

Cognitive Enhancement using Odor as

Intervention

*A dissertation submitted in partial fulfillment of the
requirements for the award of degree of*

**Master of Engineering in
Electronic Instrumentation and Control**



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June 2014

DECLARATION

I hereby certify that the work is being presented in this thesis work entitled "**Cognitive Enhancement using Odor as Intervention**" in partial fulfilment of award of degree of **Master of Engineering in Electronic Instrumentation & Control** submitted in Electrical & Instrumentation Engineering Department, Thapar University, Patiala is an authentic record of my own work carried under the supervision of **Dr. Mandeep Singh**, Associate Professor, Department Of Electrical & Instrumentation Engineering, Thapar University, Patiala, Punjab.

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ACKNOWLEDGEMENT

"Achievement is finding out what you would be doing, what you have to do. The higher the summit, higher will be the climb." It has been rightly said that we are built on the shoulders of others but the satisfaction that accompanies the successful completion of any task would be incomplete without the mention of the people who made it possible.

I am very thankful to **Prof. Prakash Gopalan**, Director of Thapar University, Patiala for providing the facilities for the completion of M.E. I express my deep sense of gratitude towards **Dr. Ravinder Agarwal**, Professor and Head of the Department of Electrical & Instrumentation Engineering, Thapar University, Patiala who has been a constant source of inspiration for me throughout this work.

With deep sense of gratitude I express my sincere thanks to my esteemed and worthy supervisor **Dr. Mandeep Singh**, Department of Electrical & Instrumentation Engineering, Thapar University, Patiala for his valuable guidance in carrying out this work under his effective supervision, encouragement, enlightenment and cooperation. Most of the novel ideas and solutions found in this thesis are the result of our numerous stimulating discussions. His feedback and editorial comments were also invaluable for writing of this thesis.

Date:

14th July '14

Place: Thapar University, Patiala



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ABSTRACT

Brain is the most sophisticated part of the human body. We concentrate our research on how to enhance the abilities of a healthy brain. The science dealing with this concern is called cognitive science. Cognitive assessment is a formal assessment of an individual's abilities in a range of areas such as verbal and non-verbal skills, memory and speed of processing. The research assesses the cognitive abilities through videos. The study examined and analyzed the electroencephalographic signals of various individuals acquired while the individual is made to go through distinguished emotions- happy and sad. The subject is made to watch two different videos related to happy emotions and sad emotions. The pilot study involves 10 healthy engineering students on whom tests are carried out. The intervention used in this research is odor of lemon. The subjects were exposed to the odor for one hour daily for 15 days. Cognitive Enhancement, i.e., advancement or betterment of mental abilities, is initiated with assessing cognitive abilities. As a part of pre-recording, the ElectroEncephaloGraphy (EEG) signals are acquired while the person watches the videos. During the intervention part, the subject is exposed to odor and lastly, during post-recording the EEG signals are acquired again while the subject watches videos. Analysis of both pre and post-recording signals is done using MATLAB (EEGLAB, Discrete Wavelet Transform) and comparison of various features of both recordings is done. The comparison is done by calculating asymmetry indices and energies of different bands of physiological EEG signals. It is found that asymmetry indices are improved in case of happy emotions as compared to the sad ones which become even sadder. Hence, making an individual emotionally sensitive.

