributes of activation, attachment, and power encompass the orientation dimensions of emotional experiences. Emotions combine subjective experience, expressive action, and neuro-chemical activity. It has been discovered that the neurological system is stimulated by the expression of high-arousal emotions like anger, pleasure, and fear in the physiology of emotion production mechanisms. This phenomenon results in increased cardiac output, increased blood pressure, altered breathing patterns, increased subglottal air pressure in the lungs, and dry mouth.[45] Positive and negative behaviours are common ways to convey emotions. Positive emotions like pleasure, enthusiasm and happiness are pleasant. They are viewed as constructive in a person, but negative emotions like sorrow, rage, and fear are unpleasant and could be perceived as harmful to a person.[46] Any emotion is based on one of the six fundamental emotions, according to P. Ekman.[47] Happiness, sadness, anger, disgust, fear, and surprise are regarded by most scholars as to the primary or basic emotions and are referred to as archetypal emotions.[48] The capacity to infer a person's emotional state from their facial expressions has been one of the most fiercely debated topics in study and conversation. Researchers have developed a variety of techniques for monitoring facial expressions that act as emotional encoders. One of the most often used tools among them is the Facial Action Coding System (FACS), which was developed by **Ekman & Friesen** in 1978 and extensively improved in 2002. FACS is a thorough technical manual that also includes a variety of facial expressions and motions. The movements of the muscles are referred to as action units (AU). The most recent version of FACS has 18 lower-face AUs, 9 upper-face AUs, 5 additional AUs, 14 head and eye positions and motions, 9 action descriptors, 9 gross behaviours, and 5 visibility codes. The six basic emotions (shown in figure 15) identified by **Ekman** may be distinguished by certain facial muscle movements that are characteristic of that emotion. The following is a short discussion of the facial expressions:

- **Happiness** is the emotion that expresses various degrees of positive feelings, ranging from satisfaction to extreme joy. A joyful face may be distinguished by narrowed eyes, elevated cheek and pushed back lip corners to form a smile.[49]

- **Sadness** is the emotion that expresses a state of loss or difficulty. Sadness causes individuals to be slow at processing information. A sad face often has the inner corners of the eyebrows slightly pushed upwards, sagging upper eye-lids & eyes staring down, and the lip corners pulled downwards.[50]

- **Anger** is the emotion expressing dislike or opposition toward a person or thing causing aversion. Anger is sometimes displayed through sudden and overt aggressive acts. The muscular movements that go towards forming an angry face include lowered eyebrows, wide-open eyes, and lips pulled together exceptionally firmly.[51]

- **Disgust** is the emotion that expresses a reaction to things considered dirty, revolting, contagious, contaminated, or inedible. Disgust is associated with a distinct facial expression and a drop in heart rate. The eyebrows are pushed downwards, the side and bridge of the nose are wrinkled, the upper lips bend to create a shape of an inverted U, and the lower lip is somewhat pulled upwards; that is the disgusted face.[52]

- **Fear** is the emotional reaction to an actual and specific source of danger. Fear is often confused with anxiety, which is an emotion that is often exaggerated and experienced

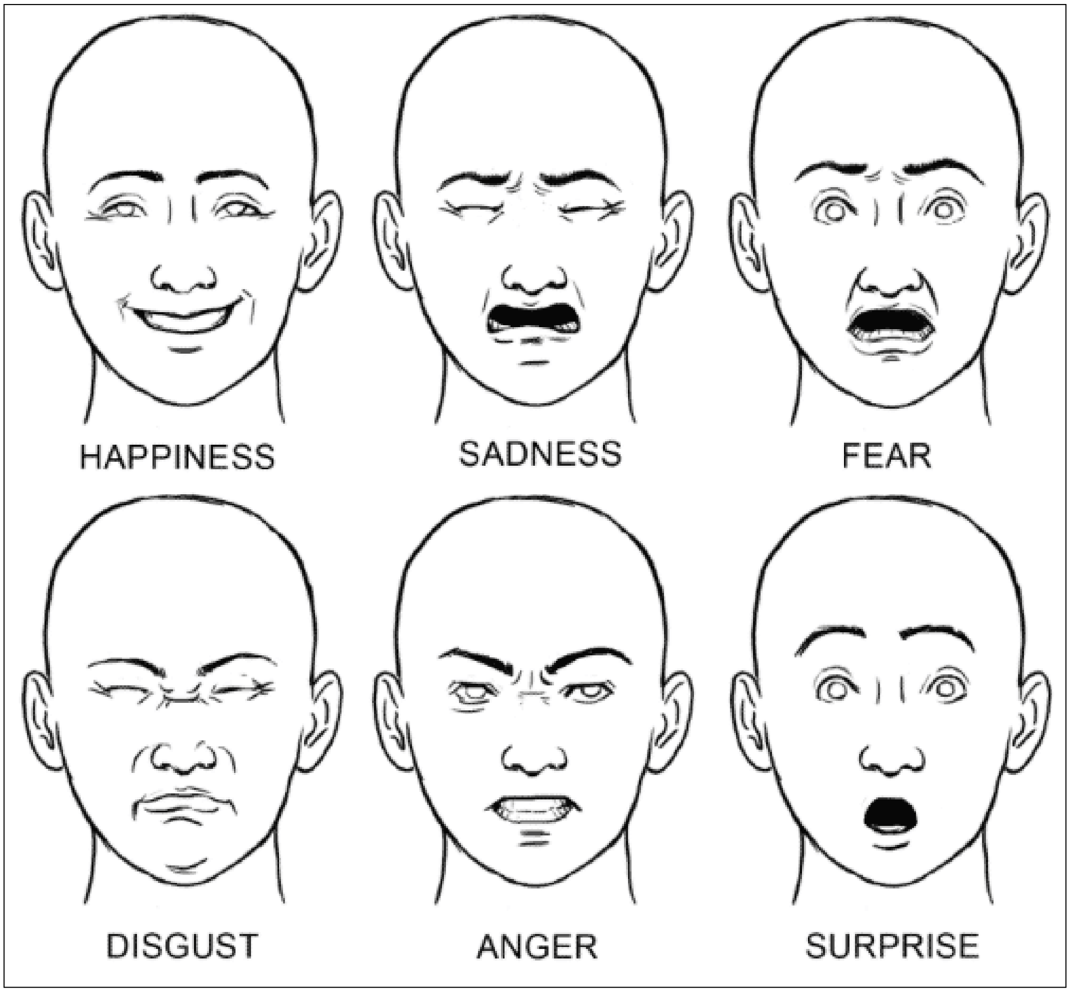


Figure 15: Figure of Basic Emotions

even when the source of danger is not present or tangible. A scared face has its eyebrows and upper eyelids elevated upwards, the lower eyelid is extended, the mouth is a tiny bit opened, and the lips are spread horizontally.[53]

- **Surprise** is the emotion that arises when an individual comes across an unanticipated situation. A surprise emotion can be a positive, neutral, or negative experience. A surprised face has its eyebrows pulled upwards but not drawn together, raised upper eye-lids & neutral lower eyelids and jaw is lowered downwards.[54]

  A human being can understand the emotional state of another human being and behave in the best manner to improve the communication in a certain situation. This is because emotions can be recognised through various modalities such as words, voice intonation, facial expression, body language, and brain signals.[55]

1.12 Brain Physiology

The brain is one of the human body's largest and most complicated parts. The brain integrates sensory information and directs motor responses; in higher vertebrates, it is also the centre of learning. The human brain weighs about 1.4 kg (3 pounds) and is composed of billions of neurons. Synapses, or junctions between neurons, allow electrical and chemical messages to be transmitted from one neuron to the next in the brain, a process that underpins essential sensory functions and is critical to learning, memory, thought formation, and other cognitive activities. The brain serves as the body's primary control centre. Numerous scientific researches have revealed that certain brain areas are engaged in emotional thinking, emotional response to strong emotional stimuli, and emotional perception of circumstances. Almost all life-sustaining processes and all emotional states begin inside the brain. In addition, the brain receives and processes a wide variety of information from the body and the surroundings.[56][57]

1.12.1 Major Part of Brain

The brain has many regions or parts categorised by functions. Figure 16 indicates major parts of the brain. The brain stem and mid-brain make up the brain's central core. This central core is covered by the cerebral cortex. The core nucleus is more primitive and older, and it mostly engages in unconscious activities. While the older portions of the brain remain relatively stable, the cerebral cortex is highly developed and capable of thought and activities.

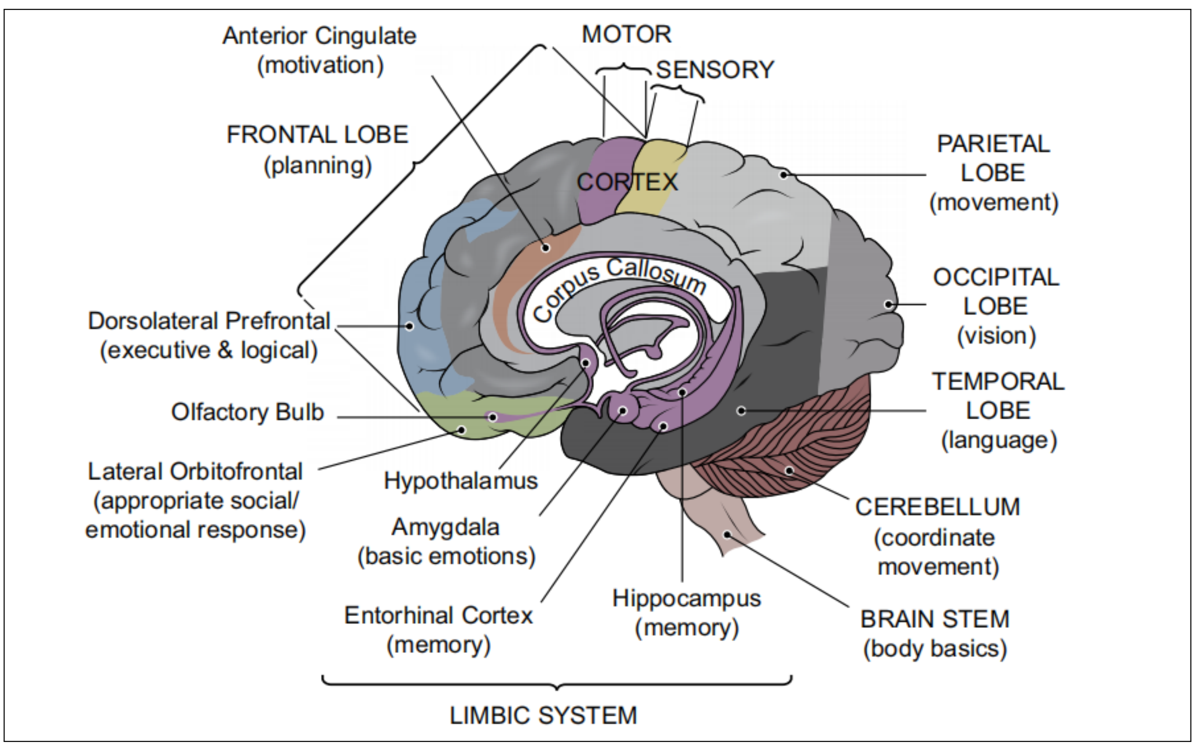


Figure 16: Major Part of The Brain

1.12.1.1 Brain Stem

The stem separates the spinal cord and the remainder of the brain. It is comprises cerebellum, which synchronises sensory input with muscular activity, and the medulla, which regulates respiration, heart rate, and digestion. The activities of the brain stem control respiration, blood pressure, and other reflexes. The mid-brain, pons, and medulla oblongata are three more divisions of the brain stem.

1.12.1.2 Cerebrum Cortex

It is the outermost layer of the brain. The beginning of thinking and deliberate actions begins here. The cerebral cortex has developed into two symmetrical hemispheres in humans.

1.12.1.3 Mid-Brain

The mid-brain contains components that, through neuronal connections to the cortex's lobes, are directly involved in forming long-term memory and human emotion. The structures also connect the lower brain stem and thalamus, allowing sending information from the senses to the brain and then returning and limbic system.

1.12.1.4 Cerebellum

The cerebellum is situated under the cerebrum at the back of the brain. It aids in human development and equalisation. The cerebellum, for instance, facilitates tasks like walking or playing the piano. It enhances speech regulation and involves a significant percentage of the brain's abilities in ways that are not fully understood. It is separated into right and left hemispheres.

1.12.1.5 Cerebrum

The term "Mind" is frequently referred to as the "Cerebrum". It occupies the bulk of the top skull and is the largest component of the brain. The cerebrum uses information from the human five faculties to help human grasp what is happening around them. It then instructs our body on how to respond. It also regulates human capacity for speaking, thinking, reading, and learning as well as emotions. The equator's left side has a crucial role in speech, verbal memory, reading, writing, and computation. It has control over the body's right side's muscles. The interpretation of what Humans see and touch as well as non verbal memory, music and emotions all are major influenced by the right half of the hemisphere. It is divided into four lobes, these are Frontal lobe, Parietal lobe, Occipital lobe and Temporal lobe.

1.12.2 Division of Brain

The brain is split into two equal and symmetrical halves known as left and right hemispheres. These two sides only symmetrically identical but both sides have different functions. The corpus callosum connects the both hemispheres, which have different functions for the body.

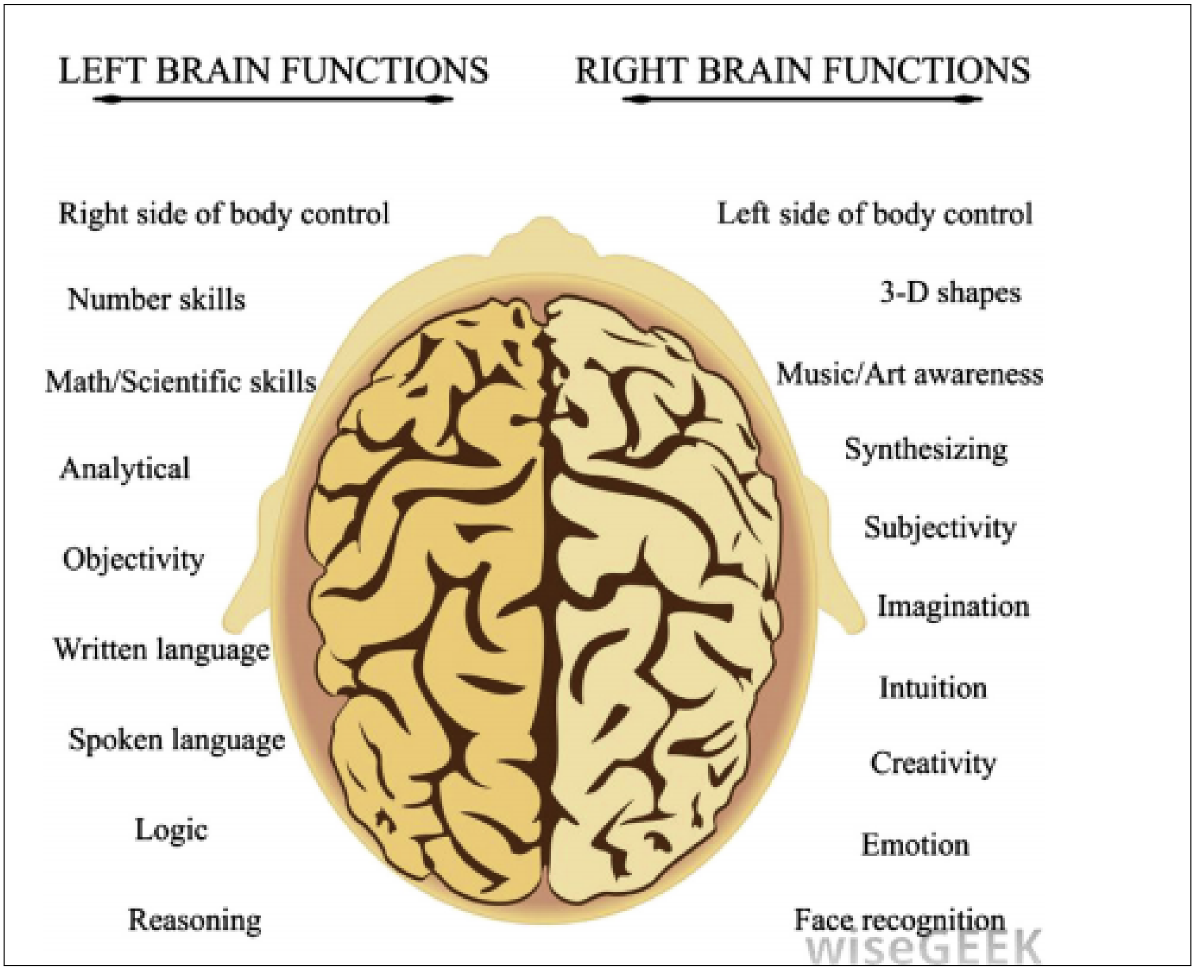


Figure 17: Functions of Left and Right Hemispheres of The Brain.

1. **Functions of the left brain.**

a. The left side of the brain is responsible for controlling the right side of the body.
b. It also performs logical tasks such as those found in science and mathematics.
c. The left hemisphere is dominant in language.
d. The left hemisphere is important for preprocessing social emotions.

2. **Functions of the right brain**.

a. The right hemisphere is responsible for controlling the left side of the body.
b. It is responsible for creative awareness.
c. The right hemisphere is dominant in emotional expression.
d. It is also dominant in the perception of facial expression, body posture, and prosody.

1.12.3 Other Important Parts of Brain

The limbic system, pituitary gland, basal ganglia, and thalamus are some further essential parts of the brain. On top of the mid-brain lies a structure known as the thalamus. The thalamus serves as the intermediary for all communications with the cerebrum. It contributes to experiencing agony.

1.12.3.1 Hypothalamus

The hypothalamus is located below the thalamus. It regulates body temperature, emotions, pulse, craving, and sleepiness. To the pituitary gland, it releases compound signals that are necessary hormones.

1.12.3.2 Pituitary Gland

The hypothalamus is linked by the pituitary gland. It receives communication from the hypothalamus. Additionally, it releases vital hormones, which act as chemical signals throughout the body.

1.12.3.3 Basal Ganglia

A cluster of structures in the middle of the brain called the basal ganglia control communication between various brain regions.

1.12.3.4 Limbic System

The limbic system comprises the hypothalamus, amygdala, and hippocampus, is located beneath the cerebrum (the largest and newest part of the brain).

- The hypothalamus is responsible for driving actions.
- The almond-shaped amygdala is connected to aggressive behaviour, emotional importance to events and memories.
- The hippocampus plays a crucial role in processing various types of information to form long-term memories.

The reticular activating system (RAS) is a crucial component of the limbic and cerebrum systems. This region is what keeps human alert and conscious of our surroundings. As a master switch, the RAS notifies the brain of incoming information and the urgency of the message.

1.12.4 Lobe of The Brain and Their Functions:

The brain is a most complex part of the human body. The brain has two sides, i.e. left side and the right side. Each side of the brain contains four lobes. These are Frontal, Occipital, Temporal and parietal, as shows in figure 18. The four lobes have different locations and functions that support the responses and actions of the human body.[58]

1.12.4.1 Frontal Lobe

Human personality and ability to make decisions are formed by the frontal lobe, which is the emotional control centre of the brain. It is placed at the front of the central sulcus, where it receives information signals from other lobes of the brain. In addition to regulating thinking, planning, organising, short-term memory, and movement, the frontal lobe is also in charge of problem-solving, judgement, and motor function. Regulating social conduct is the main focus of most of its activities. The main functions of the frontal lobe are:

- cognition, problem solving, and reasoning
- motor skill development
- parts of speech
- impulse control
- spontaneity
- regulating emotions
- regulating sexual urges
- planning.

1.12.4.2 Occipital Lobe

The occipital lobe, which is positioned behind the parietal and temporal lobes at the posterior of the brain, is mainly in charge of processing visual stimuli and information. It interprets visual information from human eyes and connects it to memories of visual information. The cerebral cortex's posterior area lies close to the back of the skull, and the occipital lobe, the smallest of the four lobes, resides there. It is the brain's main processing area for visual information; other functions are

- visual-spatial processing.
- movement and color recognition.

Visual problems include a challenge recognising objects, a challenge identifying colours, and a challenge recognising words that might result from damage to this lobe.

1.12.4.3 Temporal Lobe

The temporal lobe on each side of the brain, near to the ears, is positioned at the base of the brain beneath the lateral fissure. The main auditory cortex, which is essential for deciphering sounds and language, is located in this lobe. Human perceptions of smell, taste, and sound are processed by the temporal lobes, which also play a role in memory and hearing. The primary function of the temporal lobes is to process auditory sounds. Other functions include

- help in formation of long-term memories and processing new information.
- formation of visual and verbal memories.
- interpretation of smells and sounds.

The temporal lobe of the brain is also linked to the hippocampus, which explains why memory formation plays a significant role in this area of the brain. Memory, speech perception, and language issues can result from temporal lobe damage.

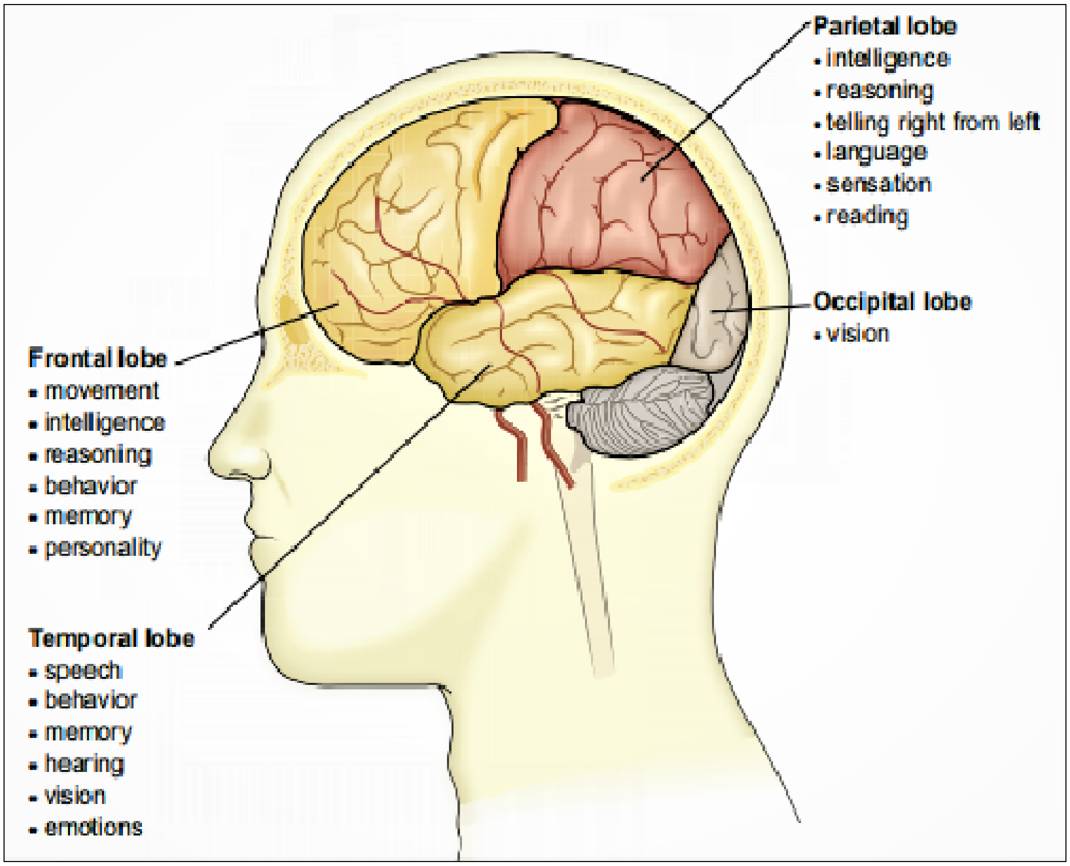


Figure 18: Different Part of Lobes and Their Functions

1.12.4.4 Parietal Lobe

For cognitive purposes, the parietal lobe analyses sensory data and aids in the coordination of spatial relationships. It is located above the occipital lobe in the middle region of the brain, behind the central sulcus. Sensation, handwriting, and body position are all controlled by the parietal lobe. It is in charge of processing sensory data from many sections of the body and interpreting sensory data such as temperature and touch. Some of the functions are

- sensing pain, pressure, and touch.
- regulating and processing five senses of the human body.
- movement and visual orientation.
- speech.
- visual perception and recognition.
- cognition and information processing.

1.13 How The Brain Processes Emotions

Mainly, emotions are complex entities. According to psychologists, humans only have six fundamental emotions: happiness, anger, sadness, fear, surprise, and disgust. The six core emotions serve as the foundation for all of the other emotions. For instance, pleasure may be a form of happiness, but jealousy comes from a combination of anger and sadness. It has been discovered that each of the six primary emotional states is connected to a distinct area of the brain, specifically the limbic system. Emotions are genuine experiences linked to the activation of certain brain areas.[59][60]

Studies using functional MRI and positron emission tomography (PET) scans have demonstrated that some emotions are more likely than others to be linked to particular limbic system activity locations.

1. **Happiness** activates several areas of the brain, including the right frontal cortex, the precuneus, the left amygdala, and the left insula. This activity involves connections between awareness (frontal cortex and insula) and the "feeling center" (amygdala) of the brain.

2. **Fear** activates the bilateral amygdala, the hypothalamus and areas of the left frontal cortex. This involves some thinking (frontal cortex), a "gut" feeling (amygdala), and a sense of urgency typically associated with survival (the hypothalamus).

3. **Sadness** is associated with increased activity of the right occipital lobe, the left insula, the left thalamus, the amygdala and the hippocampus. The hippocampus is strongly linked with memory, and it makes sense that awareness of certain memories is associated with feeling sad.

4. **Disgust** is an interesting feeling that is often associated with avoidance. This emotion that is associated with activation and connections between the left amygdala, the left inferior frontal cortex, and the insular cortex.

5. **Anger** is an important emotion that many people, adults and children alike, try to control. Anger is associated with activation of the right hippocampus, the amygdala, both sides of the prefrontal cortex and the insular cortex.

6. **Surprise** is an emotion that can either make someone feels good or it can make someone feels bad. Surprise activates the bilateral inferior frontal gyrus and the bilateral hippocampus. The hippocampus is strongly associated with memory, and the element of surprise is, by nature, associated with experiencing something that someone does not remember or does not expect.[61]

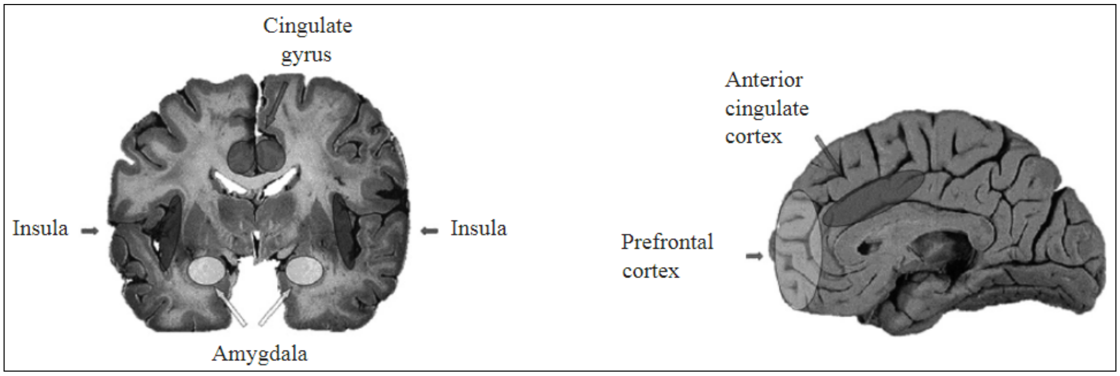


Figure 19: Part of The Brain Responsible For Emotions

1.14 Emotional Response to Light Spectrum

One of the major key elements in generating overall mood or emotion is colour. This is mostly due to how well it will be at influencing viewers' moods and potential psychological reactions. Intensity is primary concern of lighting then colour comes to point to creates and regulates once mood and emotion. The light can be characterising by its sense of warmth. Red, orange and yellow light spectrum are called Warmth light wave. On the other hand, blue, violet and green light spectrum are called Cool light wave. Most people link warm colours to high levels of energy, stress, and excitement, whereas cool colours tend to elicit a lot of calm and serene reactions. A person's emotional responses quite consistently by looking at colour associations and mood. As an example, the colour red creates arousal and draws human mind. It also elicits rather strong reactions and may be related to feelings of enthusiasm, conflict, and anger. Yellow occupies the region of the spectrum to which humans are most sensitive and is generally seen as white light. Green tends to have a negative reaction on skin tones and is linked to unnatural emotions. Additionally, it frequently offers an answer that is generally impartial. Blue is associated with calmness, various soothing emotions, and creating the appearance of remoteness (particularly in tints or medium saturations). Last but not least, Violet frequently gives sad or depressing comments. Less intensely saturated colours tend to evoke strong good feelings in human. More positive connections are made with pink than red. Golden hues are frequently connected to natural light sources that support everyday lives, such as the sun, candle flames, and table lamps. A lightweight with a strong orange or red colour, in comparison, is unnatural and may struggle with a broader metaphorical interpretation often in an extremely negative context, such as the suggestion of hell or rage. A medium blue colour might be related to romantic moonlight, whereas a deep blue would possibly facilitate the mystery of a scene. Warm colours tend to draw human attention, whereas cool colours tend to be submissive and draw many neutral responses.[38]

Below describe some points of how the colours may change once mood or emotional state.

WHITE: It is a combination of all other colours and is frequently used to enhance or enrich the colours of any thing that it is illuminating. What is more, often imagine white light to be a faint tinge of the other hues. As a result, it is commonly linked to pleasant feelings and reduces how strongly people feel when they are exposed to the colours that the tints are linked to.

RED: It may arouse positive sensations of desire, wickedness, or violence in addition to the negative emotions of warmth, passion, energy, and excitement. It frequently provides the impression that things are getting closer and might grab people attention. Additionally, it has been demonstrated to increase human heart and breathing rates.

YELLOW: It is frequently linked to happy emotions and a general sense of optimism, and is considered to elicit some of the greatest psychological reactions. Additionally, it has been shown to improve self-esteem and may be utilised to convey assurance and optimism. But too much of it can have adverse consequences and reactions like visual tiredness and irrational emotional outbursts of impatience and anger.

GREEN: It is in the middle of the colour spectrum and is frequently linked to equilibrium and harmony. It may result in a calm, cosy, and pleasant condition. It can also be connected to unpleasant emotions like boredom and stagnation.

BLUE: This colour is linked to serenity and inspires feelings of tranquilly or peace. It may imply a more contemplative mindset and ease stress. Since it has a relaxing effect, it is frequently employed to imply darkness on stages where visibility is still necessary. Additionally, blue-coloured things have a propensity to look farther away than they actually are.

VIOLET: It elicits calm, calming emotional reactions. Although it may have a relaxing effect, it may also connote a mood that is more enigmatic or ominous. It frequently relates to spirituality as well as the court or royalty.

CHAPTER-2

2 LITERATURE REVIEWS

Prior to beginning the experimental research, pertinent research papers, articles, journals, and books were analysed for about a month. Three sorts of papers have primarily been read out. One of them is how light affects this field and the results of the articles in both visible and non-visual ways. The second category focuses on the impact of colour on human emotion elicitation and colour perception in this area. The third one is an EEG-based research article, how to use an EEG machine, how to perform an analysis, etc.

There had been about fifty articles that are comparable. However, this section only lists a few significant research papers.

One of the experiments in this domain conducted by Suddhasatwa Chakraborty was "A laboratory-based study on influence of peripheral source on On-axis object detection under different correlated color temperatures".[62] A buzzer switch and a shutter glass were distributed among 20 participants. Objects were positioned beneath the main source of light. After the items were correctly positioned at a distance of 4 meters from the subjects, the active shutter glass turned transparent for 0.7 seconds, and the subjects were instructed to hit the buzzer switch as soon as the object was observed. The reaction time was then assessed in two sessions at four distinct CCTs (2500 K, 4000 K, 5000 K, and 6000 K). The peripheral source was switched off during the first session, but it was switched on during the second. As a result of participants quickly to respond when objects were displayed when the CCT was set at 5000 K but when the glare incorporated participants taking much longer time in 6000 K.

Suddhasatwa Chakraborty[63] conducted a laboratory-based EEG research to compare the effects of High-Pressure Sodium Vapour (HPS) and Metal Halide (MH) lamps on object recognition in the context of road lighting. Eleven individuals were chosen for the study, and while wearing a portable EEG device, they had to complete the match/mismatch-to-sample task under both illumination conditions one at a time. On a computer screen, they were presented picture stimuli, and the EEG signals from their response were recorded. Once the artefacts had been rejected, the recorded signals were examined. Participants answered more quickly under Metal Halide (MH) lamps than under High-Pressure Sodium Vapour (HPS) lamps, according to the results, demonstrating how the spectral composition of a light source affects overall job performance.

According to Cuykendall[64], colour psychology, particularly the impact of colour on emotional reactions, is impacted by cultural context, individual experiences, and evolution. People who live in that location may have emotional reactions as a result of how colours are perceived since regional and cultural interpretations of colour can vary greatly. For instance, the colour red is linked to Indian weddings, and the colour saffron conjures images of Indian monks. Similar to this, the emotional reaction to any colour is affected by an emotional connection to that colour due to particular personal experiences. Additionally, all the things and occasions necessary for survival have a connection to their distinctive colours in evolutionary terms. To make it simple to differentiate between kerosene and drinking water, commercially available kerosene has been artificially coloured blue.

By using a set of mathematical equations, *Valdez and Mehrabian* conducted one of the early studies on the relationship between colour and emotion in 1994 [65]. To examine the emotional reaction caused by colour brightness and saturation with continuous hue, colour with constant brightness and saturation, and achromatic colours, they developed three research. The Munsell Colour System and Colour Chips were utilised to precisely represent the colour samples, and the Pleasure-Arousal-Dominance (PAD) emotion model was employed to gauge how people feel when they see various hues. According to research 1's findings, Pleasure, Arousal, and Dominance are greatly influenced by the Brightness and Saturation of Colour. It was also shown that women choose their emotional reactions more carefully than males did. According to Study 2, the impact of colour wavelengths on arousal and dominance was minimal. Even so, short-wavelength colours are what make one happy, whereas long-wavelength colours — with the exception of red — are the least pleasurable.

Li-Chen Ou [66] study looked at how colours affected persons with diverse gender identities and cultural backgrounds' emotional reactions. The participants (14 British + 17 Chinese) were instructed to evaluate 20 test colours (chosen from NCS Colour Atlas) based on 10 colour emotion measures, including 'warm-cool', 'heavy-light', 'modern-classical', 'clean-dirty', 'active-passive', 'hard-soft', 'tense-relaxed', 'fresh-stale', 'masculine-feminine', and 'like-dislike'. The findings indicated that when evaluating the colours that corresponded to the colour emotional scales, women were more accurate. However, there was no discernible gender difference in the emotional reactions to colour. The answers of British and Chinese observers varied on the "Like-dislike" and "Tensed-relaxed" scales. Based on the 10 colour emotional scales that were employed in the experiment, a three-dimensional colour emotion space was developed. Three colour-emotional elements were found to be connected with the colour emotional scales: colour weight, colour heat, and colour activity. The new colour emotion model and existing models' comparisons revealed that four colour emotions —'warm-cool', 'heavy-light', 'active-passive', and 'hard-soft' — were not influenced by cultural differences.

To better understand children's emotional impressions of colours, *Debbie J. Pope* [67] utilised color-emotion connections to youngsters between the ages of 7-8. This experiment involved 40 kids from a school in the north of the United Kingdom (15 boys and 25 girls). Students were initially asked to describe a circumstance in which they and another person experienced one of the 10 basic feelings (happy, sad, mad, scared, love, proud, guilty, jealous, nervous/anxious, and lonely). Only six of the ten emotions — happy, sad, love, proud, jealous, and nervous — were given more consideration. Next, the students were given a five-point Linkert scale to use to rate ten different colours (red, orange, yellow, green, blue, purple, pink, white, brown, and black), with the options being "Very happy" to "Very unhappy". Each child was then handed a response booklet and ten pens with the aforementioned ink colours. The children were then asked to pick a colour to represent each of the six emotions described in three short stories that were read to them. The Expressive One-Word Picture Vocabulary Test (EOWPVT), which presents the students with a sequence of progressively more challenging images, asks them to identify the activity shown. In line with earlier studies, it was discovered that girls were able to provide considerably more definite, correct, and high-quality replies than boys. Students performed better on assessments of simple emotions (happy, sad, and love) than complicated emotions (proud, jealous, and nervous). Pink and purple were found to have the greatest gender disparity. Boys classified it as an unpleasant colour, whereas girls designated pink and purple as joyful colours. The findings also demonstrated that children were better able to link colours to positive feelings than negative ones.

Researchers have discovered that using one's imagination may also cause emotional reactions akin to those experienced while viewing a cinema, dreaming or feeling real stimuli. In 2012 *Anishka. A. Hettiarachchi*[68] saw research into colour associations with fictitious stimuli. The experiment involved 86 undergraduate students (52 females and 34 males). Five questionnaires were given to them. Each question was thoughtfully constructed to lead the participants to an emotional reaction. Each question contained three alternatives from which students had to select one. The choices mostly consisted of colour names. According to earlier studies, one of the choices matched the colour that was most strongly associated with that feeling. The final choice was a neutral colour, while another was the colour that evoked the opposite emotion. The findings indicated that red is both more enticing (79%) and stimulating (45%) than other colours, while blue had a soothing impact on participants (49%) and high-frequency colours (red 37% and yellow 39%) made participants happier than other colours.

Electroencephalography (EEG) data has been collected during the past several years as researchers attempt to understand the relationship between emotional responses and brain activity. When compared to other emotion-related modalities like facial expressions, self-assessment tools, etc. the information retrieved from the EEG data is then considered. Then, using various machine learning methods, this data is kept as a training dataset so that it may be used to predict other people's emotional states by comparing their EEG data to the training dataset. Juan Cheng utilised the deep forest algorithm to recognise emotions in a research. While their EEG data was being captured, participants were presented images from two publicly accessible image databases (DEAP and DREAMER). After preprocessing the data, important characteristics were retrieved, and then they were later categorised using the deep forest method. Valence and arousal accuracy for the DEAP database were 97.69% and 97.53%, respectively, but the findings for the DREAMER database were 89.03%, 90.41%, and 89.89% accuracy for valence, arousal, and dominance, respectively. There are several feature extraction and categorization tools available at the moment. Filipe Galvão [69] put out a valence and arousal prediction model that made use of a KNN regressor ($K = 1$) model with Manhattan distance. Participants were asked to express their feelings using the DEAP and DREAMER databases. The results shown that their model was capable of accurately predicting valence and arousal with low error (mean absolute error < 0.06 and root mean square error < 0.16) and strong correlation (Pearson correlation coefficient > 0.8) between anticipated and predicted values.

CHAPTER-3

3 EXPERIMENTATION

3.1 Background of The Experiment

Theatrical performance relates to performers' expression, body language, and emotional involvement in a scripted act. Without knowing the script, the audience can understand the act and get entertained and feel the emotion of the act. Usually, the stage or theatre lighting is done for the aesthetic and betterment of the audience so that the audience can watch every moment of the performer's expression. Also, according to the change of the scene layers, the lighting scenario changes, the audience does understand the scene has changed. Sometimes light colour changes as per the emotional scene to understand the immense of the scene. Theatre stage lighting is intended to make the stage performance visible to the audience, but the technique utilised to light the stage will have an affect on how the stage picture is perceived, and it should enhance the production's overall dramatic impact. A lighting effect is a means for the director to direct audience's attention to a certain area of the performance where they want audience to see or focus on something. The light on stage during a performance may make characters, props, or even forms visible. Light plays a crucial role in the play and also helps to convey the emotion. The emotion and ambiance of the theatre greatly influence how an audience will react to the performance, and lighting has a significant impact on these factors.[70] Whatever lighting modifications should only be changed with the audience's better visualisation. All of this done from views' point of view. Nobody has concerned about the performer. How they are affected by light. what impact perceived light has on them while they are expressing emotion.

According to section 2 colour may affect anyone's emotional state. Following the discovery of ipRGC cells, understood that light has also a non-visual effect that controls people's motivation, mood, and performance. Some literature has been cited in the 2 section to demonstrate how the non-visual impact influences performance. Emotion is strongly influenced by both the visual and non-visual impacts of light.

Here was a study gap : Up until now, no research work has been done to examine how the spectrum of light affects artists psychologically when they are exhibiting emotion.

It is a fact, nevertheless, that the effect of light on a performer's performance is as significant. Theatre artists must experience a range of emotions throughout a performance, thus it's likely that the correct spectrum of light provides psychological comfort to them and enables them to communicate emotions more successfully. The best light spectrum for eliciting emotion during a theatrical performance was studied in an experiment to test this hypothesis.

3.2 Experimental Objective

The primary goal of this study is to determine how much the four colour spectra may influence "Sadness" emotion. Ten people with theatrical experience were therefore chosen to perform a written scene that mostly portrayed the sensation of sadness. The screenplay was adapted from a symbolic drama, "Raktakarabi" written by Rabindranath Tagore. The ten subjects acted the script under four different colour spectra i.e. 'Red', 'Yellow', 'Green' and 'Blue'. Four wifi enabled colour tunable Led bulbs, mounted at four positions such that participants could perceive the colour, were used to get the monochromatic colours(Red, blue, yellow and green). Additionally, each participant had an EEG with 32 channels placed on their scalp to capture their brain activity while performing. To get participants' behavioural information on how they felt while performing the script under four different monochromatic lighting, self-assessment manikin data was collected. Later, it was identified which colour spectrum had more impact to convey the emotion "Sadness" by analysing the SAM and EEG data.

3.3 Design

3.3.1 Participants

There were ten professional theatrical performers selected for this experiment. All the participants with four years of experience in theatrical performance were chosen for this study as they perceive emotion better when compared with beginners. In this experiment, 10 participants were chosen, six male and four female. All the performers' mean age was 23 years, and the standard deviation was 2 years. Before selecting the performers, they were tested and passed the medical fitness (physically and mentally)and colour vision. The Participants were not allowed to smoke or drink during the experiment period. All participants also read and signed an informed consent before participating.

3.3.2 Script Selection

The script was decided based on two criteria :

1. Its completion should not take more than two minutes.
2. A general sense of sadness needs to permeate the entire scene.

A scene from "Raktakarabi", one of Rabindranath Tagore's symbolic dramas, was chosen as the screenplay keeping these requirements in mind. The scene portrays about a depressing conflict between a servant couple who were the victims of Yuksha Town's founding. Also the Lead character expressed grief to her lover in another scene. The script, mentioning below was extracted from the English translation, "Red Oleanders".[71]

3.3.2.1 Script for Male Performer for Expressing Sadness Emotion

Phagulal	:	My bottle, Chandra? Out with it!
Chandra	:	What! Drink from early morning?

Phagulal	:	Isn't it our holiday? Yesterday was the fast day of the War Goddess. To-day they worship the Flag.
Chandra	:	Must you drink just because it's a holiday? In our village home, on feast days, you never-
Phagulal	:	Freedom itself was enough for the holidays in our village. The caged bird spends its holiday knocking against the bars. In Yaksha Town holidays are more of a nuisance than work.
Chandra	:	Let's go back home, then.
Phagulal	:	The road to our home is closed for over.
Chandra	:	How's that?
Phagulal	:	Our homes don't yield them any profit.
Chandra	:	But are we closely fitted to their profits only,-like husks to grains of corn, with nothing of us left over?
Phagulal	:	Our mad Bishu says: to remain whole is useful only for the lamb itself; those who eat it prefer to leave out its horns and hooves, and even object to its bleating when butchered. There's the madcap, singing as he goes.
Chandra	:	It's only the last few days that his songs have burst forth.
Phagulal	:	That's true.

3.3.2.2 Script for Female Performer for Expressing Sadness Emotion

Nandini to Ranjan	:	My love, my brave one, here do I place this blue-throat's feather in your crest. Your victory has begun from to-day, and I am its bearer. Ah, here is that tassel of my flowers in his hand. Then Kishor must have met him But where is he? King, where is that boy?

3.3.3 Experimental Site

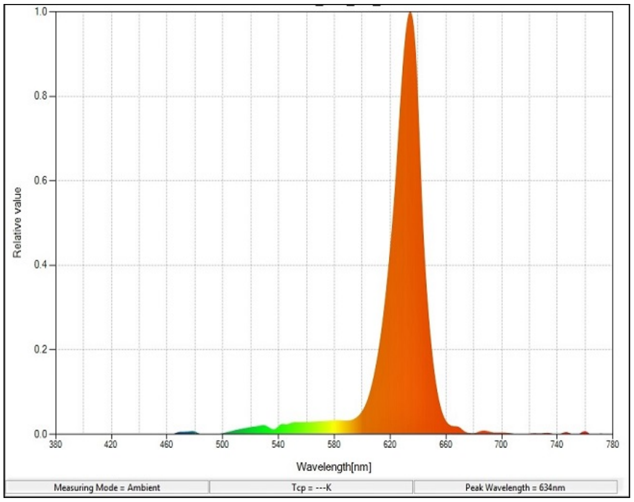
The experiment was carried out in a Darkroom (shown in figure 20) that was set up on the fifth floor of the Jadavpur University Electrical Engineering Department. The darkroom has measurements of $5m \times 5m \times 2.5m$. A black cloth covered the whole space (floor, ceiling, and walls) to block out daylight and other light sources from the outside that may interfere the experiment. The darkroom has an extremely low effective reflectance of 2.75%.

Figure 20: Figure of The Darkroom

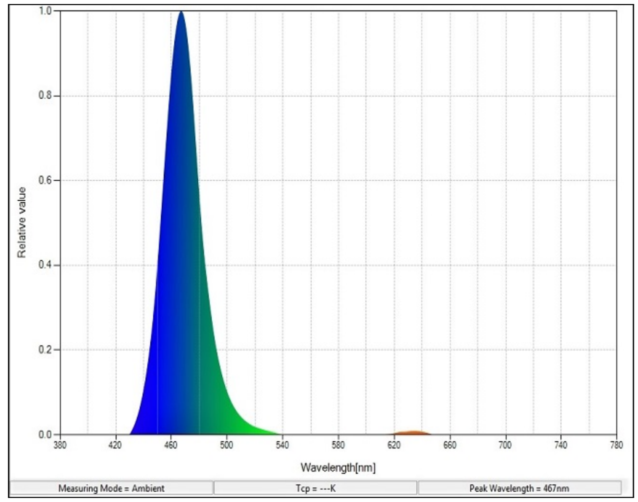
3.3.4 Lighting

Prime objective of this experiment was the use of color-tunable light bulbs that could transition between hues. In this experiment, four 9-watt Wi-Fi enabled color-tunable LED smart lamps were deployed. These bulbs are dimmable and can produce 16 million different colours, including white colour, at various CCTs, range from 2500 K to 6500 K. A smart phone application is employed to control the lights. A colour palette in this application makes it easier to get variation of colours. Four monochromatic colours were selected from the colour palette of mobile application.

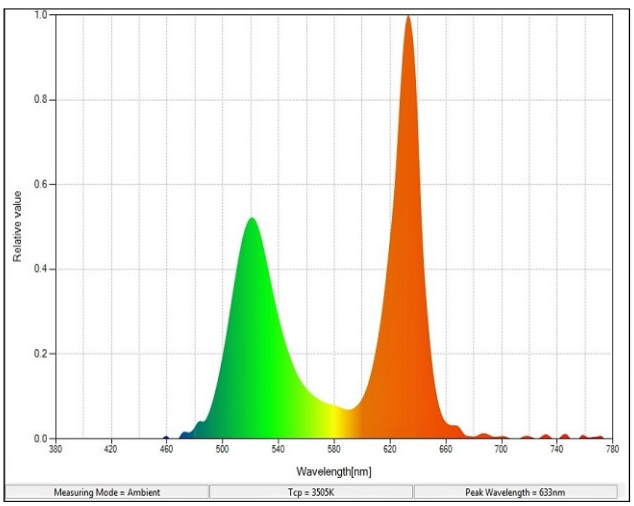
The selected four distinct monochromatic colours were 'Red', 'Yellow', 'Green', and 'Blue'. These four colour spectra were one of the main elements of this study. In this experiment, four monochromatic hues (Red, Yellow, Green, and Blue) were utilised to see how the performers responded to the emotion of "Sadness". The spectral composition of each light source was evaluated using a spectrometer beforehand of each session to ensure that there is no spectral discrepancy for any colour. Figure 21a, fig. 21b, fig. 21c and fig. 21d show the relative Spectral Power Distribution of light sources when selecting red, blue, yellow, and green light, respectively, from the colour palette.



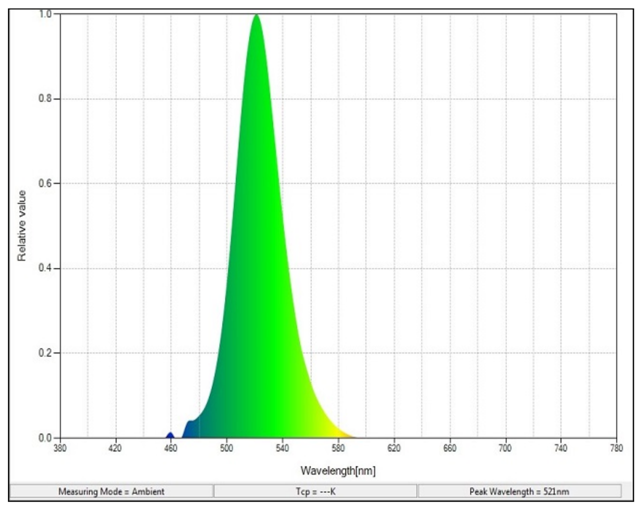
(a) Spectral Power Distribution of Red Light Spectrum Used for This Experiment



(b) Spectral Power Distribution of Blue Light Spectrum Used for This Experiment



(c) Spectral Power Distribution of Yellow Light Spectrum Used for This Experiment



(d) Spectral Power Distribution of Green Light Spectrum Used for This Experiment

Figure 21: Spectral Power Distribution of Four Lighting Conditions

The bulbs had to be placed exactly where it needed to be in order to recreate the lighting arrangement used for on-stage lighting or theatre lighting. The four lights were mounted on adjustable holders at four different places. The adjustable lights moved in accordance with the participant's height. Also, it shifted position with the movement of the subject. A baffle made of black art paper was placed around all four of these light bulbs to restrict the spread of the light beam.

To eliminate the shadow effects created by the participants in the background, the first light, a shower light, was mounted above the performer's head in the centre of the space.

The second light, known as the foot light, was placed at 45° on the floor to provide light from the bottom. The other two lights, known as follow lights, were mounted in the two side corners of the room.

The two-dimensional view of the lighting layout designed for this study is depicted in Figure 22.