V

1.5 Interventions	19
1.5.1 Meditation	19
1.5.2 Color	19
1.5.3 Odor	20
1.5.4 Music	20
1.5.5 Electroencephalography (EEG) and Neuro-feedback	20
1.6 Cognitive Enhancement	20
1.6.1 Conventional	21
1.6.1.1 Education	21
1.6.1.2 Enriched Environment	21
1.6.1.3 Mental Training	22
1.6.2 Unconventional	23
1.6.2.1 Drugs.....	23
1.6.2.2 Gene Therapy	23
1.7 Electroencephalogram (EEG)	23
1.7.1 Basic Principles of EEG	24
1.7.2 Frequency Bands of EEG	26
1.7.3 Recording Methods	30
1.7.3.1 International 10/20 System:	30
1.7.3.2 Source of EEG activity	31
1.7.4 Artifacts	32
1.7.4.1 Biological Artifacts	32
1.7.4.2 Environmental Artifacts	32
1.7.4.3 Artifact Correction	33
CHAPTER 2 EMOTIONS:EFFECTS ON ELECTROENCEPHALOGRAPHY	34
CHAPTER 3 ODOR FOR COGNITIVE ENHANCEMENT	36
3.1 Introduction	36
3.2 Olfaction	36
3.3 How brain detects odor	37
3.4 How the sense of smell works	37
3.5 Effects of different odors.....	38
CHAPTER 4 PROBLEM DEFINITION.....	45
CHAPTER 5 PROPOSED METHOD	46

5.1 Participants	46
5.2 Preparation of participant for EEG.....	46
5.3 Baseline data acquisition	46
5.4 Tests for pre-intervention cognitive assessment	47
5.5 Intervention	47
5.6 Tests for post-intervention cognitive assessment	47
5.7 Statistical analysis of data	47
5.8 Signal Processing and feature extraction	48
5.9 Comparison of EEG data acquired during pre and post-intervention procedures	48
CHAPTER 6 IMPLEMENTING THE PROPOSED METHOD	49
6.1 Data Acquisition	49
6.1.1 BioPac MP150 System	49
6.2 Signal processing and Data Analysis	52
6.2.1 Software used for data analysis: MATLAB and EEGLAB Software	52
6.2.1.1 MATLAB	52
6.2.1.2 EEGLAB	53
6.2.2 Steps for Signal Processing	56
6.2.2.1 Pre-processing: Filtering of data (Band Pass Filter).....	56
6.2.2.2 Independent Component Analysis	57
6.2.2.3 Wavelet Transform	61
6.2.3 Feature Extraction	64
CHAPTER 7 RESULTS AND DISCUSSION	65
7.1 Changes in Asymmetry of Brain Wave Rhythms	65
7.2 Cognitive Enhancement using Odor as Intervention.....	71
CHAPTER 8 CONCLUSION AND FUTURE SCOPE	74
8.1 Conclusion	74
8.2 Future Scope	74
CHAPTER 9 CHECK FOR ORIGINALITY	75
REFERENCES	

LIST OF FIGURES

Figure no.	Figure's Title	Page no.
Figure 1.1	Brain rhythms	27
Figure 1.2	International 10-20 Placement	

Figure 3.1	Flow chart for signal processing	48
Figure 5.1	MP150 BioPac system	49
Figure 6.1	MP150 Block Diagram	50
Figure 6.2	Marked electrodes for recording	51
Figure 6.3	Window of AcqKnowledge acquiring EEG signals	52
Figure 6.4	The MATLAB environment consisting of the MATLAB desktop	52
Figure 6.5	EEGLAB windows	54
Figure 6.6	Topography before removal of artifact: 3, 5 and 6 is artifact	55
Figure 6.7	Topography after removal of artifact by running ICA	55
Figure 6.8	Filter response plot	56
Figure 6.9	Schematic illustration of the procedure of ICA	59
Figure 6.10	Summed projection of selected components in ICA	60
Figure 6.11	Blink and muscle artifact removal by ICA	61
Figure 6.12	Daubechies Family	63
Figure 6.13	Comparison of asymmetry indices	65
Figure 7.1	Asymmetry indices of subject 1 for happy, sad emotions and baseline	66
Figure 7.2	Asymmetry indices of subject 2 for happy, sad emotions and baseline	66
Figure 7.3	Asymmetry indices of subject 3 for happy, sad emotions and baseline	67
Figure 7.4	Asymmetry indices of subject 4 for happy, sad emotions and baseline	67
Figure 7.5	Asymmetry indices of subject 5 for happy, sad emotions and baseline	68
Figure 7.6	Asymmetry indices of subject 6 for happy, sad emotions and baseline	68
Figure 7.7	Asymmetry indices of subject 7 for happy, sad emotions and baseline	69
Figure 7.8	Asymmetry indices of subject 8 for happy, sad emotions and baseline	69
Figure 7.9	Asymmetry indices of subject 9 for happy, sad emotions and baseline	70
Figure 7.10	Asymmetry indices of subject 10 for happy, sad emotions and baseline	70
Figure 7.11	Comparison of Asymmetry Indices obtained during pre-intervention	71