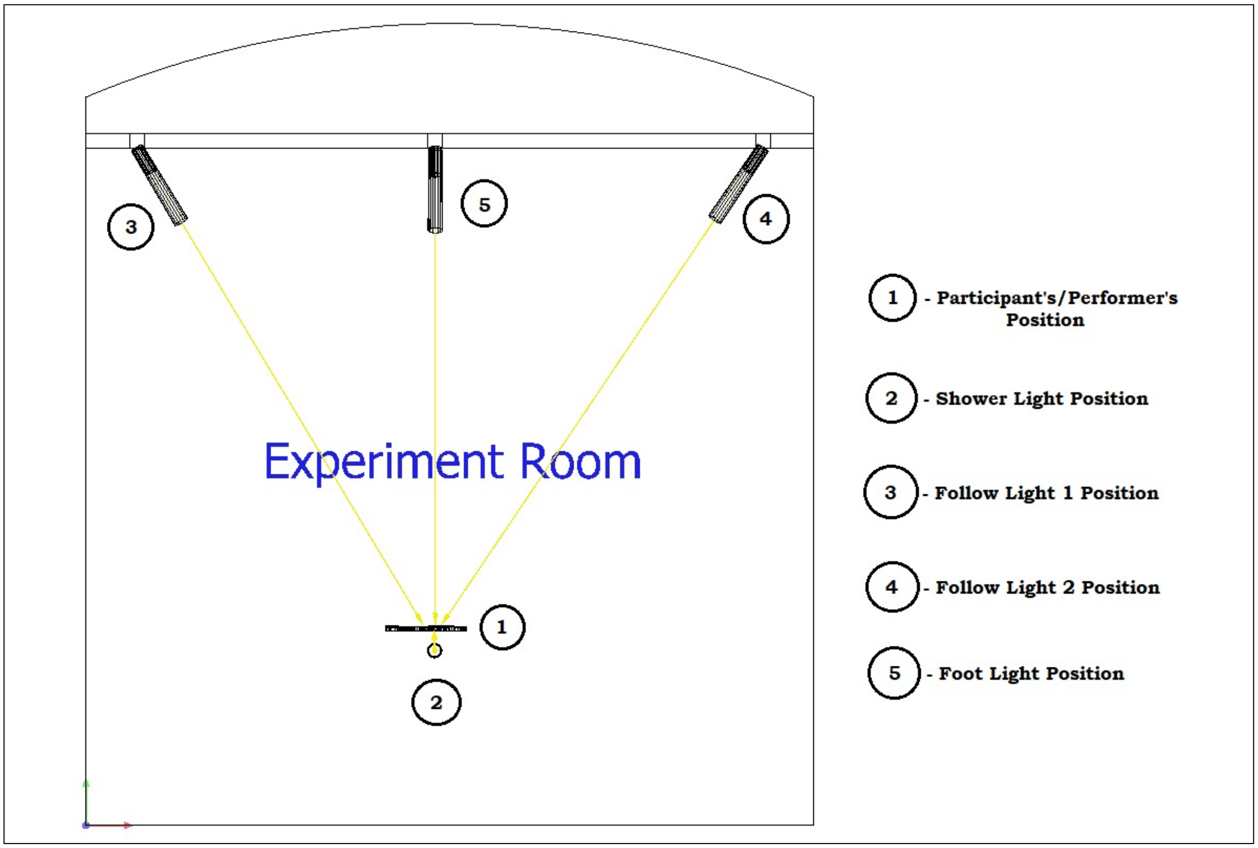
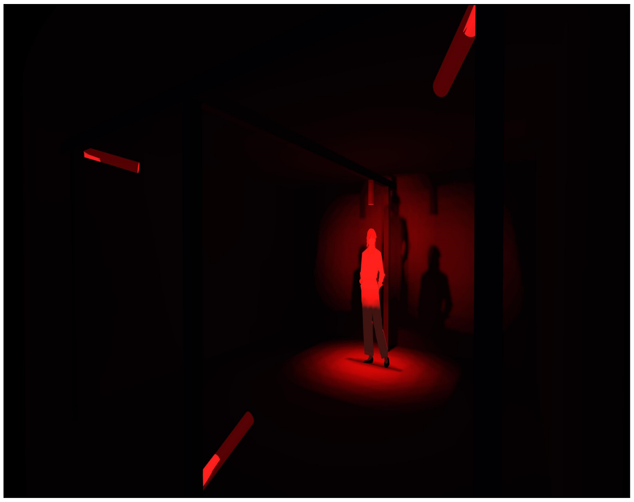
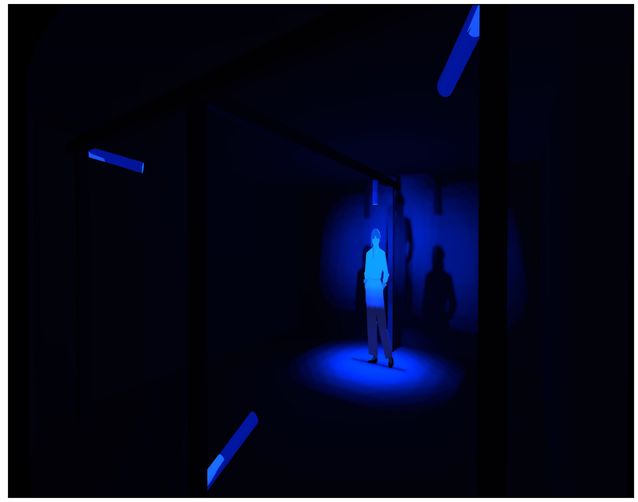


Figure 22: Two Dimensional View of Lighting Layout for The Experiment of The Darkroom.

Using lighting design software, a virtual replica of the experimental set up was also developed. Figure 23a, fig. 23b, fig. 23c and fig. 23d are ray-traced representations of the virtual simulation's depictions of the lighting ambience in the dark room under red, blue, yellow, and green lights, respectively.

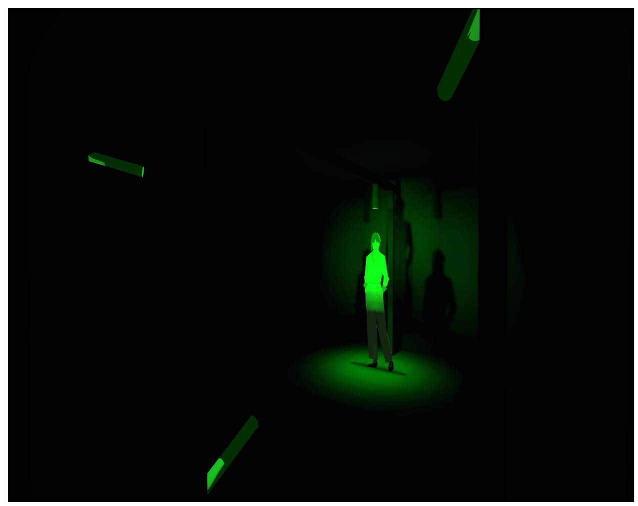


(a) Light Distribution throughout The Darkroom under Red Lights in The Virtually Simulated Environment.



(b) Light Distribution throughout The Darkroom under Blue Lights in The Virtually Simulated Environment.

(c) Light Distribution throughout The Darkroom under Yellow Lights in The Virtually Simulated Environment.



(d) Light Distribution throughout The Darkroom under Green Lights in The Virtually Simulated Environment.

Figure 23: Light Distribution throughout The Darkroom under All Lighting Conditions in The Virtually Simulated Environment

3.3.5 Data Collection

There are three ways to gauge emotional reaction. These include affective reports, psychological reactivity, and overt behavioural actions (Lang, 1969).[72] In this experiment, the data were gathered in two distinct methods. The first method involved utilising the Self

Assessment Manikin (SAM) rating system to gather information on behaviour, while the second included using an EEG headset to get information about the brain while performer enacted the scripted part and felt emotion.

3.3.5.1 Self Assessment Manikin Rating System

The Self Assessment Manikin is a picture-based scale for assessing emotional responses. It is primarily a pictorial, non-verbal, and three-dimensional assessment approach that immediately classifies a person's happiness, excitement, and dominance level. The first model of Self Assessment Manikin devised by Bradley and Lang was an interactive computer program model in 1980. [73] Later, a paper-pencil version of SAM was established, shown in figure 24. It depicts various places along each of three major affective dimensions in a non-verbal, graphical representation. There are specifically single-item scales to determine the valence/pleasure of the response (from negative to positive), perceived arousal (from low to high levels) and perceptions of dominance/control (from low to high levels). SAM represents the pleasure dimension varies from a frowning, unhappy figure to a smiling, happy figure. The arousal dimension varies from a relaxed, drowsy figure to an excited, wide-eyed figure. The dominance dimension reflects variations in control as the size of the figure changes: a large figure suggests maximum control in the situation.

- Valence: It is a scale for identifying if an emotion is elicited positively or negatively. It is shown in the first row of figure 24. The scale is from 1 to 9, where 1 means sad, 3 means unsatisfied, 5 means neutral, 7 means satisfied, and 9 means happy or pleasant. Odd numbers represent the emotional state as mentioned above and the intermediate emotional state is indicated by even numbers in the figure 25.

- Arousal: It is a scale that measures how active the elicited emotion is. It is shown in the second row of figure 24. The scale is from 1 to 9, with 1 denoting calm, 3 indicating dull, 5 denoting neutral, 7 denoting wide-awake, and 9 denoting excited. Odd numbers write the emotional state as mentioned above and the intermediate emotional state is implied by even numbers in the figure 25.

- Dominance: The scale measures the participant's control state. It is shown in the third row of figure 24. The scale is from 1 to 9, where 1 means independent, 3 means powerful, 5 means neutral, 7 means powerlessness, and 9 means dependent. Odd numbers imply the emotional state as mentioned above and the intermediate emotional state is denoted by even numbers in the figure 25.

A set of emotions may be represented using a two-dimensional coordinate system using the valence and arousal levels determined by the SAM rating system. The "Circumplex Model of Affect" which describes 28 emotions as a function of the happiness-sadness scale and the arousal-sleepiness scale, was first presented by **Russel** in 1980.[74] The neutral emotional state (5,5) may be used to visualise SAM data in a similar way in a two-dimensional space. Valence is often depicted along the X-axis whereas arousal is frequently shown along the Y-axis. If the emotion of happiness is considered, for example, it is a pleasant emotion and contains a fair amount of excitement, therefore its valence and arousal are both positive.

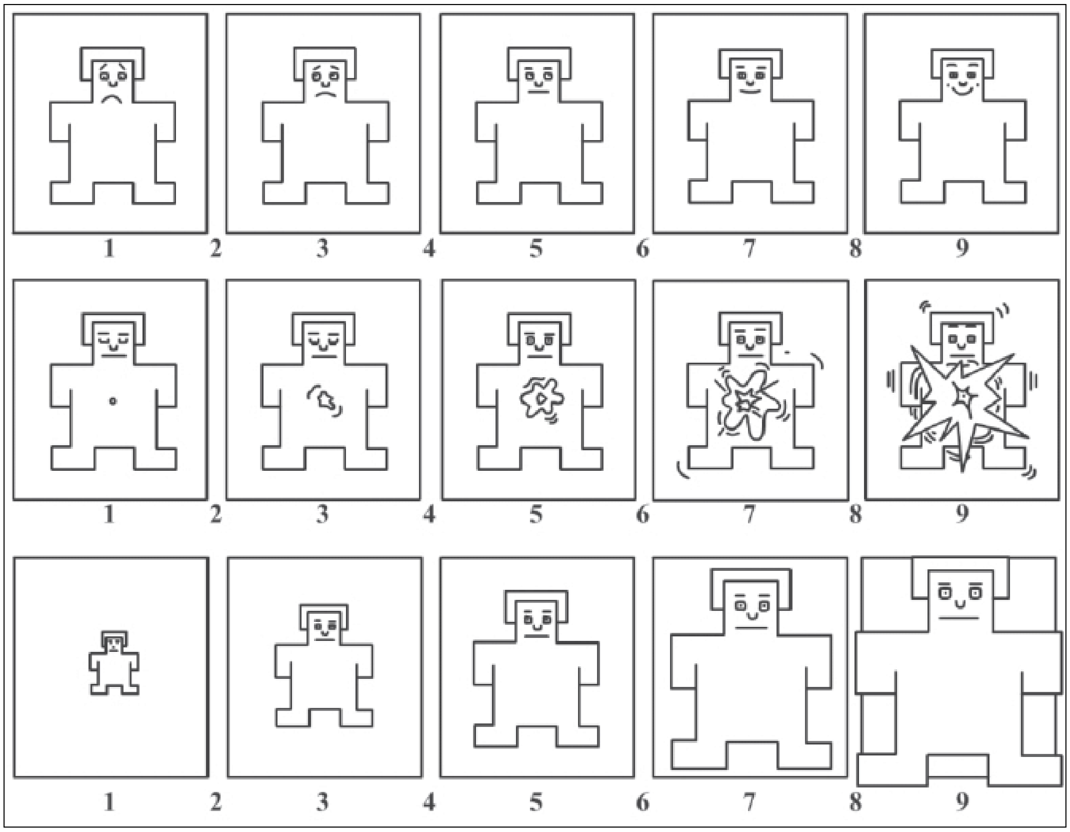


Figure 24: Figure of Paper-Pencil Version of Self Assessment Manikin

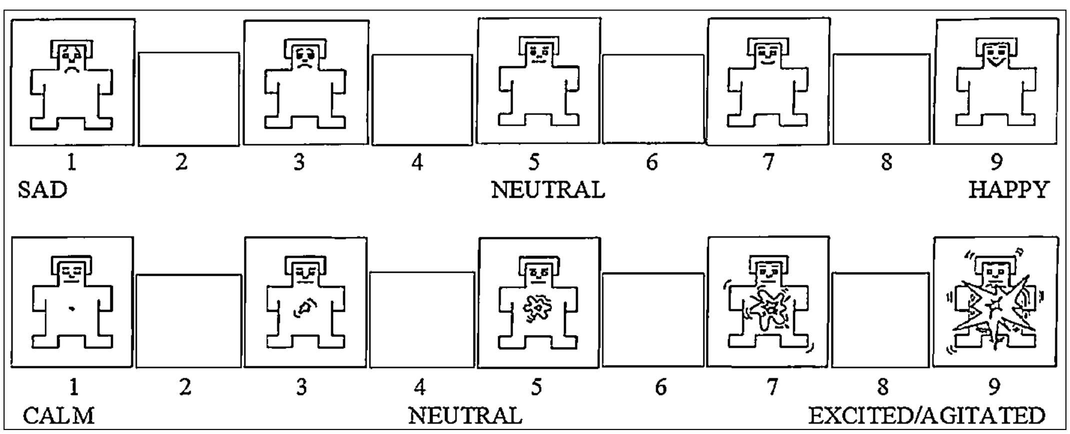


Figure 25: Figure of Valence and Arousal of Self Assessment Manikin

The first quadrant can be used to map the emotion of happiness. On the other hand, sadness is a negative emotion with little excitement. Therefore, the third quadrant stands for sadness. Anger is a powerfully arousing and slightly unfavourable emotion.

The valence rating for anger is therefore lower than neutral while the arousal level is higher. So, the second quadrant should be used to map it. As a result, anger has a lower

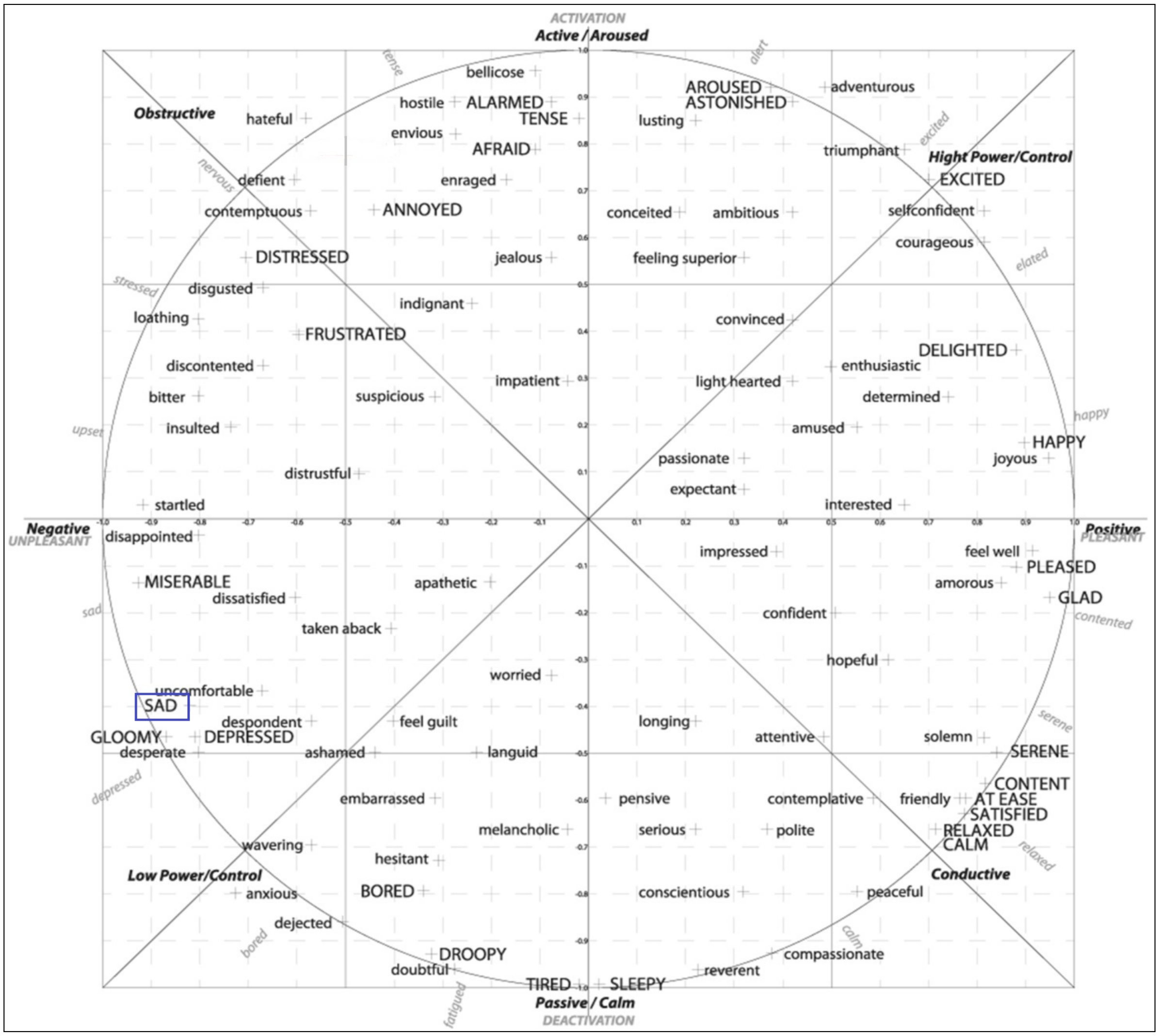


Figure 26: Two-Dimensional Circumplex Model of Different Emotions. Sadness Emotion Which Is Assessed in This Experiment Is Marked in Blue Rectangle.

valence rating than neutral but a greater arousal level. Therefore, it should be mapped using the second quadrant. Figure 28 displays the distinct emotions in a two-dimensional space plotted as a function of valence and arousal.

3.3.5.2 Electroencephalography (EEG) Study

Electroencephalography in short term EEG is a non-invasive brain imaging method which records the electrical activities or electrical signal of the brain through surface of the scalp. Hans Berger monitored brain activity underneath the closed skull and reported changes during various states in 1929, which is when EEG was first utilised. Gray Walter was the first to use electrodes to record the brain activity in 1957, and he showed how various mental demands affected the rhythms of the brain.[75] EEG apparatus often takes the shape of a cap or headset with a number of electrodes or sensors that are intended to adhere to the surface of the head. Through electrodes affixed to the subject's scalp, subdural (i.e., beneath the dura mater, the outermost, toughest, and most fibrous of the three membranes enclosing and protecting the brain and spinal cord), or even the cortex itself, an EEG device records electrical signals from the brain, specifically post synaptic potentials of neurons (these latter two cases are relatively rare). The principle of ionic current volume conduction across non empty extracellular space is the foundation of EEG. An EEG is used to diagnose certain brain disorders. The measurements given by an EEG are used to provide information about disorders such as:

- seizure disorders, including epilepsy
- head injury
- encephalitis, or inflammation of the brain
- brain tumour.
- encephalopathy, or brain dysfunction resulting from various causes
- memory problems
- stroke
- sleep disorders.

Only the cerebral cortex, the brain's outermost layer, may be used by EEG equipment to record brain waves. The ionic current is created by millions of neurons, and the resulting electric field may push or pull the valence electrons away from the metal electrodes. Any two electrodes' push or pull potential differences can be recorded. Raw EEG data is the documentation of voltage fluctuations throughout time, as seen in figure 27. The brain signal records in various software. In this study the raw data is captured in Emotiv Pro software.

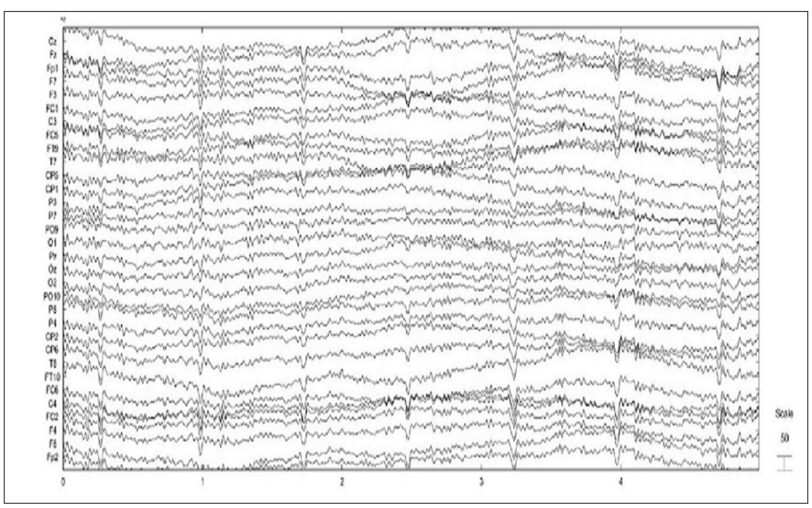


Figure 27: Raw EEG Data Recorded on Emotiv Pro Software

In this study, the performers' brain signals were recorded using an Emotiv EPOC Flex EEG headset(shown in figure 29) while they were acting out the sad emotional part. The Driven Right Leg (DRL) and Common Mode Sense (CMS) reference electrodes were used as the reference electrodes for a portable 32 channel dynamic based EEG headset called the Emotiv EPOC Flex. Following, the electrodes were applied to the scalp using the 10 – 20 international BESA method. By adding saline solutions, which was utilised to clean the electrode locations for optimal signal conduction, inter electrode impedances were kept low ($< 20K\Omega$).

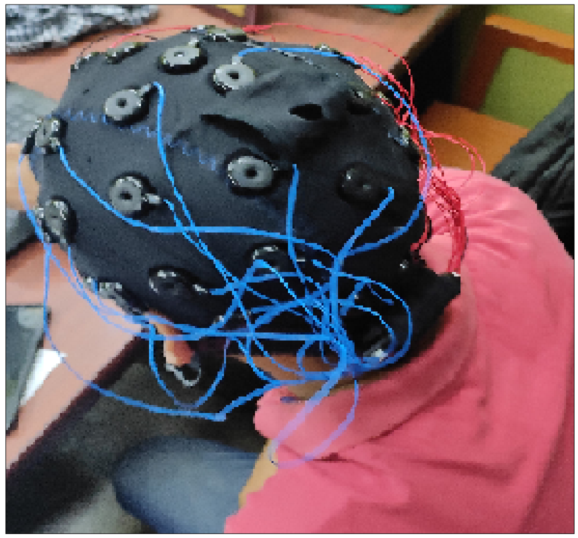


Figure 28: Saline Based Emotiv EPOC Flex EEG Headset

Normally, the neurons' electrical pulses range in frequency from 0.5 Hz to 100 Hz. Depending on the actions or experiences on a physical and mental level, the frequency of brain wave oscillations changes. It has been discovered that the frequency of these signals and the level of neuronal activity are related.[76]

While high frequency and low amplitude waves are linked to a noticeably more active state of mind, low-frequency waves with bigger amplitude are associated to a peaceful and sleepy state of mind. Although there is no direct correlation between brainwave frequency and brain function, brainwaves are divided into five frequency sub-bands based on the activity of the brain: delta (0.5 - 3 Hz) band, theta (4 - 7 Hz), alpha (8 - 13 Hz), beta (14 - 30 Hz), and gamma (31 - 100 Hz).[77]

- **Delta Band** - Delta brainwaves are defined as brainwaves with a frequency between 0.5 and 3 Hz as shown in figure 29. It is the slowest and strongest brain signal that has ever been observed. In contrast to the left hemisphere of the brain, it is more obvious in the right hemisphere. Deep non-REM sleep and delta waves have frequently been linked.

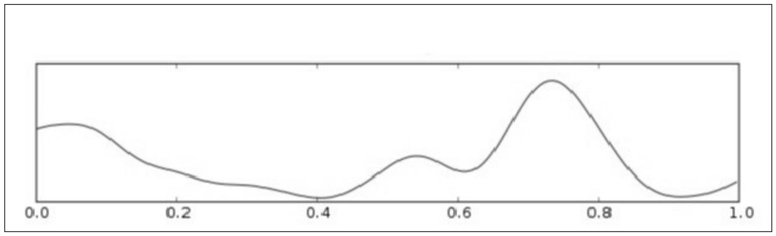


Figure 29: Delta Wave

- **Theta Band** - Theta brainwaves are the term for brain oscillations that occur between 4 and 7 Hz as shown in figure 55. These waves may be found across the whole skull, from the frontal and central regions to the parietal and temporal regions. Theta waves are associated with light sleep or tiredness.

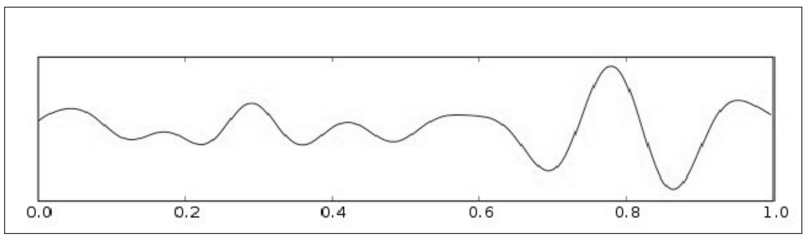


Figure 30: Theta Wave

- **Alpha Band** - The alpha brainwave is associated with a tranquil, calm, and clear state of mind. Its frequency range is between 8 and 13 Hz as shown in figure 31. When the eyes are closed and the mind is at peace, alpha waves may be easily recorded. It can be found in the brain's occipital and posterior regions.

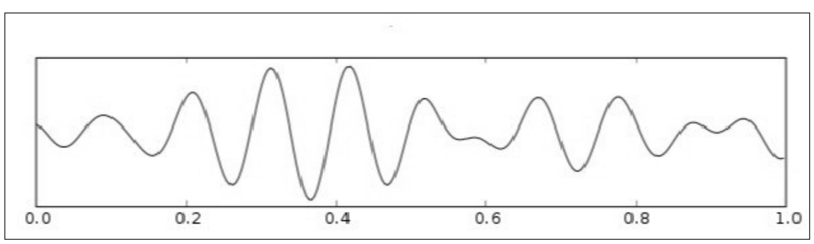


Figure 31: Alpha Wave

- **Beta Band** - When the mind is busy, such as when thinking, doing mental calculations, or solving problems, the brain produces beta waves. Although the frequency is substantially greater than that of alpha waves, the signal strength is smaller. Beta waves have a frequency range of 14 Hz to 30 Hz as shown in figure 32.

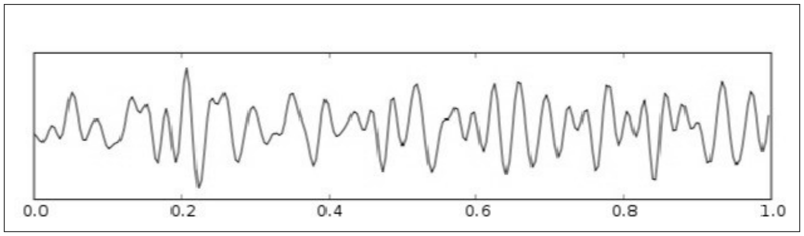


Figure 32: Beta Wave

- **Gamma Band** - It is the quickest brainwave ever seen. Gamma waves oscillate with a frequency that ranges from 31 to 100 Hz as shown in figure 46. Gamma waves have been linked to higher order thinking and emotional expression in several studies, despite the fact that the connection between these waves and brain function is still being researched.

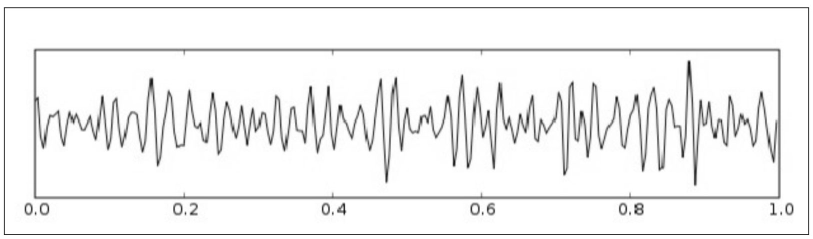


Figure 33: Gamma Wave

Heartbeat, muscle movement, and eye blinking are a few examples of internal noises and external disturbances (power frequency interference) that might corrupt the raw data being recorded in EEG recording software. “Artefacts” are the name for these noises. Therefore, pre-processing the data and removing artefacts is the first step in separating important information from the brain signals. Extraction of the relevant data or feature for in-depth analysis comes after the data has been cleansed.

Event-Related Potential studies, Statistical Features, Hjorth Features, Non-Stationary Index, and Higher-Order Crossings are examples of features that may be extracted in the time domain. Spectral Power Density, Band Power Feature, Common Spatial Pattern, and Auto-regressive Method are extracted in the frequency domain. Techniques like the Wavelet Transform and Hilbert-Huang Spectrum operate in the time-frequency domain. Non-linear analytic techniques include entropy analysis, fractal dimension, correlation dimension, lyapunov exponent, hurst exponent, lempel-ziv complexity, and recurrence quantification analysis. To arrive at the final conclusion, the attributes are then examined.[78]

3.4 Experimental Procedure

Before commencing the experiment, the data recording procedure to be discussed and how many days are necessary to finish the experiment were addressed.

	Red	Blue	Yellow	Green
Participant 1	17/01/2022	02/02/2022	18/02/2022	08/03/2022
Participant 2	18/01/2022	03/02/2022	22/02/2022	09/03/2022
Participant 3	19/01/2022	04/02/2022	23/02/2022	10/03/2022
Participant 4	20/01/2022	07/02/2022	24/02/2022	11/03/2022
Participant 5	21/01/2022	08/02/2022	25/02/2022	14/03/2022
Participant 6	24/01/2022	09/02/2022	28/02/2022	15/03/2022
Participant 7	25/01/2022	10/02/2022	02/03/2022	21/03/2022
Participant 8	27/01/2022	11/02/2022	03/03/2022	22/03/2022
Participant 9	28/01/2022	15/02/2022	04/03/2022	23/03/2022
Participant 10	31/01/2022	17/02/2022	07/03/2022	24/03/2022

Table 1: Time Schedule of Participants

So, for simplicity, a schedule (as Shown in table 1) was prepared for the whole experiment, so participants knew that at what day they would come for the experiment. As per the schedule almost 65 days were required. Each participant had to come one by one to do a single act in four different lighting conditions. On the first day, all the participants were called for a briefing on what they would do, and the selected script was handed over to them. Also, they were given the schedule matrix on what day they would come. For this experiment, four different lighting set up had been used. Every lighting condition required the 10 individuals to execute the same script for 2-3 minutes each. Each participant had so experienced four distinct performance sessions displaying the identical "Sadness" emotion under four distinct sets of coloured lights.

1. First, the darkroom was illuminated by natural white Led light source and the performer was given five minutes to rest and psychologically get ready for performing the act in the darkroom.

2. Second, the participants were given shampoo to remove dirt and dust particles from their hair. The presence of moister can impair the EEG signal quality. So, they were provided with a hair dryer and a comb. Hair washing and drying are essential because the contact resistance($< 20K\Omega$) between the scalp and EEG electrode can be minimised, and the EEG quality can be improved. It took almost 20-25 minutes.

3. Meanwhile, at that time, the EEG headset was prepared by the following process:

    - Charged the EEG controller and soaked the Felt pads into a Saline solution.

- After all the felt pads were thoroughly soaked up, they were inserted into the correct position of the electrode sensors in the EEG cap precisely.
- After that, the EEG cap was worn to the participant's head, the EEG controller was placed on top of the cap's head position, and the sensors wires were connected to the EEG controller.
- Opened the EMOTIV launcher, and the USB Dongle was plugged into the laptop's USB port.
- Powered on the controller to establish the wireless connection between EEG head set and laptop.
- Then, EMOTIV Pro software was opened and selected the controller position(Top of the head); went to on next tab, "Contact quality", to check the contact quality. If contact quality was not 100%, added saline solution through the orifice of the electrode and adjusted them.
- after achieving 100% contact quality, went to on next tab, "EEG quality", to check the EEG quality. By adjusting the sensors, 100% EEG quality was achieved. The EEG headset was ready to collect the brain signal.

4. After the EEG device was up to the hilt, ready to receive the brain signal, the light colour was changed from natural white to red colour spectrum using the Wiz application through mobile.

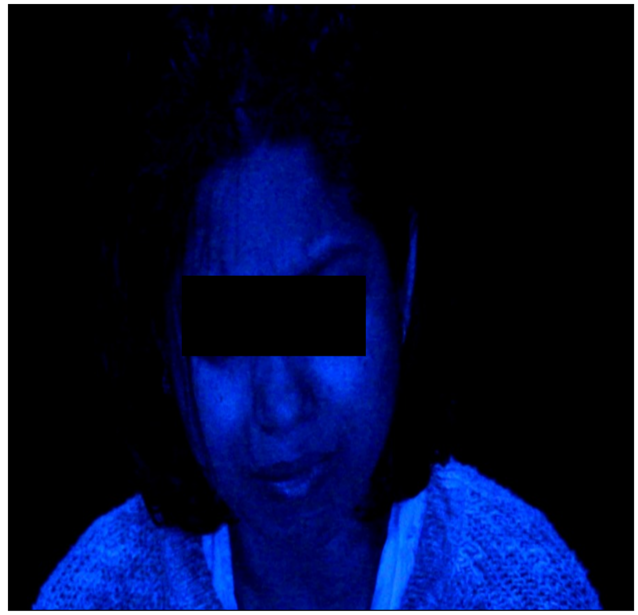
5. As directed, the participants performed the emotional act for "Sadness", which took them 2-3 minutes to finish..

6. They were handed a pen-and-paper Self Assessment Manikin sheet to complete after the act to score their emotional state, what they felt during the performances. Before leaving the darkroom, they were instructed to keep their fellow participants in the dark regarding the experiment's scoring system and methodology.

Using the 'Blue', 'Yellow', and 'Green' colour spectra for additional lighting situations, the same procedure was carried out for a single subject. The aforementioned process had to be followed in all lighting conditions for a single participant. The identical steps were taken with each of the 10 participants. To finish the entire experimental procedure, it had been repeated 40 times.

A camera had caught a glimpse of a scenario being played throughout the performance. It is clear from the picture 35 that they were showing sadness emotion.

(a) Sadness Emotion Expressing under Red Light



(b) Sadness Emotion Expressing under Blue Light

(c) Sadness Emotion Expressing under Yellow Light

(d) Sadness Emotion Expressing under Green Light

Figure 34: Subjects Expressed Sadness Emotion under Four Lighting Conditions

3.5 Experimental Results

3.5.1 Data Recorded Through SAM Rating System

The subject's emotional state might be evaluated using the Self Assessment Manikin (SAM) scale. The SAM scale assessment was briefly explained to the respondents so they could accurately score their emotional experiences and score them in the scale format. Data on valence and arousal alone were recorded. As the values of these two scales might indicate someone's emotional experience. It is clear which sort of emotional value was displayed by charting these data on the two-dimensional valence and arousal axes. Therefore, one of the primary criteria for this investigation was SAM rating assessment. The individual participant was handed the SAM in paper-pencil and directed to score their degree of emotional state using only the valence and arousal scale after each performance session.

The ten subjects' self assessment manikin (SAM) data has been shown in table 2 under four different lighting conditions. Thus, there were 40 SAM ratings (10 subjects $\times$ 4 colour spectra situations) available. The valence and arousal ratings for each participant and for each lighting condition are presented on a total of 40 bar graphs.

Figures 35a to 35j display bar graphs of the SAM ratings received from each of the 10 participants after finishing their performance under a red light, in that order. Given that the data was taken in red monochromatic light, red has been chosen in these graphs to better portray it visually. The SAM Scale labels, valence and arousal, are shown on the horizontal axis of the bar graphs, and the scale rating values are displayed on the vertical axis.

The figs. 36a to 36j depict a bar graph of the 10 performers lit in a blue monochromatic hue to represent sadness. Additionally, these graphs include blue colouring for easier observation.

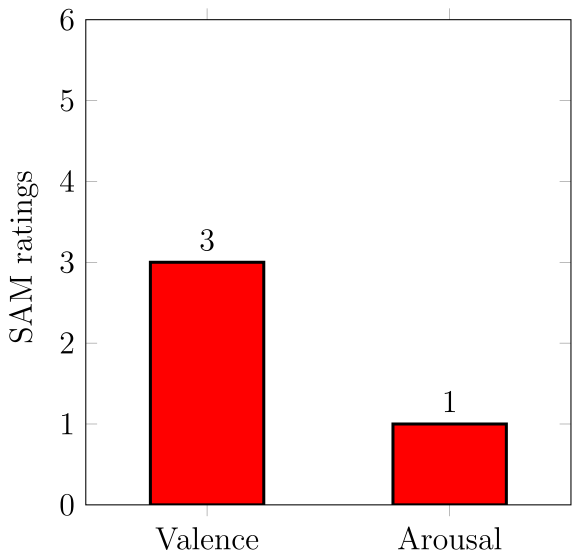
The bar graph of the ten subjects expressing sadness under yellow monochromatic light is implied by figs. 37a to 37j. Additionally, these graphs have a yellow colour for easy understanding.

The figs. 38a to 38j show the bar graph of each of the 10 individuals expressing grief under green monochromatic light. Additionally, these graphs have been coloured in green to assist in knowing under which colour spectrum, the SAM rating had been taken.

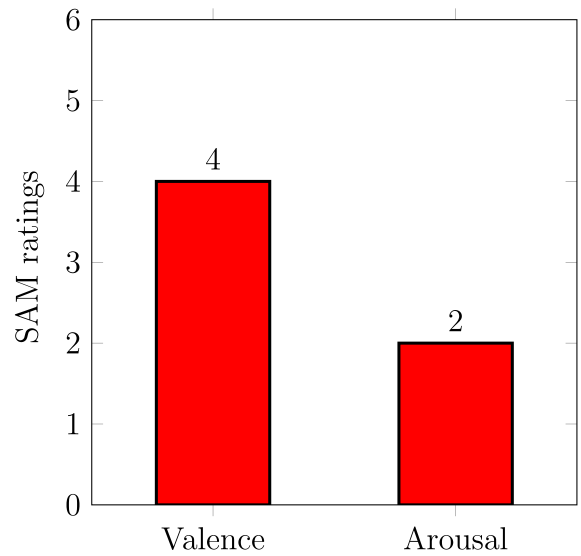
To further analysis, results and make it simpler to display the 2-d Valence and Arousal axes, these data should have been normalised in "-1 to +1".

	Red	Blue	Yellow	Green
Participant 1	Valence: 3 Arousal: 1	Valence: 1 Arousal: 2	Valence: 3 Arousal: 4	Valence: 5 Arousal: 5
Participant 2	Valence: 4 Arousal: 2	Valence: 2 Arousal: 3	Valence: 4 Arousal: 4	Valence: 3 Arousal: 3
Participant 3	Valence: 2 Arousal: 3	Valence: 1 Arousal: 2	Valence: 3 Arousal: 2	Valence: 2 Arousal: 3
Participant 4	Valence: 5 Arousal: 3	Valence: 2 Arousal: 2	Valence: 4 Arousal: 4	Valence: 3 Arousal: 3
Participant 5	Valence: 3 Arousal: 2	Valence: 1 Arousal: 1	Valence: 5 Arousal: 3	Valence: 5 Arousal: 3
Participant 6	Valence: 4 Arousal: 5	Valence: 4 Arousal: 2	Valence: 5 Arousal: 5	Valence: 4 Arousal: 5
Participant 7	Valence: 4 Arousal: 3	Valence: 2 Arousal: 3	Valence: 5 Arousal: 4	Valence: 2 Arousal: 3
Participant 8	Valence: 2 Arousal: 3	Valence: 1 Arousal: 1	Valence: 4 Arousal: 4	Valence: 5 Arousal: 4
Participant 9	Valence: 3 Arousal: 2	Valence: 1 Arousal: 2	Valence: 3 Arousal: 4	Valence: 4 Arousal: 4
Participant 10	Valence: 4 Arousal: 3	Valence: 2 Arousal: 2	Valence: 5 Arousal: 5	Valence: 5 Arousal: 3

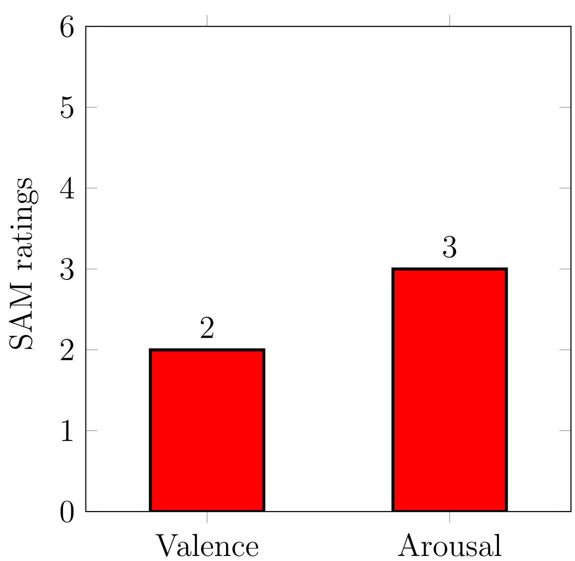
Table 2: SAM rating of ten participants under four lighting conditions



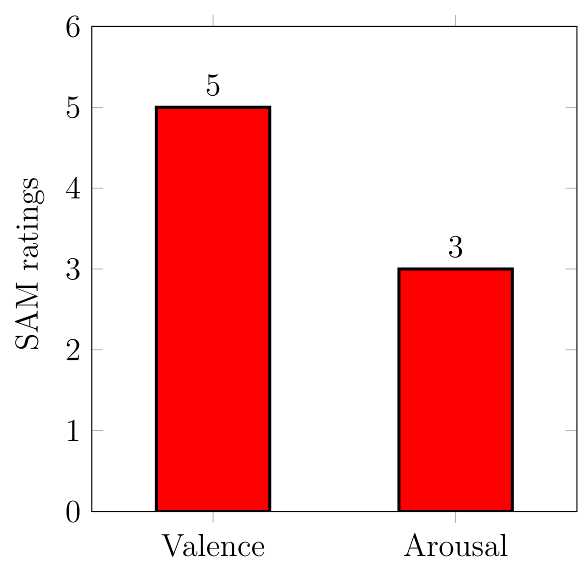
(a) Participant 1 SAM Rating under Red Colour Spectrum Depicting Emotion “Sadness”



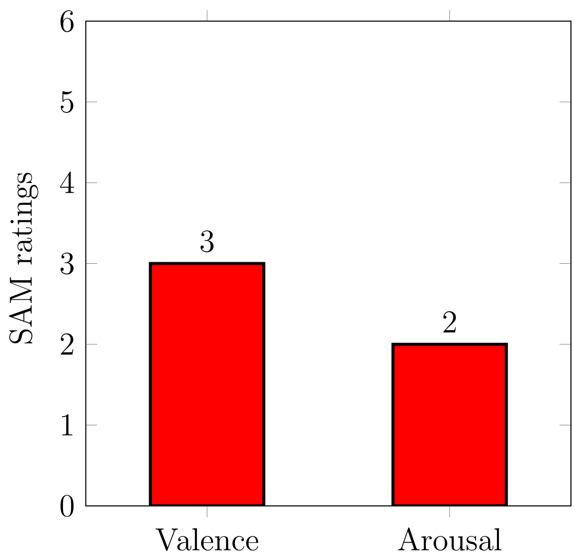
(b) Participant 2 SAM Rating under Red Colour Spectrum Depicting Emotion “Sadness”



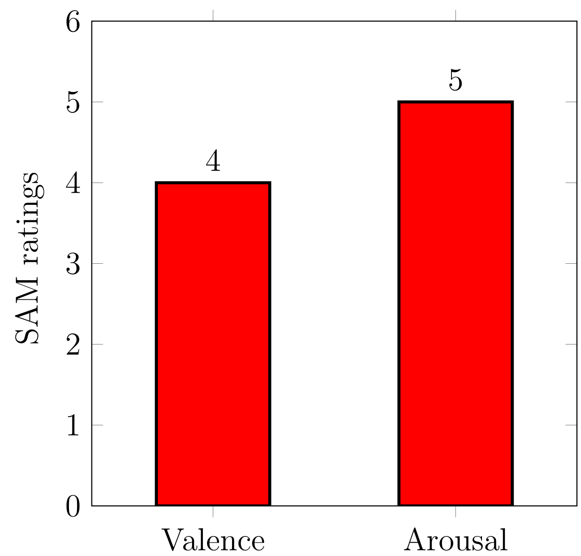
(c) Participant 3 SAM Rating under Red Colour Spectrum Depicting Emotion “Sadness”



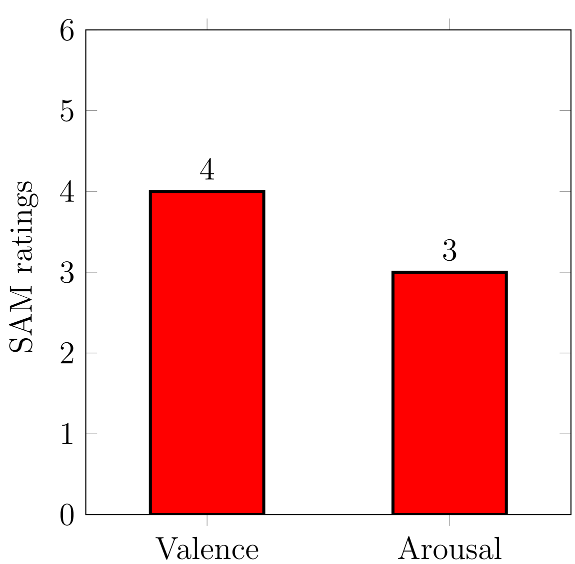
(d) Participant 4 SAM Rating under Red Colour Spectrum Depicting Emotion “Sadness”



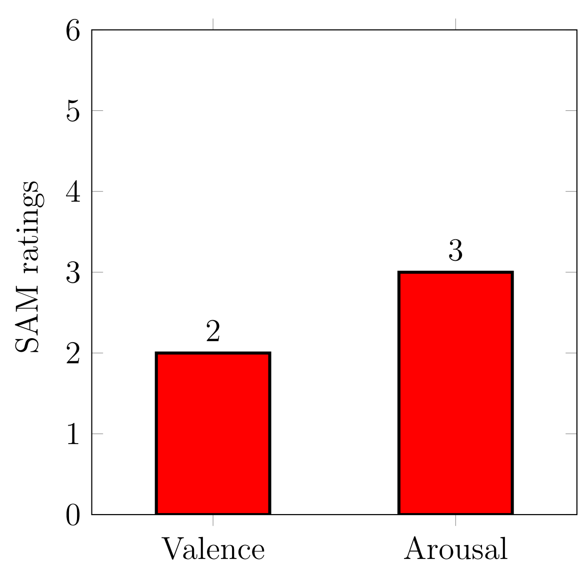
(e) Participant 5 SAM Rating under Red Colour Spectrum Depicting Emotion “Sadness”



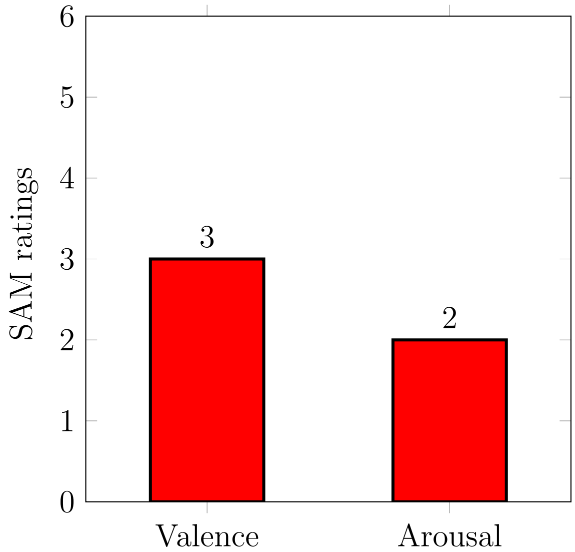
(f) Participant 6 SAM Rating under Red Colour Spectrum Depicting Emotion “Sadness”



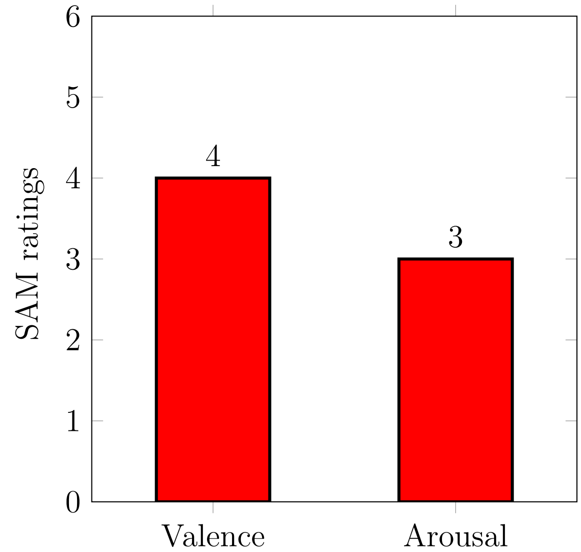
(g) Participant 7 SAM Rating under Red Colour Spectrum Depicting Emotion “Sadness”



(h) Participant 8 SAM Rating under Red Colour Spectrum Depicting Emotion “Sadness”

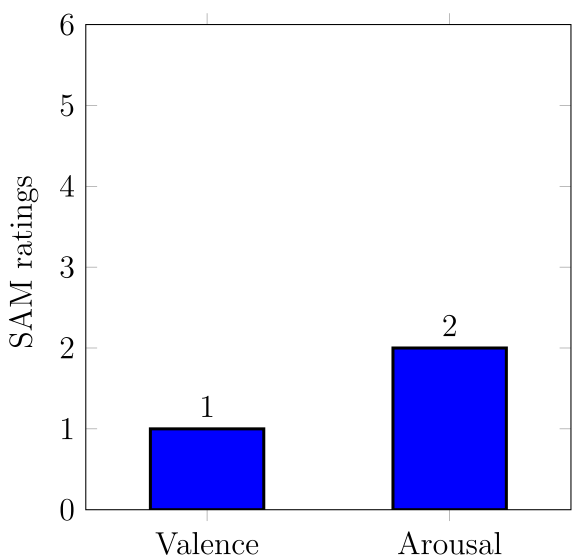


(i) Participant 9 SAM Rating under Red Colour Spectrum Depicting Emotion “Sadness”

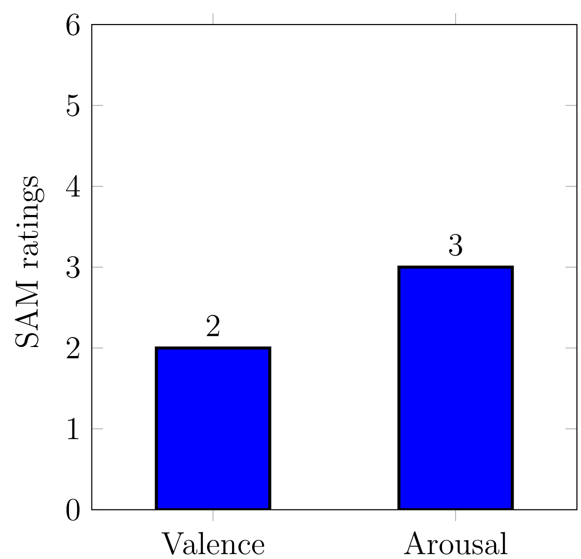


(j) Participant 10 SAM Rating under Red Colour Spectrum Depicting Emotion “Sadness”

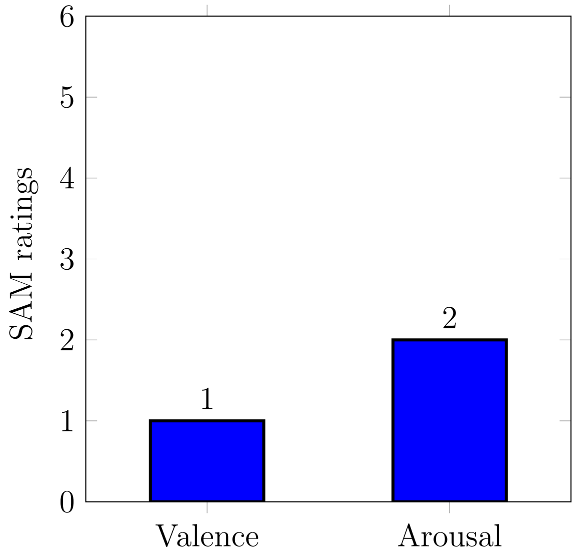
Figure 35: SAM Rating of The Subjects Expressing “Sadness” Emotion under Red Light