Figure 7.13	Comparison of Asymmetry Indices obtained during intervention	post-	72
Figure 7.14	Comparison of Asymmetry indices of happy emotion during and post-Intervention	pre	72
Figure 7.15	Comparison of Asymmetry indices of sad emotion during and post-Intervention	pre	73

LIST OF TABLES

Table no.	Table's Name	Page no.
Table 4.1	Piaget's theory of developmental psychology	2
Table 5.1	Comparison of EEG bands	29

LIST OF ABBREVIATIONS

PEBL - Psychology Experiment Building Language
PEPP - The Prevention and Early Intervention Program for Psychoses
NART - National Adult Reading Test
WAIS - Wechsler Adult Intelligence Scale
WMS - Wechsler Memory Scale
WCST - Wisconsin Card Sorting Test
CDR - Cognitive Drug Research EEG
– ElectroEncephaloGraphy
ECG – ElectroCardioGraphy
GSR - Galvanic Skin Resistance
HRV - Heart Rate Variability
SVM – Support Vector Machine
DWT – Discrete Wavelet Transform
BVP - Blood Volume Pulse
BR – Breathing Rate
CE – Cognitive Enhancement
EOG – Electrooculography
ICA – Independent Component Analysis

1.1 Cognition

Cognition refers to the intellectual process of knowing, including aspects such as consciousness, awareness, reasoning, and judgment. Cognition, in layman's language refers to thinking [1]. Thinking is mandatory at almost every slight aspect of daily routine be it playing monopoly or doing calculations but a thought takes many understated forms such as inferring sensory input and then subsequently guiding the physical actions. Thus, Cognition is the process by which the sensory input detected by the human brain is altered, concentrated, enlarged, kept, improved, and used. Cognition is essentially a mental process that comprises various capabilities of brain like attention of working memory, calculating, reasoning, problem solving, and decision making [2].

"Cognition" is a word that dates back to the 15th century and it meant 'thinking and awareness' [3]. Cognitive procedure came more into consideration more than twentythree centuries ago, opening with Aristotle and his attention in the inner-workings of the mind and how they shake the human experience. Aristotle engrossed on cognitive areas relating to memory, perception, and mental imagery. The Greek philosopher found great prominence in guaranteeing that his studies were based on empirical proof; scientific information that is gathered through observation and careful experimentation.

In science, cognition is a group of mental processes that includes attention, memory, producing and understanding language, learning, reasoning, problem solving, and decision making. Various disciplines, such as psychology, philosophy, linguistics, and computer science all study cognition. However, the term's usage varies across disciplines; for example, in psychology and cognitive science, "cognition" usually refers to an information processing view of an individual's psychological functions.

Cognition is an ability for the handling of information, relating knowledge, and changing favourites. Cognition, or cognitive processes, can be natural or artificial, conscious or unconscious. These processes are analyzed from different viewpoints within different perspectives, particularly in the fields of linguistics, psychology, philosophy, anthropology, etc. Within psychology or philosophy, the concept of

cognition is closely connected to some concepts such as mind, intelligence. It covers the mental functions, mental processes (thoughts), and states of intelligent entities.

Piaget's theory of developmental psychology tackled cognitive development from infancy to adulthood [4].