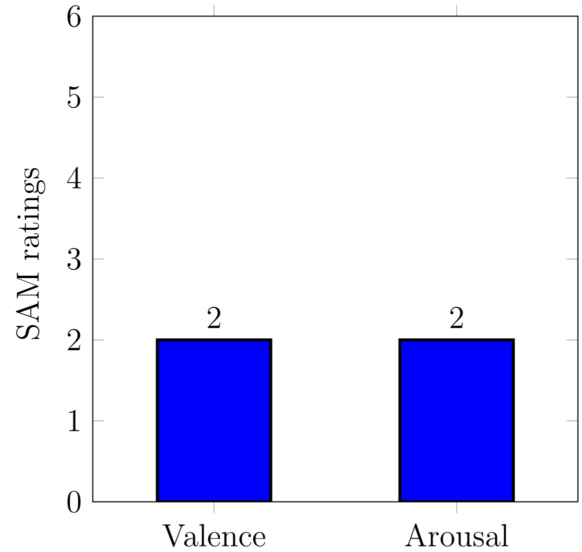
(a) Participant 1 SAM rating under Blue colour spectrum depicting emotion “Sadness”



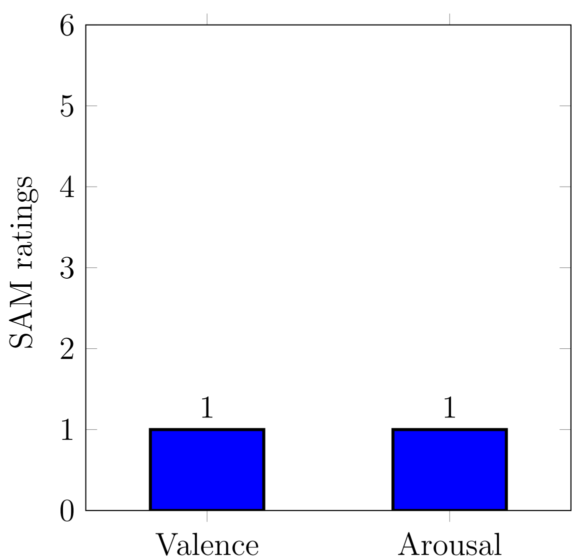
(b) Participant 2 SAM rating under Blue Colour Spectrum Depicting Emotion “Sadness”



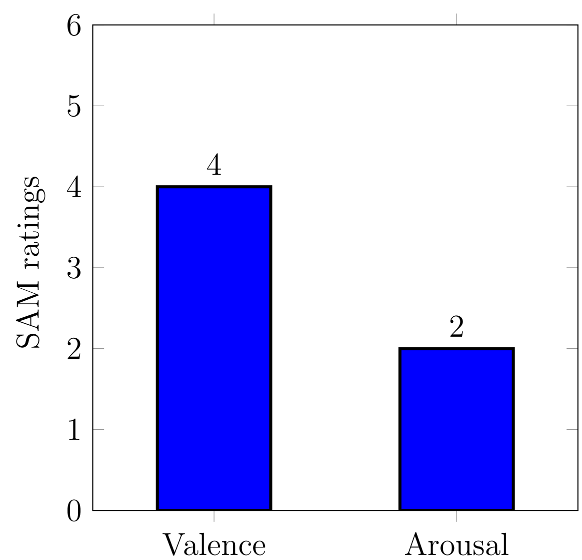
(c) Participant 3 SAM rating under Blue Colour Spectrum Depicting Emotion “Sadness”



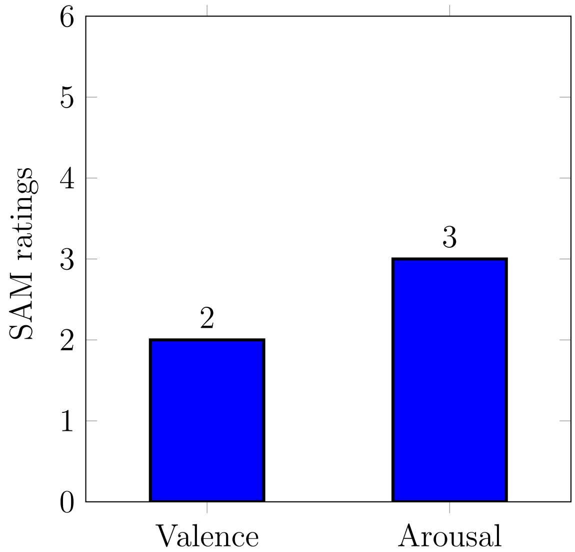
(d) Participant 4 SAM rating under Blue Colour Spectrum Depicting Emotion “Sadness”



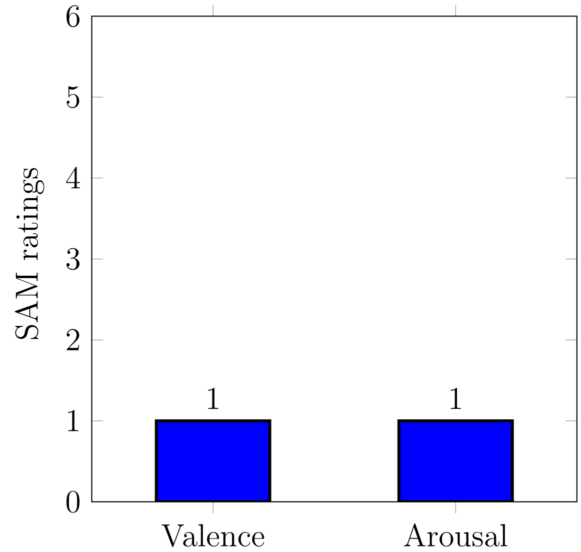
(e) Participant 5 SAM rating under Blue Colour Spectrum Depicting Emotion “Sadness”



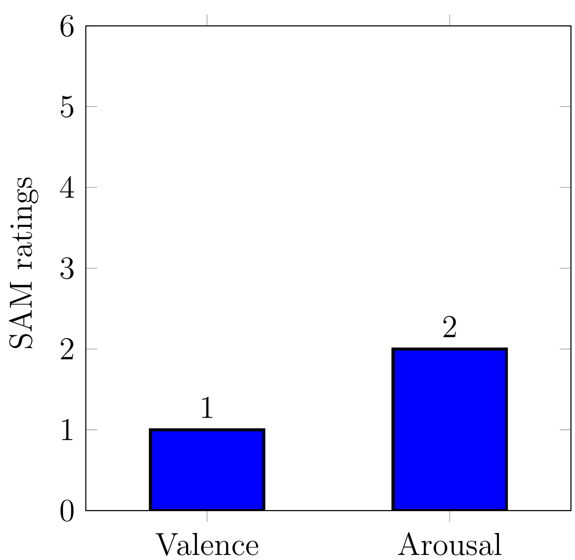
(f) Participant 6 SAM rating under Blue Colour Spectrum Depicting Emotion “Sadness”



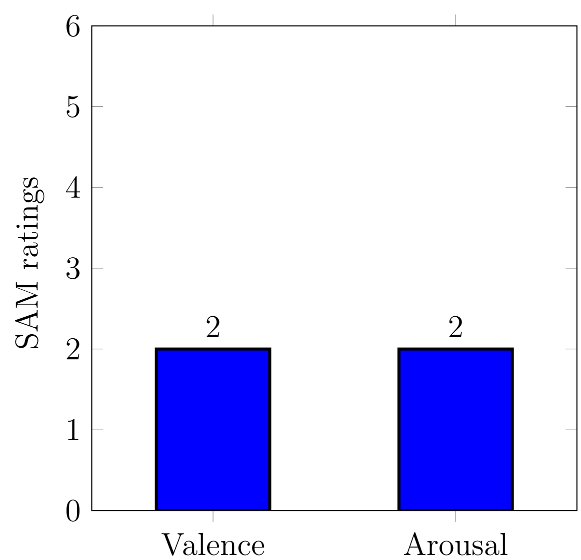
(g) Participant 7 SAM rating under Blue Colour Spectrum Depicting Emotion “Sadness”



(h) Participant 8 SAM rating under Blue Colour Spectrum Depicting Emotion “Sadness”

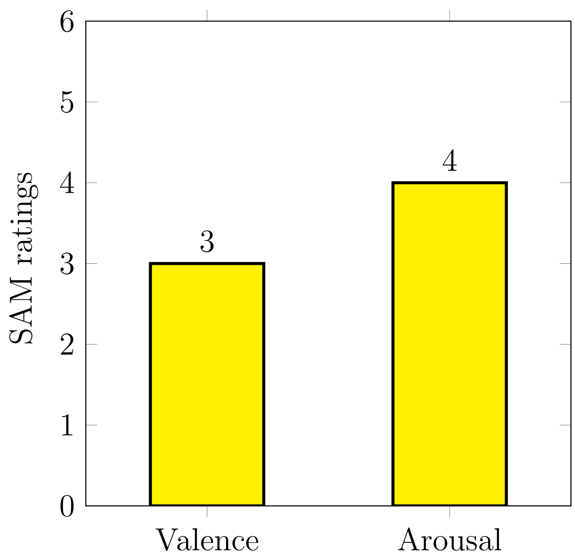


(i) Participant 9 SAM rating under Blue Colour Spectrum Depicting Emotion “Sadness”

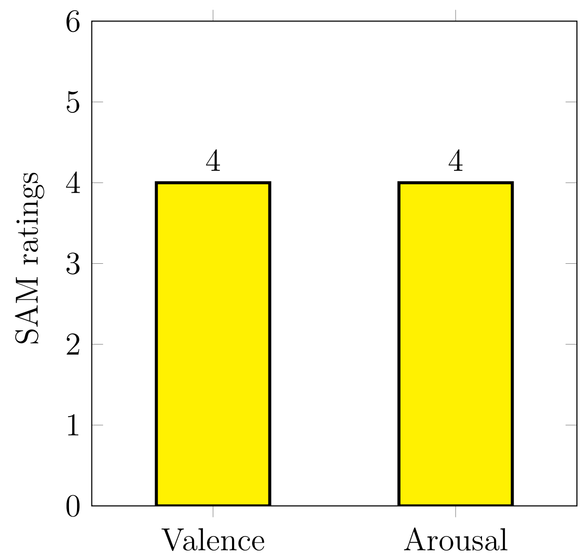


(j) Participant 10 SAM rating under Blue Colour Spectrum Depicting Emotion “Sadness”

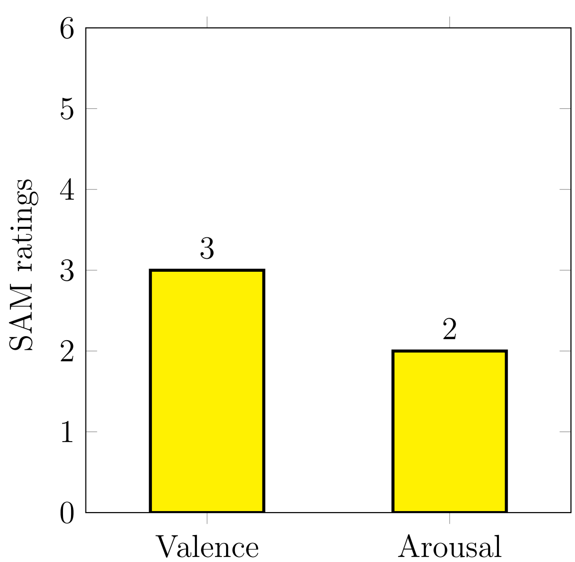
Figure 36: SAM Rating of The Subjects Expressing “Sadness” Emotion under Blue Light



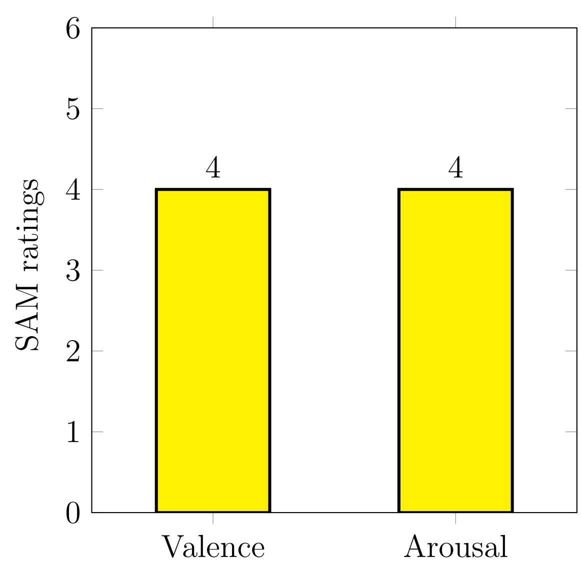
(a) Participant 1 SAM rating under Yellow Colour Spectrum Depicting Emotion “Sadness”



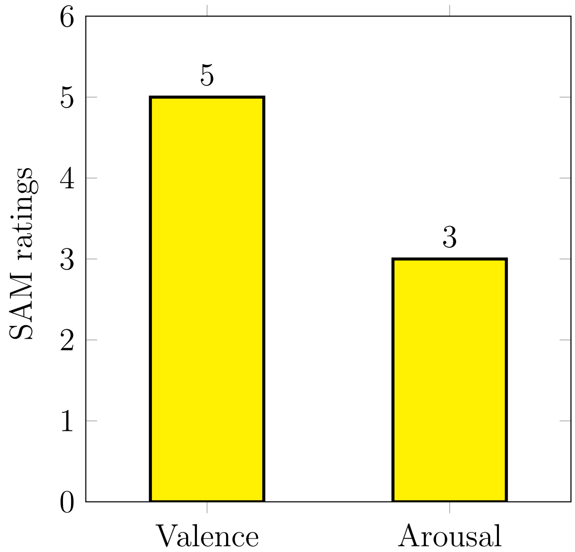
(b) Participant 2 SAM rating under Yellow Colour Spectrum Depicting Emotion “Sadness”



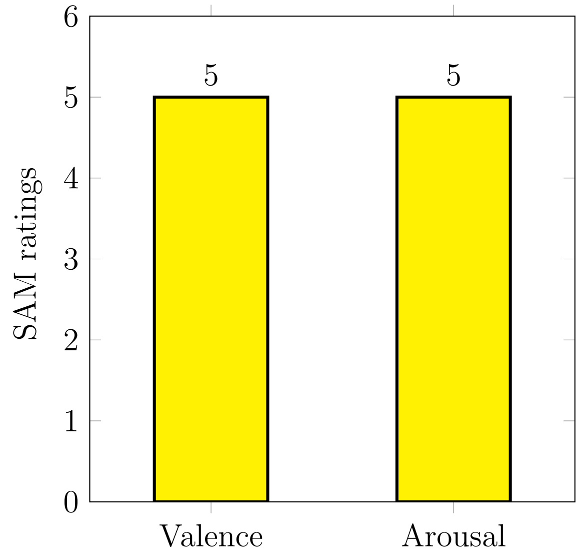
(c) Participant 3 SAM rating under Yellow Colour Spectrum Depicting Emotion “Sadness”



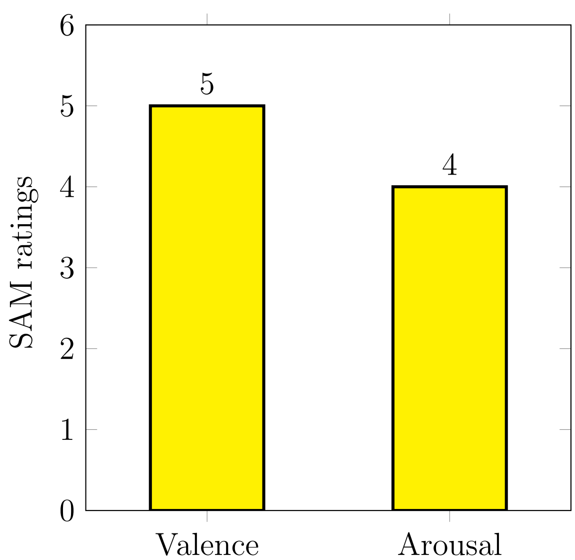
(d) Participant 4 SAM rating under Yellow Colour Spectrum Depicting Emotion “Sadness”



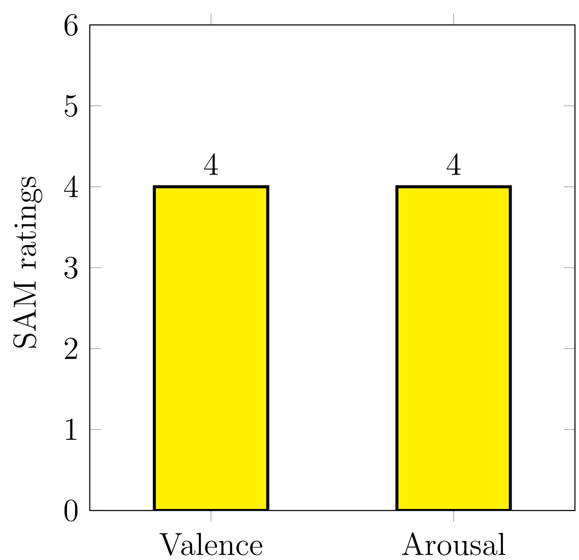
(e) Participant 5 SAM rating under Yellow Colour Spectrum Depicting Emotion "Sadness"



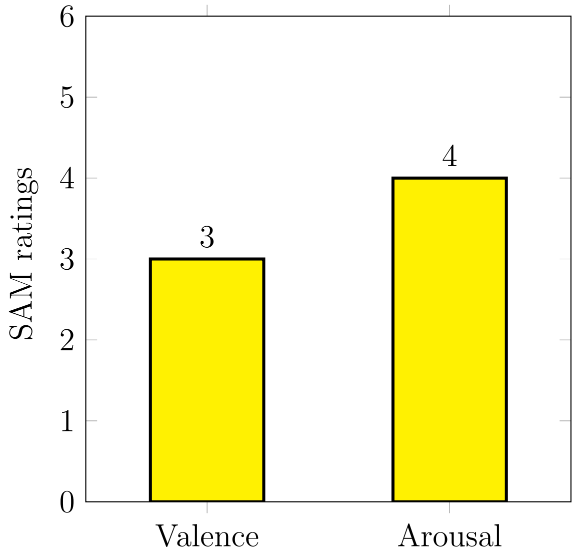
(f) Participant 6 SAM rating under Yellow Colour Spectrum Depicting Emotion "Sadness"



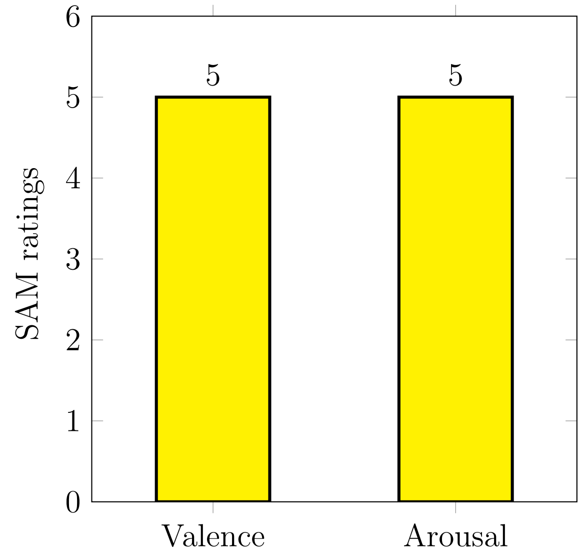
(g) Participant 7 SAM rating under Yellow Colour Spectrum Depicting Emotion "Sadness"



(h) Participant 8 SAM rating under Yellow Colour Spectrum Depicting Emotion "Sadness"

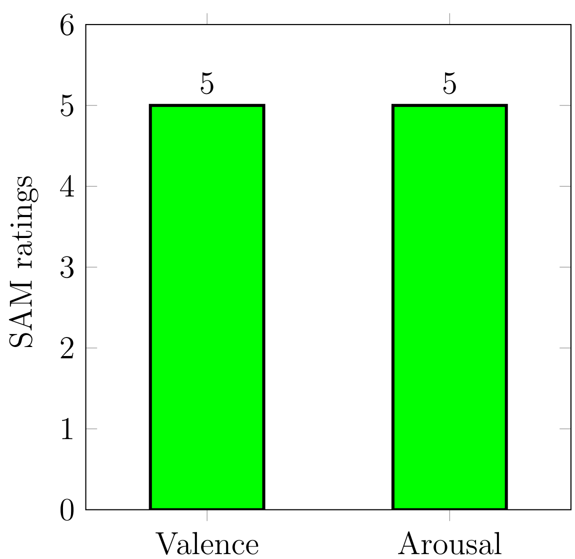


(i) Participant 9 SAM rating under Yellow Colour Spectrum Depicting Emotion "Sadness"

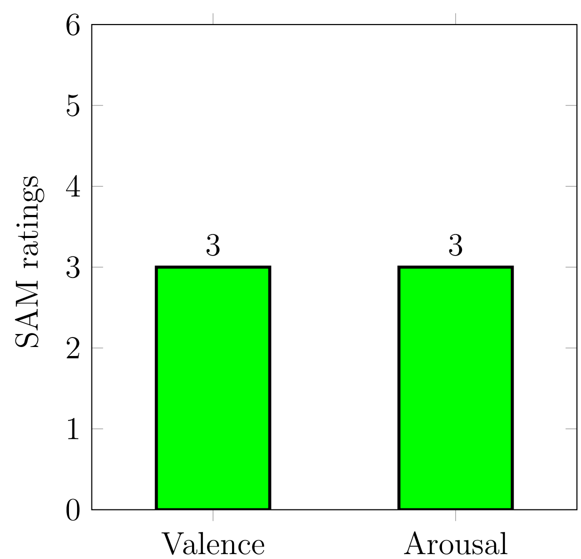


(j) Participant 10 SAM rating under Yellow Colour Spectrum Depicting Emotion "Sadness"

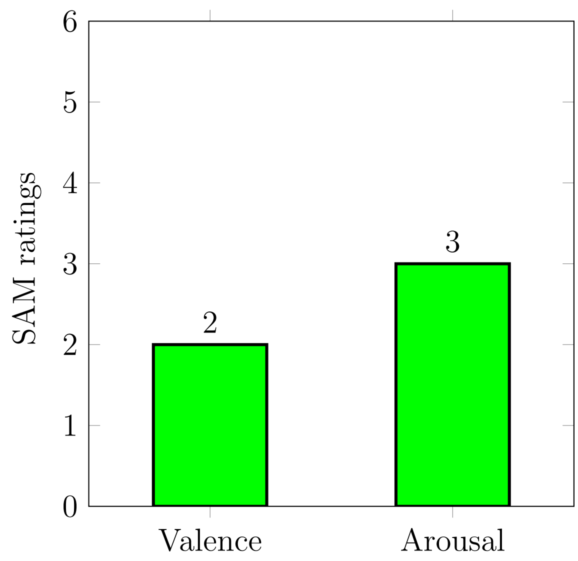
Figure 37: SAM Rating of The Subjects Expressing "Sadness" Emotion under Yellow Light



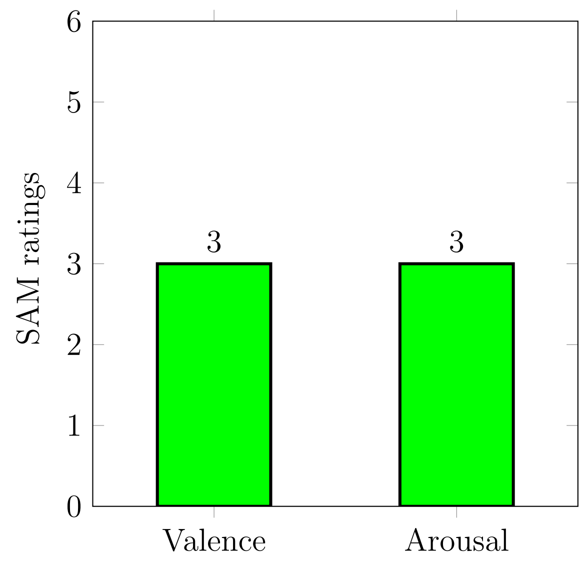
(a) Participant 1 SAM rating under Green Colour Spectrum Depicting Emotion "Sadness"



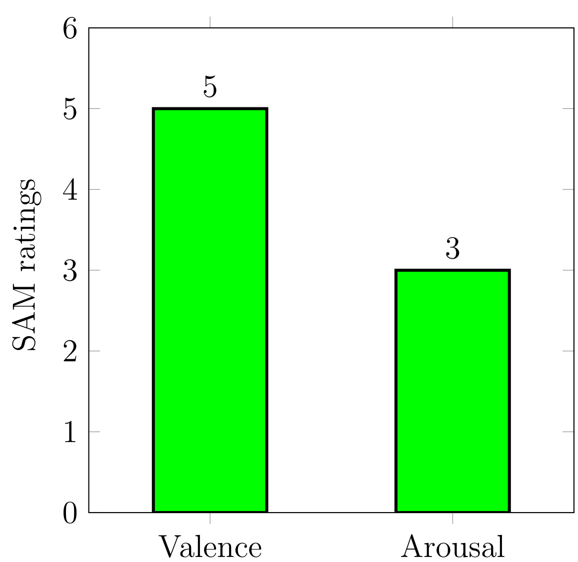
(b) Participant 2 SAM rating under Green Colour Spectrum Depicting Emotion "Sadness"



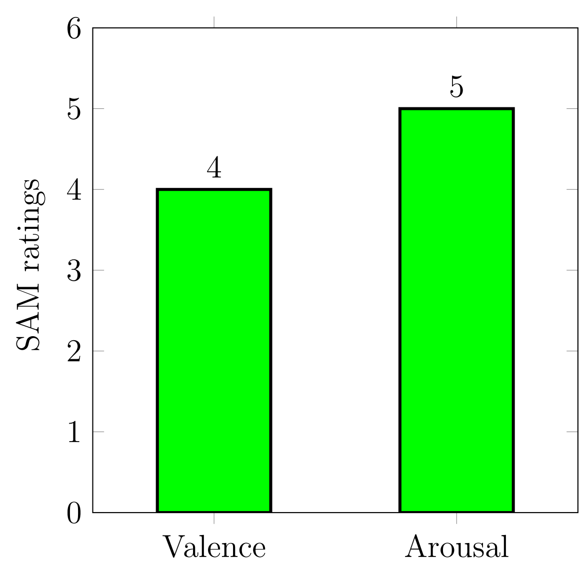
(c) Participant 3 SAM rating under Green Colour Spectrum Depicting Emotion “Sadness”