Stage	Age or Period	Description
Sensorimotor stage	Infancy (0-2 years)	Intelligence is present; motor activity but no symbols; knowledge is developing yet limited; knowledge is based on experiences/ interactions; mobility allows child to learn new things; some language skills are developed at the end of this stage. The goal is to develop object permanence; achieves basic understanding of causality, time, and space.
Preoperational stage	Toddler and Early Childhood (2-7 years)	Symbols or language skills are present; memory and imagination are developed; non-reversible and nonlogical thinking; shows intuitive problem solving; begins to see relationships; grasps concept of conservation of numbers; egocentric thinking predominates.
Concrete operational stage	Elementary and Early Adolescence (7-12 years)	Logical and systematic form of intelligence; manipulation of symbols related to concrete objects; thinking is now characterized by reversibility and the ability to take the role of another; grasps concepts of the conservation of mass, length, weight, and volume; operational thinking predominates non-reversible and egocentric thinking
Formal operational stage	Adolescence and Adulthood (12 years and on)	Logical use of symbols related to abstract concepts; Acquires flexibility in thinking as well as the capacities for abstract thinking and mental hypothesis testing; can consider possible alternatives in complex

		reasoning and problem solving.
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Table 1: Piaget's theory of developmental psychology

1.2 Cognitive Assessment

Cognitive Assessment is a kind of technique to predict or assess the abilities be it logical or reasoning of a human brain. It involves the use of pencil and paper tasks or certain computerized batteries to assess a wide range of abilities like attention (how attentive the brain is while doing a task), memory (how efficiently the memory is working), reasoning capabilities, language skills and intellectual functioning. It is the process of determining a patient's cognitive strengths and weaknesses through qualitative (approach to tasks and observed behaviour) and quantitative (standardized and scaled measures) approaches. Test scores are then evaluated on the basis of data acquired after the test and expected level of performance for a given individual based upon their educational/occupational level and estimates of their intellectual functioning [5].

1.3 Cognitive abilities

Cognitive Assessment is a kind of examination that is conducted to predict the mental abilities of a human being. While doing so many abilities of brain are taken into account. H.J. Woodford and J. George stated numerous cognitive abilities for the elderly in their research [6]. Some of the key components to consider while assessing the cognitive abilities are as follows:

1.3.1 Attention

Attention is a process of focussing. There are various definitions of the term 'attention'. Attention is the cognitive process of selectively concentrating on one aspect of the environment while ignoring other things. Attention has also been mentioned as the distribution of processing resources. A number of tasks can be considered to

measure this cognitive ability. A simple example can be mathematical problems which draw a lot of attention of a human brain. An individual can be asked to recall a number of digits after the digits are shown to him/her for a short duration of time. Attention is a basic requirement for being able to perform other elements of the cognitive assessment [7].

1.3.2 Memory

Memory can be considered as the ability to remember things. Memory makes us. If we couldn't remember the what's, who's, when's and where's of our daily lives, we'd never be able to manage. Memory can be long-term memory or short-term memory. Short-term memory is more dependent on an intact limbic system (mainly in the temporal lobes) than long-term remembrance, which is reliant on upon other cortical processes [8]. Various tests for assessing such memories are available. For example, the working memory of an individual can be evaluated by making him/her remember a bunch of images and then recalling it after a specified time span.

1.3.3 Visuospatial Skills

Visuospatial skills permit us to visually observe objects and the interactions among objects. These are the skills that allow us to identify a triangle, square, cube or pyramid. They let us to review our way across the city because we have a visual map in our reminiscence from the last time we completed the trip. They permit us to know that the car is closer to us and smaller than the building just after the car. They enable us to comprehend that the car we see two blocks away is actually about the similar size as the car that is just in front of us, even though it seems to be much smaller. Most of what we analyze visually would take many words to define yet we do it visually in a fraction of a second. Visuospatial skills comprise a wide diversity of individual abilities that differ from identifying complex intersecting angles and curves to knowing faces from the shape of eyes, noses, mouths and hair. Impairment of these abilities can have an overwhelming effect on even modest everyday functions that we take for decided.

1.3.4 Frontal/Executive Function

Executive function is a term for the higher cerebral functions, mostly resulting from the frontal lobes, but also connecting subcortical connections with the basal ganglia and thalamus. They contain components such as abstract thought, development and decision. They are required to complete composite jobs. There is a wide range of procedures available to the clinician to assess frontal lobe functions. They include the trail-making tests. In the simplest form, this includes joining a sequence of numbers dispersed across a page, in the correct order (e.g. 1!2!3 . . .).