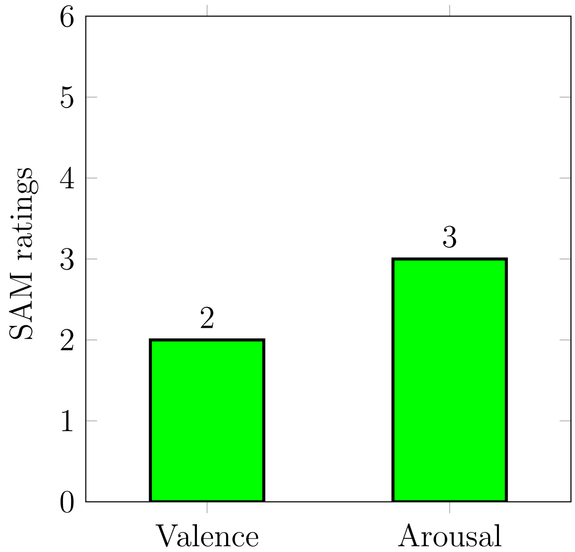
(d) Participant 4 SAM rating under Green Colour Spectrum Depicting Emotion “Sadness”



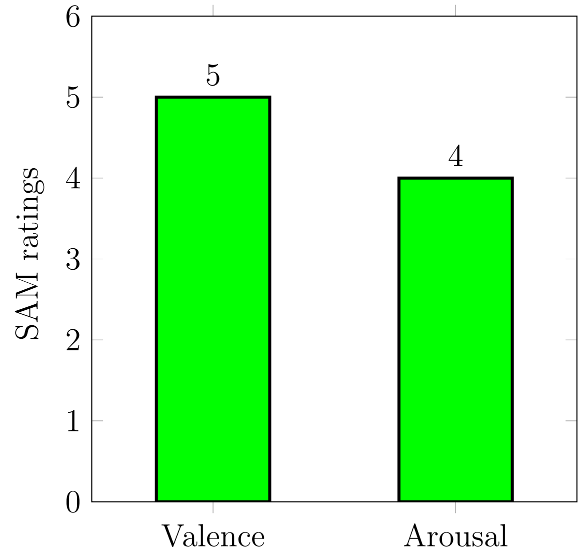
(e) Participant 5 SAM rating under Green Colour Spectrum Depicting Emotion “Sadness”



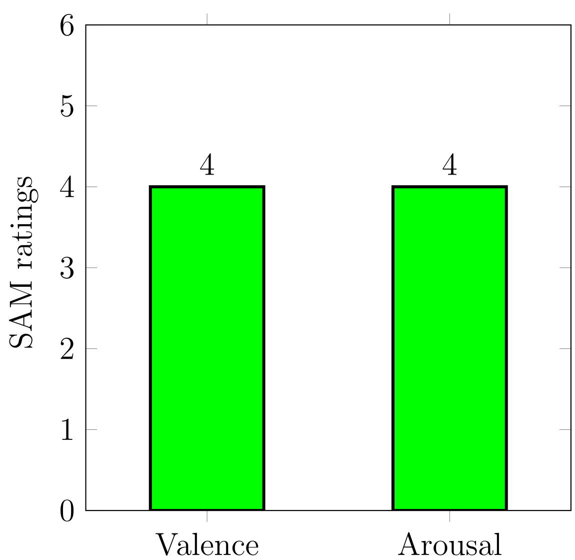
(f) Participant 6 SAM rating under Green Colour Spectrum Depicting Emotion “Sadness”



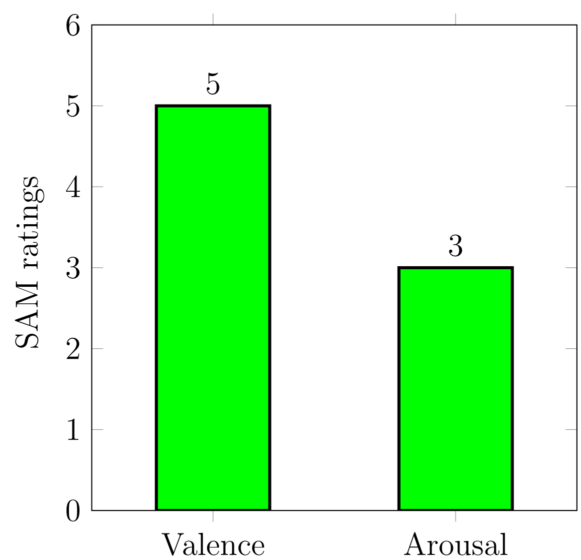
(g) Participant 7 SAM rating under Green Colour Spectrum Depicting Emotion “Sadness”



(h) Participant 8 SAM rating under Green Colour Spectrum Depicting Emotion “Sadness”



(i) Participant 9 SAM rating under Green Colour Spectrum Depicting Emotion “Sadness”



(j) Participant 10 SAM rating under Green Colour Spectrum Depicting Emotion “Sadness”

Figure 38: SAM Rating of The Subjects Expressing “Sadness” Emotion under Green Light

3.5.2 Data Recorded Through Electroencephalography (EEG) Device

The EEG gadget concurrently captured the subjects' EEG data as they performed under various lighting conditions. In this study, the "EMOTIV EPOC FLEX" with saline sensors was used. One of the main factors in choosing this gadget was its mobility, which was necessary to guarantee the performers' freedom of movement. 32 electrodes (Cz, Fz, Fp1, F7, F3, FC1, C3, FC5, FT9, T7, CP5, CP1, P3, P7, PO9, O1, Pz, Oz, O2, PO10, P8, P4, CP2, CP6, T8, FC6, C4, FC2, F4, F8, Fp2) and two reference electrodes, Common Mode Sense (CMS) and Driven Right Leg (DRL), are included (DRL). DRL must be positioned over the right mastoid, and CMS must be positioned over the left mastoid. According to the

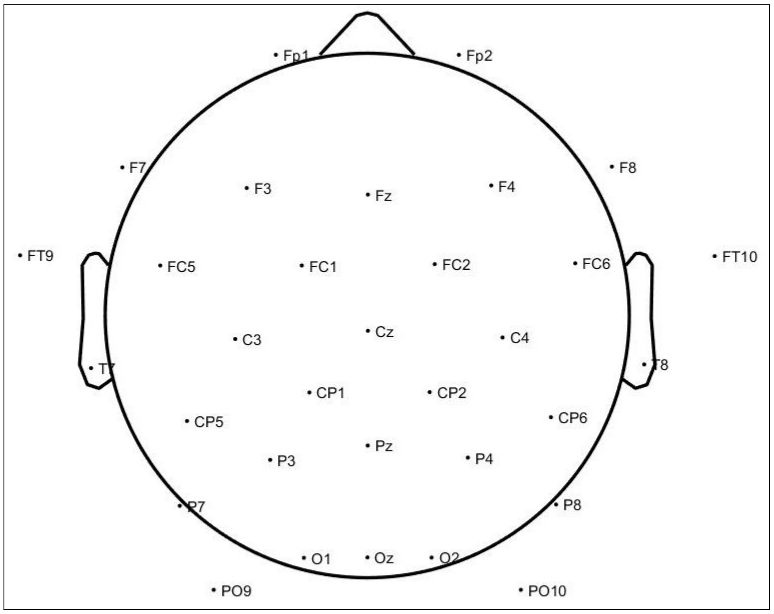
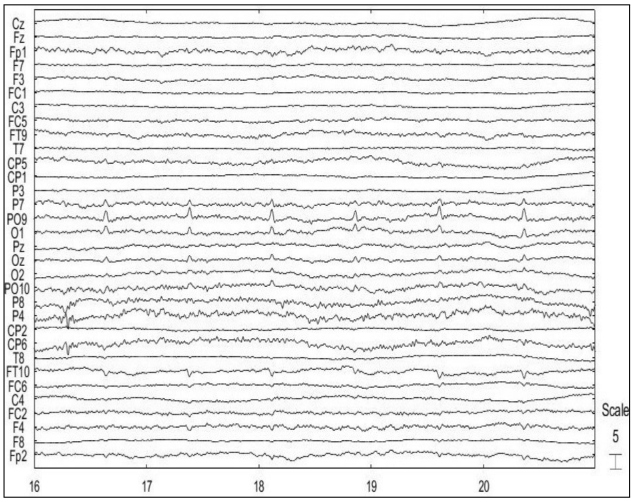


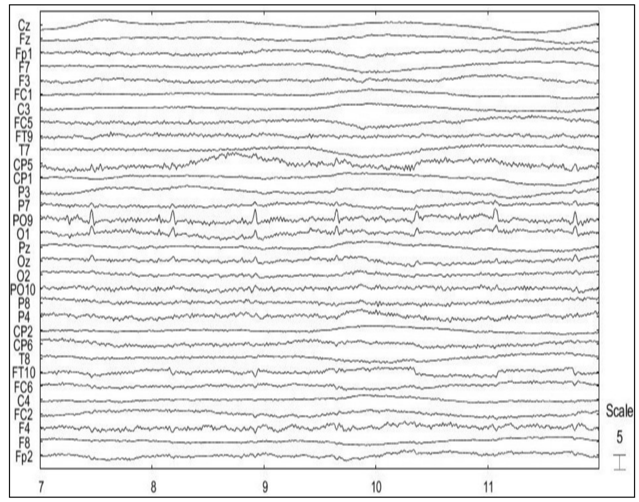
Figure 39: EEG channel locations

International 10-20 system, all of the sensors are encased in caps at the predetermined places. 17 sensors (16 sensors + 1 reference) are coloured blue and should be placed on the left side of the scalp. The remaining sensors are coloured red and should be placed on the right side. Each sensor has a hollow aperture to fit the felt pads, which must be soaked in saline solution before utilising the EEG machine. The outputs of the sensors must be connected to a wireless controller once the electrodes have been set up and placed appropriately. Each electrode's raw EEG data is captured at a sampling rate of 128 sampling per second (SPS) and wirelessly sent to a computer via a generic USB receiver. The "EMOTIV Pro" software allows for the visualisation of real-time data.[79]

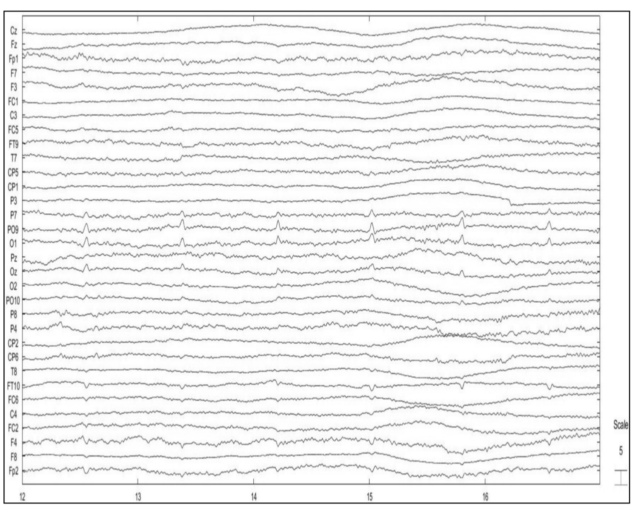
Figures 40a to 40d provide the raw EEG recording of one participant under each lighting condition. The raw data should be filter out with the cut off frequencies 0.5 Hz and 45 Hz to eliminate DC offset value and higher frequency noises. Although the electrodes were placed to exclusively record brain impulses, some noise signals were also recorded due to the electrodes' high sensitivity. In order to eliminate the artefacts from the raw EEG signals, the data must first be cleaned. Later, to extract relevant information, the preprocessed signals were analysed using the Fast Fourier Transform (FFT). Power Spectral Density (PSD) Plots were made using various brain waves and topographic scalp maps plots for every 20 seconds. Also ERP analysis was done. In section 4.3 the preparation processes and analysis method are covered in detail.



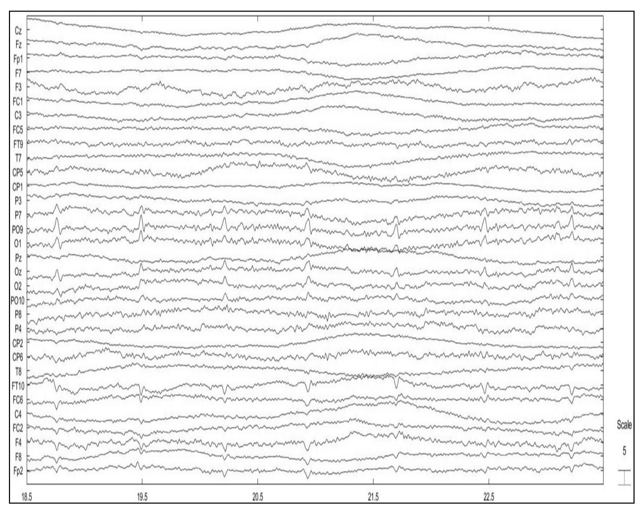
(a) Raw EEG Data Recorded During a Performance under Red Lights



(b) Raw EEG Data Recorded During a Performance under Blue Lights



(c) Raw EEG Data Recorded During a Performance under Yellow Lights



(d) Raw EEG Data Recorded During a Performance under Green Lights

Figure 40: Raw EEG Data Recorded During Performance under All Lighting Conditions.

CHAPTER-4

4 DISCUSSION & ANALYSIS

4.1 Self Assessment Manikin Data Analysis

The SAM rating scale was used to evaluate the individuals' emotional states. Participants filled out a Valence scale to indicate their positive emotions, and an Arousal scale to indicate how excited they felt emotionally. The range of both scales is 1 to 9. Where 5 represents the neutral condition on both scales.

The scales are then normalised to have a range of "-1 to +1," with "Neutral" emotional state being at (0,0). The formulae used for normalisation are -

$$Normalised\ Valence = \frac{Actual\ Valence - 4}{5} \tag{9}$$

$$Normalised\ Arousal = \frac{Actual\ Arousal - 4}{5} \tag{10}$$

The equations 9 and 10 state equivalence Valence and Arousal rating, respectively.

The data has been normalised for easier understanding, visual interpretation and depiction. The first quadrant has positive X-axis and Y-axis coordinates when mapping data in two dimensions space, whereas the second quadrant has negative X-axis and positive Y-axis values. In the third quadrant, both the X coordinate and Y coordinate are negative, and in the fourth quadrant, the X coordinate is positive but the Y coordinate is negative. The neutral point on the valence and arousal scales, which have a range from +1 to +9, is at (5,5), therefore regardless of the emotion, the data will be shown in the first quadrant, which might be misleading to a layperson, who is not experienced with this field of study. The equations 9 and 10 show how to change valence and arousal scales scientifically such that there is no confusion. By making this modification, the data is normalised from "+1 to +9" to "-1 to +1" and the origin is moved to (0,0). The data are mathematically normalised in order to suit the new range. Table 3 displays the matrix of normalised valence and normalised arousal ratings for each participant under each of the four lighting conditions. The data is then averaged for each lighting condition across all 10 subjects, is shown in table 4.

- Average Valence & average Arousal rating under Red lights are (-0.40, -0.575) respectively.
- Average Valence & average Arousal rating under Blue lights are (-0.825, -0.75) respectively.

	Red	Blue	Yellow	Green
Participant 1	Valence : - 0.5 Arousal : - 1	Valence : - 1 Arousal : - 0.75	Valence : - 0.75 Arousal : - 0.25	Valence : 0 Arousal : 0
Participant 2	Valence : - 0.25 Arousal : - 0.75	Valence : - 0.75 Arousal : - 0.5	Valence : - 0.25 Arousal : - 0.25	Valence : - 0.5 Arousal : - 0.5
Participant 3	Valence : - 0.75 Arousal : - 0.5	Valence : - 1 Arousal : - 0.75	Valence : - 0.5 Arousal : - 0.75	Valence : - 0.75 Arousal : - 0.5
Participant 4	Valence : 0 Arousal : - 0.5	Valence : - 0.75 Arousal : - 0.75	Valence : - 0.25 Arousal : - 0.25	Valence : - 0.5 Arousal : - 0.5
Participant 5	Valence : - 0.5 Arousal : - 0.75	Valence : - 1 Arousal : - 1	Valence : 0 Arousal : - 0.5	Valence : 0 Arousal : - 0.5
Participant 6	Valence : - 0.25 Arousal : 0	Valence : - 0.25 Arousal : - 0.75	Valence : 0 Arousal : 0	Valence : - 0.25 Arousal : 0
Participant 7	Valence : - 0.25 Arousal : - 0.5	Valence : - 0.75 Arousal : - 0.5	Valence : 0 Arousal : - 0.25	Valence : - 0.75 Arousal : - 0.5
Participant 8	Valence : - 0.75 Arousal : - 0.5	Valence : - 1 Arousal : - 1	Valence : - 0.25 Arousal : - 0.25	Valence : 0 Arousal : - 0.25
Participant 9	Valence : - 0.5 Arousal : - 0.75	Valence : - 1 Arousal : - 0.75	Valence : - 0.5 Arousal : - 0.25	Valence : - 0.25 Arousal : - 0.25
Participant 10	Valence : - 0.25 Arousal : - 0.5	Valence : - 0.75 Arousal : - 0.75	Valence : 0 Arousal : 0	Valence : 0 Arousal : - 0.5

Table 3: Normalised SAM Rating of Ten Participants under Four Lighting Conditions

	Red	Blue	Yellow	Green
Average Values of Normalised SAM Ratings of Ten Participants	Valence : - 0.40 Arousal : - 0.575	Valence : - 0.825 Arousal : - 0.75	Valence : - 0.225 Arousal : - 0.275	Valence : - 0.3 Arousal : -0.35

Table 4: Average Values of Normalised SAM Ratings of Ten Participants under Four Lighting Conditions

- Average Valence & average Arousal rating under Yellow lights are (-0.225, -0.275) respectively.
- Average Valence & average Arousal rating under Green lights are (-0.30, -0.35) respectively.

Figure 41 shows a scatter plot in a two-dimensional space with Valence on the X-axis and Arousal on the Y-axis. Figure 41 makes it abundantly evident that the **Blue light spectrum** is more stimulating than other light spectra that are consistent with the domain of research.

Figures 42a to 42d show bar graphs of 10 participants averaged SAM ratings as horizontal axis 'Valence' and 'Arousal' and vertical axis its value; for all the lighting conditions.

On normalised SAM data, additional statistical analysis is done to see if there are any statistically significant colours that better convey the emotion of "Sadness."

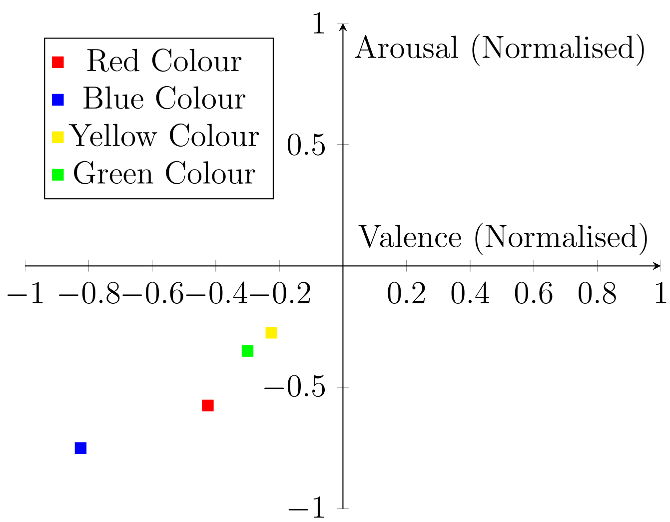
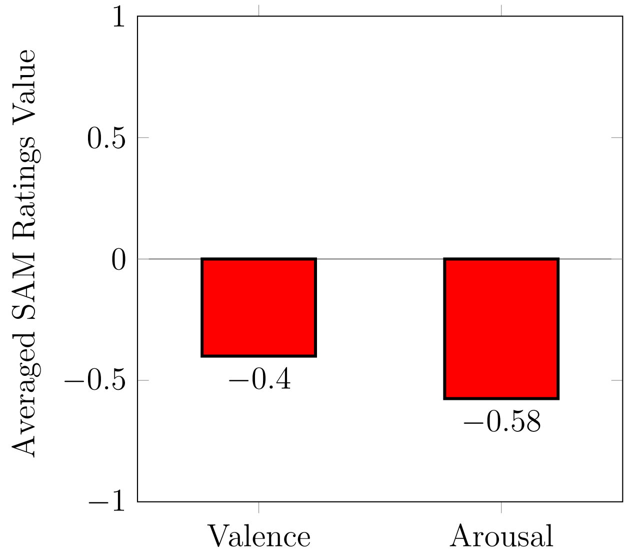
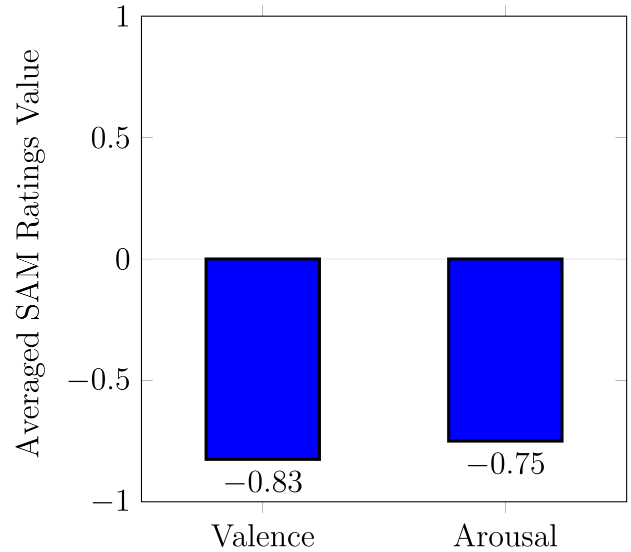


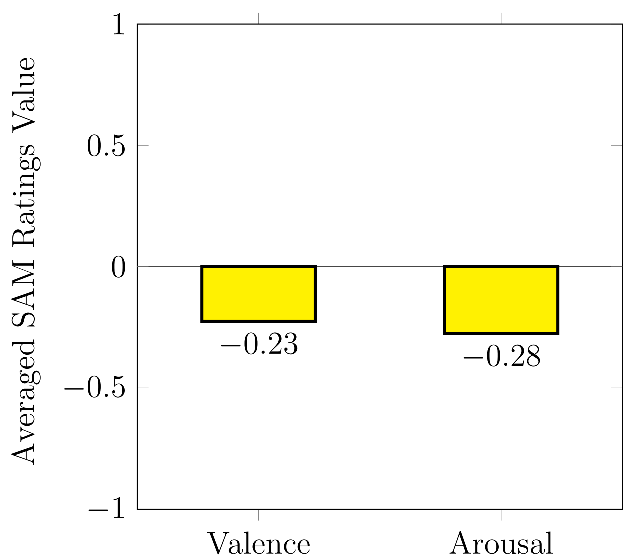
Figure 41: Plot of Average Valence (X-axis) and Average Arousal (Y-axis) Ratings in Two Dimensional Space



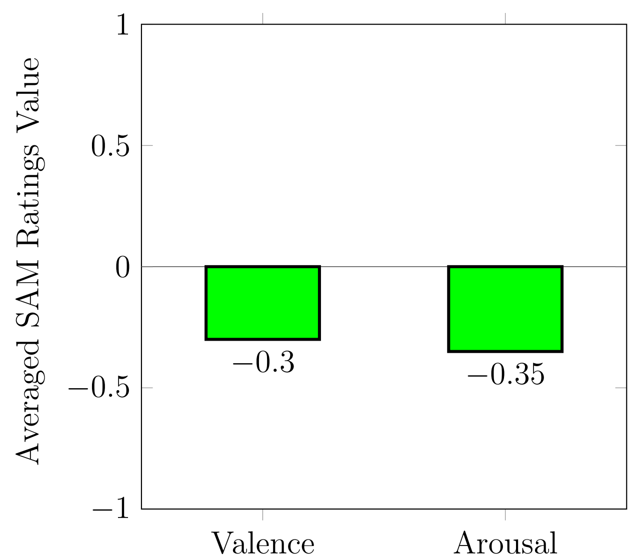
(a) Normalised Average SAM Rating under Red Colour Depicting Emotion "Sadness"



(b) Normalised Average SAM Rating under Blue Colour Depicting Emotion "Sadness"



(c) Normalised Average SAM Rating under Yellow Colour Depicting Emotion "Sadness"



(d) Normalised Average SAM Rating under Green Colour Depicting Emotion "Sadness"

Figure 42: Normalised Average SAM Rating for All Lighting Situations

4.2 Data Analysis by Single Factor ANOVA & Post-Hoc Test

A Single Factor Analysis of Variance (ANOVA) is a statistical tool for estimating if a difference between the means of three or more groups of data is statistically significant or not. The statistician Ronald Fisher first used it in 1918.[80] It became well-known when Fisher's book "Statistical Method for Research Workers" used the phrase.[81] This procedure is an improvement over the t-tests and z-tests that were in use before the invention of ANOVA. These tools had the restriction that they could only be used to compare the means of two groups at once. In order to comprehend the diversity within and between groups, it is therefore preferable to do an ANOVA on a large number of groups or populations.

ANOVA is basically a hypothesis-testing technique that analyses a relatively small sample of a larger group for the evaluation of an educated hypothesis that was prepared prior to the test. The first hypothesis is that there is no difference between the means of each group considered for an acceptable level of significance, same as in the case of an ANOVA where means of three or more groups of data are compared. This is known as "Null Hypothesis (H_0)". There is another one hypothesis known as "Alternate Hypothesis (H_1)". This states that at least one mean differs significantly from the means of the other groups. The ratio of variability between groups to variability within groups, is known as 'F' value which is the test statistic for an ANOVA.

$H_0 : \mu_1 = \mu_2 = \mu_3 = ... = \mu_k$
$H_1 :$ All means are not equal

where, k = number of groups
μ = mean of each group

The p-value can be used to confirm statistical significance of the test results. If the p-value is less than the level of significance (α)(There is likelihood of rejecting the null hypothesis even if it is true), and the F-value is high, it indicates that there is a high likelihood of having significant differences in the means of the individual groups, this is because large variations in the data between the groups. In that case, the null hypothesis has to be rejected.

An ANOVA table often includes crucial information including the F-value, mean squares, degrees of freedom, and sums of squares (SS). Below, these words and their significance are briefly discussed:

1. **Sum of Squares (SS)**:

   Data variability is represented by the sum of squares. Three separate parts are used to calculate this phrase. The Sum of Squares between (SSB) a group is calculated first, The Sum of Squares (SSW) within a group is calculated second, and then simply added both term (SST = SSB + SSW).

   Sum of Square between groups is the term used when the variation is compared between groups (SSB). It is calculated by adding together the squared differences between the individual group means ($\bar{X}_j$) and the grand mean ($\bar{X}$), and multiplying those differences by sample size of the group (n_j).

$$SSB = \sum n_j(\bar{X}_j - \bar{X})^2 \tag{11}$$

Another term used to describe data variation within a single group is Sum of Square within Groups (SSW). It is calculated by adding the squared differences between the each sample (X) of the group and the group mean ($\bar{X}_j$).

$$SSW = \sum(X - \bar{X}_j)^2 \tag{12}$$

The sum of squares between groups (SSB) and the sum of squares within groups are added to get the total sums of squares (SST) (SSW).

$$SST = (SSB + SSW) = (\sum n_j(\bar{X}_j - \bar{X})^2 + \sum(X - \bar{X}_j)^2) \tag{13}$$

where:

n : the sample size of group j

X : sample entity of group j

σ : a Greek symbol that means " Summation "

$\bar{X}_j$: the mean of group j

$\bar{X}$: the grand mean

2. **Degrees of Freedom (df)** :

The degree of freedom (df) of the estimation is the number of independent sample points utilised to compute an approximation. The formulas below can be used to determine the degrees of freedom between groups (df_1) and within groups (df_2), also known as the numerator and denominator degrees of freedom, respectively.

$$Degree\ of\ Freedom\ Between\ Groups\ (df_1) = k - 1 \tag{14}$$

$$Degree\ of\ Freedom\ Within\ Groups\ (df_2) = N - k \tag{15}$$

where :

k : Number of groups

N : Total number of sample points

3. **Mean Squares (MS)** :

The ratio of the Sum of Squares to the degree of freedom is the Mean Square value. The average sum of square between groups (MSB) is calculated by dividing sum of squares between groups (SSB) by the numerator degree of freedom (df_1) and the average sum of square within groups (MSW) is calculated by dividing the sum of square within groups (SSW) by denominator degree of freedom (df_2).

$$MSB = \frac{SSB}{(df_1)} = \frac{\sum n_j(\bar{X}_j - \bar{X})^2}{k - 1} \tag{16}$$

$$MSW = \frac{SSW}{df_2} = \frac{\sum(X - \bar{X}_j)^2}{N - k} \tag{17}$$

4. **F - Value** :

   The test statistic of Analysis of Variance (ANOVA), which is also known as F-value is the ratio between the average variability between groups and the average variability within groups.

$$F - Value = \frac{MSB}{MSW} = \frac{\frac{\sum n_j(\bar{X}_j - \bar{X})^2}{k-1}}{\frac{\sum(X - \bar{X}_j)^2}{N-k}} \tag{18}$$

After finding the F-value, it should be compared with the F-statistic or the F-critical value and the p-value should be checked in order to conclude whether any group mean is statistically significant than rest of the group means. The F-distribution curve, which is a function of the level of statistical significance (α), numerator degree of freedom (df_1), and denominator degree of freedom (df_2), may be used to determine the F-critical value. The test results are significant if the F-value exceeds the F-critical limit. In that situation, the p-value should be smaller than the statistical significance level (α), and the null hypothesis should be rejected.

One-way ANOVA and two-way ANOVA are the two categories into which are classified based on the number of independent variables or factors. A one-way ANOVA only takes into account one factor that influences the results, but a two-way ANOVA takes into account two independent variables. One may think of two-way ANOVA as a progression from one-way ANOVA. Because a two-way ANOVA test comprises two independent factors, the individual effects of each independent factor on the dependent variable are first assessed, just as it does in the case of a one-way ANOVA. Additionally, the interplay between the factors is addressed by taking into account every aspect at once.

One of the main problems with ANOVA is that it can only confirm that the means of all the groups are different; it cannot say which group is statistically different. Post hoc tests are essential when three or more groups are being analysed in order to identify the statistically significant group. The two tail t-test is one method for performing post hoc analysis . It analyses the means of two groups simultaneously and does other comparisons dependent on the group size. However, when the number of comparisons increases, the experiment-wise error rate also dramatically increases. Statistical significance level (α) is the experiment-wise error rate. The risk of false positive results or rejecting the null hypothesis when it is true increases with the number of tests performed. After a given number of groups have been analysed, getting a false positive is mostly clear. It is essential to control the error rate in order to ensure the accuracy of the results. The Bonferroni correction method is one of the easiest ways of reducing the error rate. It advises calculating the p-value for each comparison test by dividing the statistical significance threshold (α) by the number of comparisons (n). If a group continually has a p-value for comparisons with other groups that is less than α/n, that group is regarded as statistically significant when compared to other groups.

Source of Variations	Sum of Squares (SS)	degrees of freedom (df)	Mean Squares (MS)	F	p-value	F-critical
Between Groups	2.15625	3	0.71875	11.1892	0.000025	2.8663
Within Groups	2.3125	36	0.064236111			
Total	4.46875	39				

Table 5: Table for The Normalised Valence Ratings

Source of Variations	Sum of Squares (SS)	degrees of freedom (df)	Mean Squares (MS)	F	p-value	F-critical
Between Groups	1.40625	3	0.46875	9.8540146	0.0000697	2.866266
Within Groups	1.7125	36	0.0475694			
Total	3.11875	39				

Table 6: Table for The Normalised Arousal Ratings

For this study, one way ANOVA is used to analyse the normalised SAM data with Colour spectrum as a factor. The significance threshold (α) was chosen at 0.05. To determine if the colour spectrum has any discernible impact on these characteristics, two distinct tests were carried out: one for valence ratings and the other for arousal ratings. Analysing the Valence ratings is given comparatively greater attention since "Sadness" is a highly negative eliciting and low arousing emotion. The results has been shown a significant difference in valence ratings ($F = 11.1892$, p-value < 0.001) [Table 5]. Additionally, there were significant differences in the arousal ratings ($F = 9.8540$, p-value < 0.001) [Table 6]. Therefore, two-tail t-tests are used in **post hoc** testing to determine which colour is the more stimulating. The results demonstrate that Blue has the most statistically significant impact on Valence with respect to any other colour. The Arousal ratings were also subjected to post hoc testing, although none of the results were statistically significant. So it can be safely concluded that **Blue colour is the optimum choice to model highly negative and less arousal "Sadness" emotion in theatrical performance**.

4.3 Electroencephalography (EEG) Data Analysis

Emotiv Pro software was used to record the electrical activity of the brain throughout the performance. After each session, the recordings were downloaded in European Data Format (.edf) from Emotiv Pro software environment and stored into a laptop. After all of the EEG recordings for each subject under each lighting condition were accessible, the data processing method got started.

MATLAB R2019a has been used to pre-process and analyse the recorded EEG data. It was necessary to download the "EEGLAB" MATLAB toolbox, which features an interactive graphical user interface and several extensions for EEG data processing. This made the process simpler. Prior to starting the data analysis, the connection path between MATLAB and EEGLAB was set up. The steps followed for EEG data analysis is shown in figure 43.

The initial and most important step was individual data preprocessing. In this stage, the most of noises or artefacts from the recorded signals were removed, making it possible to later retrieve useful information from the preprocessed signals. Any DC offset present in raw signals was first removed. The frequency components of movement artefacts and other important artefacts are greater than those of the brainwaves, which normally vary from 2 Hz to 45 Hz. The signals were passed through a digital bandpass filter with a lower cut-off frequency and a higher cut-off frequency of 0.5 Hz and 45 Hz, respectively, to remove the high-frequency artefacts. After then, the signals were re-referenced in regard to the average of the 32 channels. The contaminated area is then manually removed from the dataset along with all of the high amplitude artefacts. To prevent the loss of any beneficial brain impulses, the rejections had been carefully carried out.[82] After manual rejection, around 100 seconds of EEG data was selected and divided into five 20-second epochs.

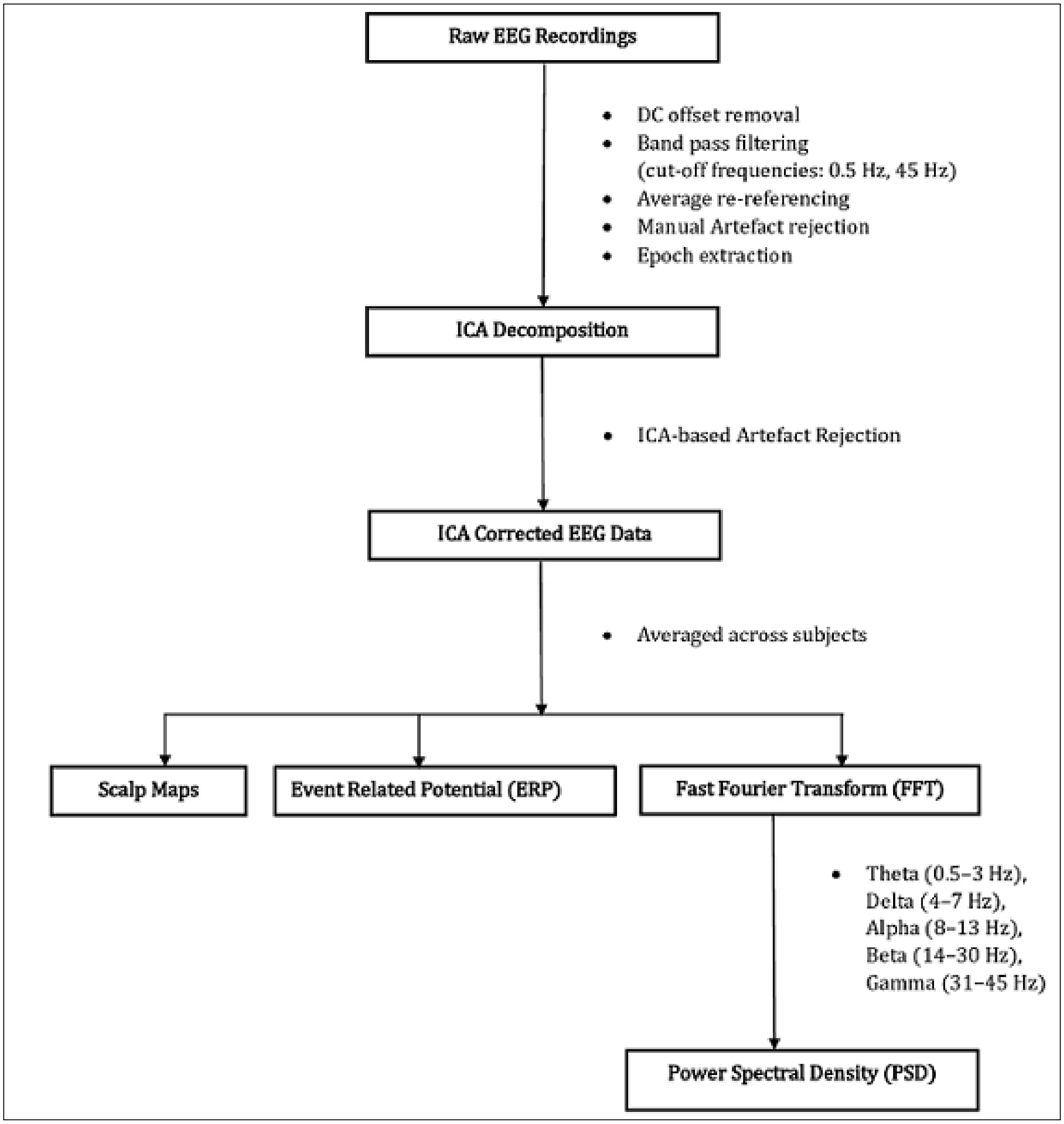


Figure 43: The Step-Wise Procedure Followed for EEG Data Analysing

Some artefacts persist even after preprocessing steps are effective in removing high frequency and high amplitude artefacts from the data. In order to discriminate between brain signals and artefactual signals with a frequency near to brain signals, such as eye blinks and muscle movement artefacts, Independent Component Analysis (ICA) was implemented.[83] A combination of such signals is separated from the statistically independent non-gaussian sources using the statistical and computational approach known as ICA. The method constructed 32 spatially fixed but maximal temporally independent components (IC) because there were 32 EEG channels. The signal was then checked for and cleaned of artefacts brought on by heartbeat, eye blink, and muscular contraction.[84]

4.3.1 Scalp Map

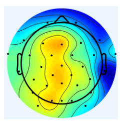
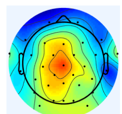
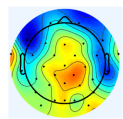
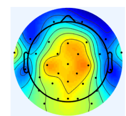
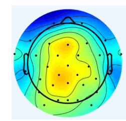
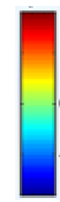
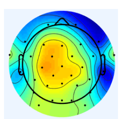
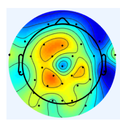
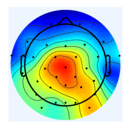
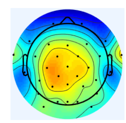
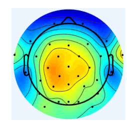
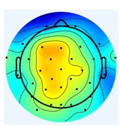
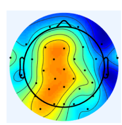
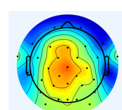
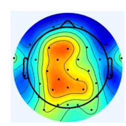
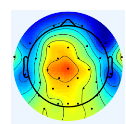
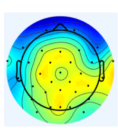
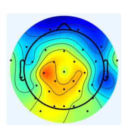
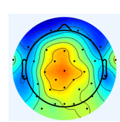
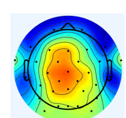
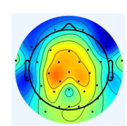
Light Spectrum	Latency (Second)					Scale
	0-20 Sec	**20-40 Sec**	**40-60 Sec**	**60-80 Sec**	**80-100 Sec**	
RED	 Peak Value: $-3.3\ \mu V$	 Peak Value: $-4.8\ \mu V$	 Peak Value: $-5.9\ \mu V$	 Peak Value: $-7.3\ \mu V$	 Peak Value: $-4.6\ \mu V$	
BLUE	 Peak Value: $-6.3\ \mu V$	 Peak Value: $-7.2\ \mu V$	 Peak Value: $-12.4\ \mu V$	 Peak Value: $-9.3\ \mu V$	 Peak Value: $-5.6\ \mu V$	
YELLOW	 Peak Value: $-2.8\ \mu V$	 Peak Value: $-4.3\ \mu V$	 Peak Value: $-5.9\ \mu V$	 Peak Value: $-6.6\ \mu V$	 Peak Value: $-5.5\ \mu V$	
GREEN	 Peak Value: $-3.5\ \mu V$	 Peak Value: $-5.1\ \mu V$	 Peak Value: $-5.8\ \mu V$	 Peak Value: $-6.2\ \mu V$	 Peak Value: $-5.3\ \mu V$	

Table 7: Topographic Scalp Maps under Four Lighting Conditions

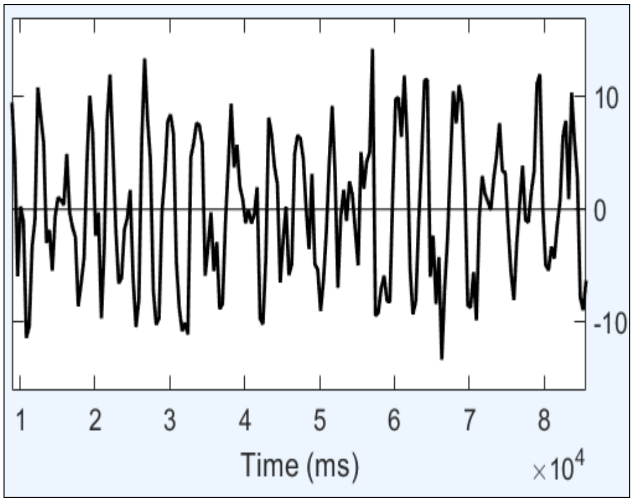
Following the preprocessing and ICA adjustment of the raw EEG data, then data from the individuals were averaged across all lighting conditions, and made four sets of EEG dataset.[85] Scalp maps at each interval of 20 seconds [Table 7] were created. The various colours depict the level of activity in the various brain areas related to the task. Red and blue show the highest levels of positive and negative involvement, respectively, while other colours indicate according to the scale.

It gives a rough idea of the areas of the brain that are activated or engaged. There are several potential sources for the electrical impulses that stimulate the brain. Using topographic plots, which have coloured contour outlines, it is simple to see the activation/engagement zones. It is clear that the brain was more negatively engaged under Blue light than it was in the other three lighting conditions. For every data epoch, the peak amplitude of brain signals during performances under Blue lights was highest, and it was discovered that the Red colour spectrum was least activating for expressing "Sadness". Only under the Blue light spectrum was it discovered that the central lobe was more active during the first 20 seconds. However, regardless of the lighting used, activity in the pre-frontal brain and temporal area increased throughout the next four epochs. The area of the brain known as the amygdala & hypothalamus, controlled Sadness emotion, is located in the Temporal region. All the emotion is pre-processed by Pre-Frontal lobe. So, in every scalp map shows the activity of pre frontal lobe. Therefore, increased activity in the vicinity of such areas verifies the EEG recording and the preprocessing procedures used. Additionally, it was discovered that the right hemisphere of the brain is more active than the left, which is consistent with the literature at hand.[86]

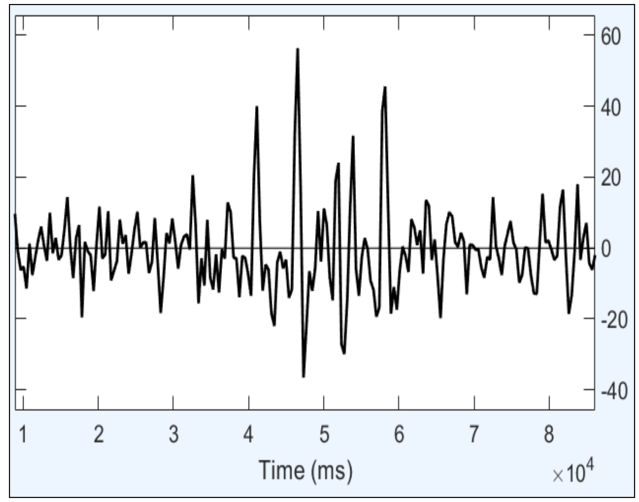
Up until the midpoint of the performance, the amplitude of the received signals were found to be increasing (the highest amplitude of the voltage across all lighting conditions was found to be **-12.4 μV** for Blue coloured lights), and as time went on, it began to decrease (the lowest amplitude of voltage recorded was found to be **-2.8 μV** for Yellow coloured lights). The participants' emotional outburst occurred in the middle of their performance, so that's possible to be said. The scalp maps only gives data of the contours of brain activity.

4.3.2 Event Related Potential (ERP) Analysis

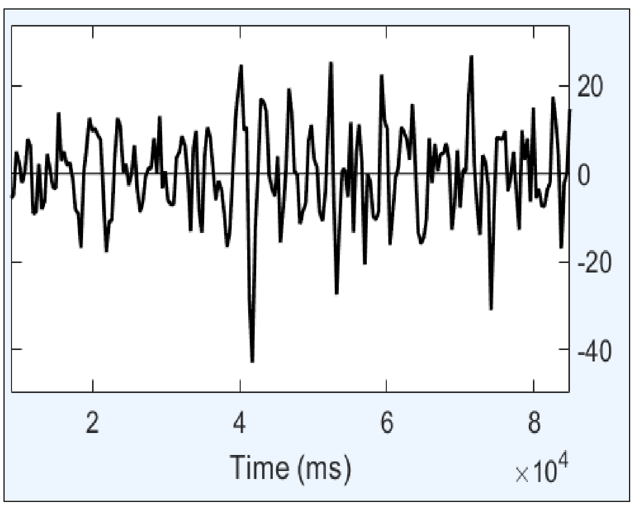
An event-related potential (ERP) in electroencephalography (EEG) is a brain response that has a consistent temporal association with a reference event (it can be motor, cognitive or sensory). It is a method that has been extremely helpful in cognitive neuroscience since Pauline and Hallowell Davis published the first ERP recordings from conscious humans in 1939.[87] Briefly, one may determine if an ERP is positive or negative by repeatedly displaying the event of interest (for example, an image) and averaging the many signals time-locked by the presentation of the stimulus.[88] Following preprocessing and ICA execution on the raw EEG data, all individuals' averages were calculated. Finally, a reliable 95 second duration of artefact-rejected data was obtained. The information provides Event Related Potential Value (ERP) ranges in μV across the time period. One can determine brain electrical signal activity from this data. A higher voltage indicates a greater response from the brain to the stimulus that initiates the activity. The ERP plot is shown in figure Figures 44a to 44d.



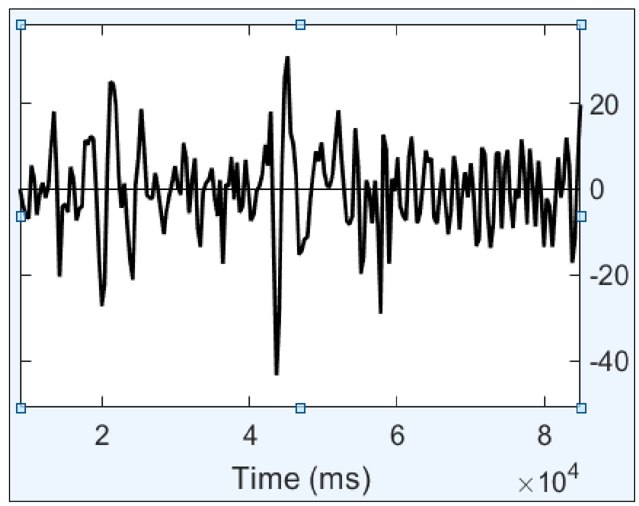
(a) Event Related Potential Analysis under Red Light



(b) Event Related Potential Analysis under Blue Light



(c) Event Related Potential Analysis under Yellow Light



(d) Event Related Potential Analysis under Green Light

Figure 44: Event Related Potential Analysis for All Lighting Conditions

It is visually evident from the fig. 44b that the ERP value was 57 μV at 48 sec. The highest positive peak gets for sadness emotion conveying while subjects operated under blue light. The ERP value is significantly lower in other lighting situations. The emotional outburst took place in somewhere between 40 – 60 seconds. So, brain is more active and voltages fluctuate from positive to negative peak. It takes 40-60 sec to response more highly for expressing emotion after getting stimulus regardless of lighting conditions.

4.3.3 Power Spectral Density (PSD)

EEG feature extraction frequently uses frequency domain analysis since the original EEG data is non-stationary and a combination of different frequencies. Power spectral density is a popular method for visualising the distribution of signal power across frequencies (PSD). Let's say there is a signal $x(t)$ with average power P . The following formula may then be used to calculate the total power:

$$P = \lim_{T\to\infty} \frac{1}{T} \int_{-\infty}^{+\infty} |x(t)|^2 \, dt \tag{19}$$

Let $\bar{X}(omega)$ be the frequency component of the signal $x(t)$, which may be derived using the Fourier Transform. Even though it is impossible to calculate the Fourier transform of every signal, the following may be expressed using Parseval's theorem:

$$P = \lim_{T\to\infty} \frac{1}{T} \int_{-\infty}^{+\infty} |\bar{x}(\omega)|^2 \, d\omega \tag{20}$$

So, the Spectral Power Density (PSD) of the signal can be computed as,

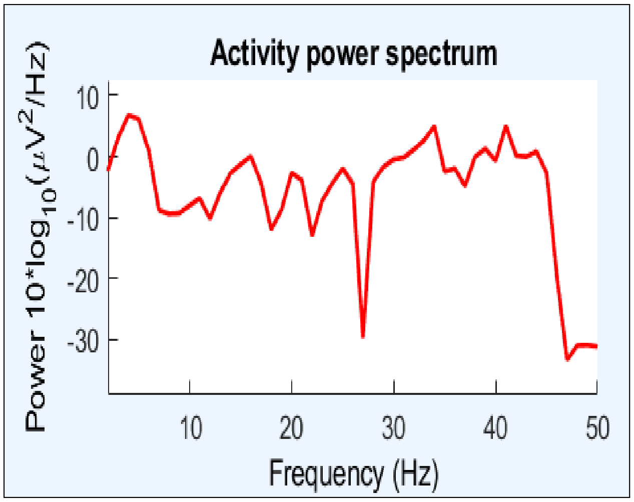
$$S_{xx}(\omega) = \lim_{T\to\infty} \frac{1}{T} |\bar{x}(\omega)|^2 \tag{21}$$

where, $S_{xx}(\omega)$ denotes the PSD.

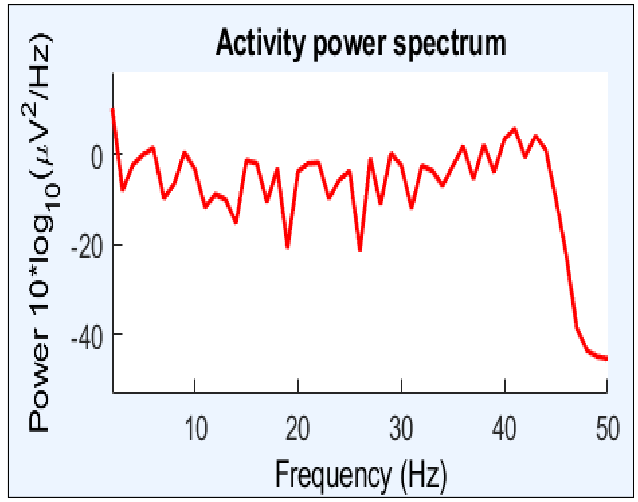
These days, feature extraction algorithms for emotion recognition frequently use this methodology.[89] [90] Researchers have been examining the brain's frequency bands to discover a pattern in the PSD that the brain generates that corresponds to a certain emotion. These patterns are then recorded as a training database, which may later be used with the EEG recordings to forecast emotional states. Numerous studies have found a connection between emotional response and high frequency brain waves like the beta and gamma frequency bands.[91][92] The right hemisphere of the brain is thought to be associated with emotions in particular through gamma activity [93] Therefore, in this study's detailed investigation of the beta and gamma frequency bands is main focused while the greatest PSD values for the four lighting conditions are evaluated for.

Fast Fourier transform (FFT) was used to the preprocessed, artefact-free, and averaged EEG recordings to turn them into frequency domain signals. The signal powers are then determined for all lighting circumstances for the beta frequency band (14–30 Hz) and gamma frequency band (31–45 Hz).[77]

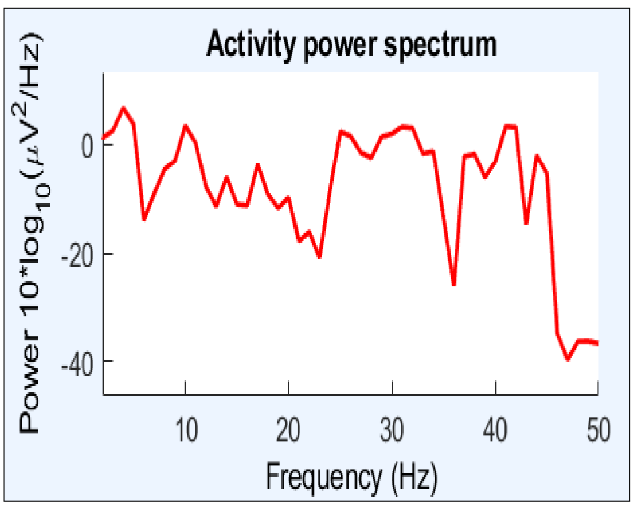
Figures 45a to 45d show the grand averaged power spectrum activity of the brain for all subjects, regardless of the lighting conditions. It is possible to infer from this fig. 45 that there are some positive and negative peaks in the 0–50 Hz frequency range. Theta band (4–7 Hz), alpha band (8–13 Hz), beta band (14–30 Hz), and gamma band (31-100 Hz) can be divided into the frequency range. Gamma(31–50 Hz) and high beta(21–30 Hz) frequency bands are often linked to emotion analysis. Power spectra feature a positive peak or a negative peak under all lighting situations, which implies the brain actively participates in emotion processing.



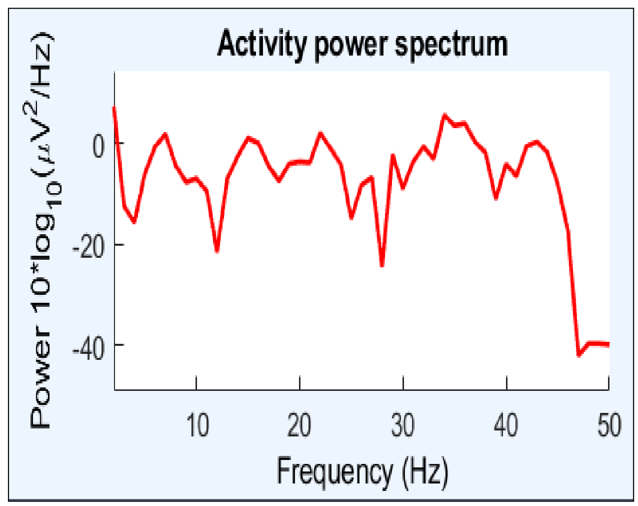
(a) Power Spectrum Activity under Red Light



(b) Power Spectrum Activity under Blue Light



(c) Power Spectrum Activity under Yellow Light



(d) Power Spectrum Activity under Green Light

Figure 45: Power Spectrum Activity Analysis for All Lighting Conditions

So it is acceptable to assume that Figure 45 reflects the data related to emotion. Additionally, it is evident that the power spectrum activity is spread more densely under blue light (Figure 45b). It means that the brain seems to be more actively pulse from positive peak to negative peak than it would be in other lighting situations. Figure 45, however, does not explicitly state which light spectrum is better suited for portraying the emotion of sadness or even what emotion it is.

CHAPTER-5

5 CONCLUSION

With the introduction of the most recent technology in illumination engineering, lighting parameters including spectrum composition, illuminance value, correlated colour temperature, colour rendering, efficacy, etc. may be simply controlled. The conventional approach to illumination engineering has evolved as a result of the discovery of intrinsically photosensitive retinal ganglion cells (ipRGC) in the human eye. Through lighting design and application, one can experience lighting's visible and non-visual effects. Numerous studies on the psychological and physiological effects of lighting on human behaviour have been conducted in the twenty-first century. Human Centric Lighting has therefore been established as the terminology. [94]

Led technology and Human Centric approach was used to complete this project study. The primary inspiration for the work was the ease with which the light spectrum could be changed to produce a monochromatic colour. Additionally, this study was EEG-based. The EEGLab toolbox can be utilized to easily analyse the brain activity electrical signal data.[95]

To talk about the stage or theatre lighting design, which should be done so that the audience can only view the performer and not the entire stage. With the aid of LEDs, numerous light colours are produced for enhanced visualisation. The audience could enjoy the performance and not become visually fatigued. But the primary concern of this study is how that colour of light affects the emotional performance of the performer.

This study used EEG data and was subject-based. Therefore, behavioural outcomes may change as the subject varies. EEG data can also differ from person to person.Additionally, recording the EEG data is a big challenge as there are disturbances present. As a result, there are several elements to consider and the outcome may vary. However, in this experimental strategy, 10 neurologically healthy, sound professional performers (6 men and 4 women, age 23 with SD $\pm$ 2 years) were chosen for the study.

The results were obtained by matching the behavioural and EEG studies. The individuals' evaluations on the Self Assessment Manikin (SAM) have been examined. The average valence and arousal plots are consistent with the two-dimensional circumplex model for blue lights, where Sadness Emotion was plotted in the Third Quadrant. The negative emotion level was significantly higher for blue lighting settings than for other lights, according to the results of the ANOVA and post hoc test on the normalised valence ratings of the individuals. Since valence is a vital component in the presentation of sad emotion, more valence (negatively) can be linked to enhanced expression of sadness. The EEG data's output is same as well. The pre-frontal and temporal areas of the brain seemed to have the highest signal under blue light (peak amplitude: -12.4 μV), and higher negative engagement is demonstrated, according to the topographic scalp maps created from the preprocessed, artefact-free EEG data. The Event Related Potential (ERP) plot also yielded the same result (largest positive peak under blue light). Although ERP can be examined for a short amount of time. However, in this case the stimulus's impact lasted for more than 100 seconds. It is challenging to establish short-duration Epoch in the study. Therefore, the 95 seconds that the ERP plot took to provide a suitable outcome. Even so, this result had to include the same details. Moreover, additional analyses were backed by the brain's power spectrum activity. The idea that theatre performers choose blue light in sorrowful scenes. From the findings of the numerous processes utilised in this experiment, it can be reasonably concluded that the participants were better able to express their sadness under **BLUE** lighting. Therefore, it can be concluded that this EEG-based technique may be utilised as a useful tool to assess how people behave emotionally under various lighting situations.

6 FUTURE STUDY

The brain, an complicated organ, processes the complex aspect of the human emotional experience. Researchers are working to determine which portion of the brain is most responsible for eliciting various emotional states. Recently, the brain's component may be studied in very small ranges and deepest part with the use of EEG and f-MRI studies. In the future, every little cell or component of the brain's structure would be recognised, and it would be known their functioning. Therefore, it would be known in the future which one or two brain regions may be combined to trigger a single emotion.

In this study, monochromatic light was employed, which implies that the light spectrum (or colour) was used discretely (changes of light spectrum is not continuously). To determine the specific light wavelength that would have the most impact on a certain emotion, the light spectrum can be gradually changed from red to violet or from violet to red for further research. For example, sadness is more evocative in the blue spectrum band region, but it is impossible to pinpoint a specific wavelength that causes that evocation.

Four monochromatic light colours Red, Blue, Yellow, and Green were utilised in this experiment to see which colour had the biggest impact in evoking the Sadness emotion during a theatrical performance. There are more fundamental emotions that have yet to be given the proper lighting, such as happiness, anger, surprise, disgust, etc. Actors usually have to deal with a variety of emotions while acting out a scene in a theatre since there may not be a single emotional backdrop in a drama. It might be challenging to find appropriate light spectra that can be used to imitate exceedingly complex emotions or combinations of basic emotions. On how to address these challenges may be the focus of future research in this field.

Future improvements in the EEG study's familiarity and ease of data recording and processing will make it easier to collect the performer's brain signal's raw data and remove disruptions. The outcome will improve. Additionally, results from power spectrum analysis in different frequency bands, such as delta, theta, alpha, beta, and, gamma may be refined.

The research only included ten participants, all of whom were in their mid-20s. Further study As time goes on, there will likely be more participants, which might improve the results. This study may potentially be carried out with non-theatrical participants and may get a different result. It will also be clear if an age group factor exists in the study includes individuals under the age of twenty and those beyond the age of thirty or forty. Additionally, it is unknown if the script itself serves as a stimulus. To extract the same emotion from a different script, the same experiment may be done. Additionally, it is believed that the gender difference factor in emotional expression exists. There were no significant findings in the present study. These are points to improve results in further study.

Future EEG analytical procedures could be enhanced by minimising the computation error. Python or Matlab programming can be used to make this improvement.

However, as the results of any human-related investigations, particularly those based on EEG, vary greatly in general, it is advisable to carry out further research and compile a larger database of various non-theatrical and professional performers for future purposes.

CHAPTER-6

7 REFERENCES

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CHAPTER-7

8 ANNEXURE

8.1 Apparatus Used in Experiment

8.1.1 Bulbs

Wi-Fi-enabled LED from Philips Smart bulbs (Shown in figure 46) that are simple to use, practical, and reasonably priced provide total control over the lighting. Simply connect them to an established Wi-Fi network to make high-quality Philips lights smarter. These bulbs can generate 16 million colours. Also, CCT can vary from 2500 K to 6500 K . Utilise the WiZ lighting app or a voice assistant that is compatible with controlling the lights. For the device to work wirelessly, a WiFi connection is necessary. The Philips Smart Wi-Fi LED smart lamp works with WiZ products and applications in addition to Alexa, Google Assistant, and Siri Shortcuts. In this study 4 Philips Led bulbs had been used.

Figure 46: Philips Smart Bulb

8.1.1.1 Additional Features

Install in 3 Easy Steps

1. Plug In the Bulb
2. Download the Free Wiz App
3. Follow Steps to Complete Set-up

8.1.1.2 Specifications of The Led Bulbs

Bulb Dimensions

Height	:	11.8 cm
Weight	:	0.07 Kg
Width	:	6 cm

Bulb Characteristics

Dimmable	:	Wireless Dim
Intended	:	Indoor
Lamp Shape	:	A19.
Socket	:	B22
Technology	:	LED
Type of Glass	:	Frosted

Durability

Average Life (at 2.7 Hrs/Day)	:	25 Years
Lumen Maintenance Factor	:	0.7
Nominal Lifetime	:	25,000 Hours
Number of Switch Cycles	:	50,000

Light characteristics

Beam Angle	:	120 Degrees
Colour Rendering Index (CRI)	:	90
Colour Temperature	:	2700-6500 K
Light Colour Category	:	Colour and Tunable White
Nominal Luminous Flux	:	825 Lumen
Starting Time	:	<1 Sec
Colour Code	:	927 - 965

Other Characteristics

Lamp Current : 100 mA

Efficacy : 91.1 lm/W

Packing Information

Product Family : LED

Product Title : Philips Smart WiFi Led Full Colour 9 Watt Led Bulb B22

Power Consumption

Power Factor : 0.9

Voltage : 220 - 240 Volt

Wattage : 9 Watt

Wattage equivalent : 60 Watt

8.1.2 KONICA MINOLTA CL-70F CRI Illuminance Meter

Throughout the duration of the experiment, this instrument had been utilised to verify the constancy of the lamp colours. Before the experiment began, each lamp's light output had its spectrum composition and chromaticity measured daily. The common name of the CRI Illuminanace Meter is CL-70 F and made by Konica Minolta company.

Figure 47: CRI Illuminance Meter CL-70F

The CRI Illuminance Meter CL-70F is a portable, lightweight equipment for evaluating the colour, spectral power distribution (spd), and illuminance of light sources, including new LED and EL light sources. The terms used to describe measurement data include

CRI, tristimulus values, illuminance, chromaticity, dominant wavelength, excitation purity, correlated colour temperature, and spd differential values from a target. The CL-70F may be used in conjunction with a flash sync connection that is easily available on the market to analyse the spectrum of photographic flashes. The utility application CL-SU1w, which is included by default, adds further capabilities for data gathering and analysis.

8.1.2.1 Features

Main features of CL-70F

- Spectral sensor.
- Measure CRI.
- Compact, easy to carry and battery operated.
- Colour touch screen.

Lighting design and continuous maintenance are only two of the usual lighting jobs that the lightweight CL-70F body is made for. The CL-70F gives entry-level access to cutting edge light measurement features by measuring CRI and providing spectral data. The CL-70F is a potent tool for professional image and entertainment sectors when used in conjunction with a flash sync connection, which permits spectral measurements of flash light.

Colour Rendering Index measurement :

Access to measurement information for the Colour Rendering Index (CRI) is made simple by the CL-70F. The display presents a simple bar graph of the Ra value together with each individual index (R1 to R15).

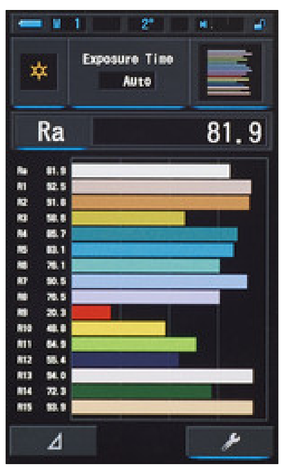

Figure 48: Colour Rendering Index

Measurement of correlated color temperature (Tcp) :

The variables that are often used to characterise the colour of light sources, correlated colour temperature and the difference from the blackbody locus Δuv, may be measured using the CL-70F. The absolute temperature (in Kelvin) at which a blackbody would produce a specific hue of light is known as the colour temperature of light. The “blackbody locus” is a curve that allows the colours of light emitted by a blackbody at various temperatures to be plotted. Since many light sources’ output does not coincide with the blackbody locus exactly, “correlated colour temperature” which are referred to as (CCT). Normally, the difference from the blackbody locus Δuv is provided in addition to the associated colour temperature when characterising a colour using correlated colour temperature.

Spectral Power Distribution :

The CL-70F provides easy access to Colour Rendering Index (CRI) measurement data. The display shows the SPD value over the wavelength. The Y scale is normalised to 1.

Figure 49: Chromaticity Diagram (for CCT Calculation), Spectral Composition & Others important Information

Rotating Receptor Head :

The rotating receptor head improves screen visibility and comfortable use of the instrument.

Figure 50: Rotating Receptor Head

Zero Adjustment :

Without a receptor cap, it is simple to modify this device's zero setting. To calibrate the dark, turn the diffusor's ring counter-clockwise.

Figure 51: Zero Adjustment Without Receptor Cap

Additional Features :

It provides including Utility software CL-SU1w with the software CL-SU1w which is included as a standard accessory, one can modify instrument settings, store & group data and make further analysis of the measured data.

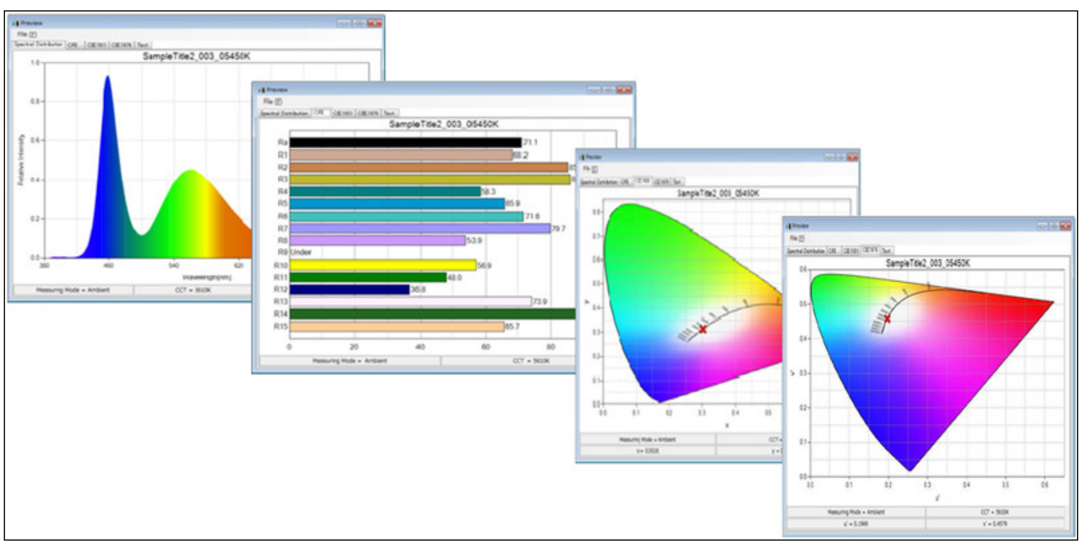

Figure 52: Stored Data in CL-SU1w Software

8.1.2.2 Specifications of CRI Illuminance Meter

Principal Specifications of CL-70F is discussed below.

Model	:	CRI Illuminance Meter CL-70F.
Illuminance Meter Class	:	Conforms to requirements for Class A of JIS C1609-1:2006 "Illuminance meters Part 1: General measuring instruments"; Conforms to DIN 5032 Part 7 Class C.
Sensor	:	CMOS linear image sensor.
Spectral Wavelength Range	:	380 nm ∼ 780 nm.
Output Wavelength Pitch	:	1 nm.
Accuracy (Standard Illuminant A) *1 * 2	:	EV: ± 5% +1 digit of displayed value. xy: 0.003 (at 800 lx).
Repeatability(2 σ)(Standard Illuminant A)	:	E_V: 30 to 200,000 lx: 1% +1 digit; 1 to 30 lx: 5% + 1 digit *3. xy: 500 to 200,000 lx: 0.001 *4. xy: 100 to 500 lx: 0.002 *4. xy: 30 to 100 lx: 0.004 *4. xy: 5 to 30 lx: 0.008 *4.
Visible-Region Relative Spectral Response Characteristics (f1')	:	Within 9%.
Cosine Response (f2)	:	Within 6%.
Humidity Drift (fH)	:	EV: ± 3% ; xy: ± 0.006.
Temperature Drift (fT)	:	EV: ± 5% ; xy: ± 0.006.
Response Time	:	Constant light (Maximum): 15 sec. Constant Light (Minimum): 0.5 sec. Flash Light: 1 ∼ 1/500 sec (in 1-step intervals)*5.
Colour Indication Modes	:	Correlated colour temperature T_{cp}, Difference from blackbody Δuv, XYZ, xy, u'v', Dominant wavelength λ_d, Excitation purity P_e, Spectral irradiance, E_V, CRI (R_a, R_i), Peak wavelength λ_p, exposure value.
Other Functions	:	Data memory: 999 data; Preset function; Auto power off function.

Display Languages : English, Japanese, Chinese (Simplified).

Interface : USB 2.0 Mini B.

Operating Temperature & Humidity Range : $-10°$ to $40°$ C, relative humidity of 85 % or less (at $35°$ C) with no condensation.

Storage Temperature /Humidity range : $-10°$ to $45°$ C, relative humidity of 85 % or less (at $35°$ C) with no condensation.

Size : 73 (W)×183 (H) ×27 (D) mm^3 (Not including projecting buttons).

Weight : 230 grams.

*1 Measurement mode : constant light (range L), Exposure time : AUTO
*2 Linear for EV
*3 10 times measurement (2σ)/Ave
*4 10 times measurement 2σ
*5 shutter speed

8.1.2.3 Principle Applications

1. Measurement and evaluation of special illumination sources used for restaurants, museums, studios, and stages, etc.
2. Measurement and evaluation of indoor light sources such as LEDs, fluorescent lamps, etc.
3. LED billboard development, quality control, and maintenance.
4. Evaluating the light distribution characteristics of LED illumination modules.
5. Evaluating the illuminance distribution of lighting luminaires.
6. Building and interior lighting research.
7. Spatial lighting production and adjustment.
8. Colour-viewing cabinet maintenance.
9. Projector light source research and colour inspection.
10. Checking environments for psychological research experiments.

8.1.3 EMOTIV EPOC Flex

The EMOTIV EPOC Flex, a portable wireless EEG device, was used in this study to record the participants' brain activity as they performed the script. To capture the EEG data and assess the contact and EEG quality of the electrodes, the device needed to be linked to the "EMOTIV Pro" software. The EEG controller (hardware part) is linked to the Emotiv Pro software (software) via two different methods: Bluetooth and USB or dongle receiver. The 32 EEG channels of EEG headset include 2 channels for reference. All of the recordings are kept in the software's cloud storage facility. This experiment made use of the most recent version of the software, EMOTIV Pro V3.3.

Figure 53: EEG Headset

8.1.3.1 Connecting EEG Headset to Emotiv

EmotivPRO is compatible with the following EMOTIV headsets: EPOC, EPOC+, EPOC X, EPOC Flex, and Insight. To connect an EEG headset to EmotivPRO:

1. Turn the headset on.
2. Check that the headset's battery is fully charged before try to connect it.
3. Click on the Connect Headset button at the top of the screen.
4. Choose the headset and click on Connect.
5. Follow the fitting instructions for headset.
6. Once EEG headset is fitted, click on Close.
7. Headset is now connected to EmotivPRO.

8.1.3.2 Product Specifications

Device	: EPOC Flex
No. of Channels	: 32 (With CMS/DRL references)
Channel names	: Configurable on standard 72 channel international 10-20 locations.
Sampling method	: Sequential sampling. Single ADC
Sampling rate	: 128 SPS (1024 Hz internal)
EEG Resolution	: 14 bits 1 LSB = 0.51 μV (16 bit ADC, 2 bits instrumental noise floor discarded)
Max Slew Rate	: 32.64 μV/sample (Compression required for BLE data transmission)
Bandwidth	: 0.2 - 45 Hz, high attenuation at 50 Hz and 60 Hz
Filtering	: Built in digital 5th order Sinc filter
Dynamic range (input referred)	: +/- 4.12 mV
Coupling mode	: AC coupled
Connectivity	: Proprietary 2.4 GHz wireless, BLE(coming soon)
Battery Capacity.	: LiPo battery 595 mAh
Battery life (typical)	: 6-9 hours
Impedance Measurement	: Real-time contact quality using patented system
Motion Sampling	: 16 Hz

Motion Resolution : 8-bit Output

IMU Part : ICM-20948 3-axis Accelerometer, 3-axis Gyroscope, 3-axis Magnetometer. Data Output 10 channels Quaternions, (Q_0, Q_1, Q_2,Q_3), Acceleration (X,Y,Z) and Magnetometer (X,Y,Z)

Sensor Material : Electroplated Ag/AgCl (EPOC Flex Saline models) with replaceable polyester felt pads that can be sterilised and re-used.

8.1.3.3 Contact Quality Map

Accurate EEG data collection depends on good sensor contact with the scalp and good EEG signal quality. The contact quality map shows a visual representation of the current contact quality at each individual sensor on the headset. Each sensor's contact quality status can be seen in real time, so simply it can be adjusted (if needed) to achieve 100% contact quality. The contact quality statuses are:

- Green - good
- Orange - moderate
- Red - poor
- Black - very poor

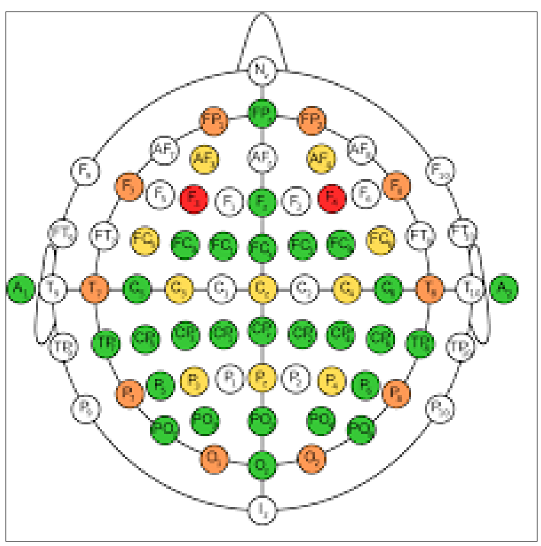

Figure 54: EEG Contact Quality Map

8.1.4 LAPTOP

For capturing the raw EEG data and connecting the EEG device with the dongle, an HP laptop (shown in figure 55) had been used. EEG Lab toolbox was also utilized to evaluate the EEG data in Matlab. To create the excel sheet and plot the SAM data, Excel was needed.

Figure 55: HP Laptop

8.1.4.1 Specifications of Product

Brand	:	HP
Model Name	:	HP Laptop 15-bs0xx
Display Size	:	15.6 Inches
Resolution	:	1920×1080
Product Dimensions	:	$38\times 25.4\times 2.4$ cm^3
Product Weight	:	2.1 kilograms
Battery	:	1 Lithium Ion batter

No of Lithium Ion Cells	:	4
Processor Name	:	Intel(R) Core(TM) i3-6006U
Processor Core Count	:	2
Processor Thread Count	:	4
Processor Speed	:	2.00 GHz
Processor Cache	:	3 MB
Integrated Graphics	:	Intel HD Graphics 520 with DirectX 12
Operating System	:	Windows 11 Home, 64-bit
Memory Type	:	DDR4 SDRAM
Maximum Memory Configuration	:	16 GB
Hard Drive Size	:	1 TB
Hard Disk Rotational Speed	:	5400 RPM
Wattage	:	41 watts

8.2 Software Used in Experiment

1. **Emotiv Pro Software**: The brain signal was recorded using this software. There is an emotive analyser that produces data that may be used in additional research.

2. **Matlab & EEGLab Toolbox**: Only Matlab(2019a) was used to manage the EEGLab toolbox. The EEGLab tool could be used to pre-process, filter out artefacts, analyse, and produced scalp maps, power spectrum activity, and event-related potential graphs from EEG data.

3. **Microsoft Excel**: The results of the Self Assessment Manikin were shown using this application as a bar graph and scatter plot. ANOVA was performed using this application as well.