1.4 Cognitive Assessment Techniques

As stated earlier, Cognitive Assessment Techniques are used to evaluate the mental abilities of the human brain. In this type of assessment, the subject will be asked to complete a series of tasks that require cognitive skills. Exams may be broken up into several different components to test things like reasoning, understanding language, and so forth. Each section is scored separately, and the results can be compared with those of other people who have taken the test to see where someone falls on a scale of cognitive performance. There are various ways of performing this process of evaluation. These methods may use a mere paper and pencil test or cognitive assessment batteries like Psychology Experiment Building Language (PEBL).

Cognitive assessment can be classified as:

- (i) Task Oriented Assessment
- (ii) Physiological Assessment

1.4.1 Task oriented Assessment

The subject is asked to complete a series of tasks like logical puzzles, matching numbers, etc. that necessitate the involvement of cognitive skills. For performing such type of cognitive assessment there are certain test batteries. Some of them are described as follows:

1.4.1.1 The Prevention and Early Intervention Program for Psychoses (PEPP) Cognitive Assessment Battery

The PEPP battery states numerous tests for assessing various cognitive abilities [9].

The list of tests administered to each patient includes the following:

National Adult Reading Test (NART): This test gives an estimate of premorbid IQ. Premorbid Intelligence of an individual refers to the estimate of person's intellectual functioning preceding to recognized or supposed onset of brain disease or dysfunction. More usually, this word is used to label a process in neuropsychological assessments in which an individuals' level of neuropsychological functioning that existed former to the onset of known or suspected neurological dysfunction is determined. The NART was developed by Hazel Nelson in the 1980s in Britain and published in 1982 [10].

Wechsler Adult Intelligence Scale: The WAIS is used to measure intelligence in adults and older adolescents [11]. The third edition (WAIS-III) delivers Verbal and Performance IQ scores and a Processing Speed Index. Currently this scale is in its fourth form. The test WAIS-IV consists of 10 core subtests and five additional subtests, with the 10 core subtests having the Full Scale IQ. In the new WAIS-IV, the verbal/performance subscales from prior versions were detached and replaced by the index scores. The General Ability Index (GAI) was encompassed, which consists of the Similarities, Vocabulary and Information subtests from the Verbal Comprehension Index and the Matrix Reasoning, Block Design and Visual Puzzles subtests from the Perceptual Reasoning Index. The GAI is clinically valuable because it can be used as a quantity of cognitive abilities that are less susceptible to deficiencies of processing and working memory.

Wechsler Memory Scale: The third edition (WMS-III) offers indexes of prompt and delayed auditory and visual memory, and working memory. The Wechsler Memory Scale (WMS) is a neuropsychological test proposed to measure dissimilar memory functions in a person. Anyone from ages 16 to 90 is qualified to take this test. The current version of this test is the fourth edition: WMS-IV.

Wisconsin Card Sorting Test (WCST): It is the measure of executive functioning of the brain. The Wisconsin Card Sorting Test (WCST) is a neuropsychological test of "set-shifting", i.e. the ability to display flexibility in the face of changing agendas of establishment. The WCST was inscribed by David A. Grant and Esta A. Berg. Initially,

a number of stimulus cards are offered to the participant. The participant is told to match the cards, but not how to match. The original WCST used paper cards and was done with the experimenter on one side of the desk facing the participant on the other [12].

Stroop Test: It is the measure of divided attention, mental elasticity, handling speed. This test is made on the Stroop Effect. In psychology, the Stroop Effect is demo of interference in the reaction time of a task. When the name of a color (e.g., "blue," "green," or "red") is published in a color not signified by the name (e.g., the word "red" published in blue ink instead of red ink), specifying the color of the word takes longer and is more disposed to errors than when the color of the ink matches the name of the color. The effect was first printed by John Ridley Stroop [13].

Trail Making Test (Parts A and B): It is the measure of attention and visual-motor sequencing. Both parts of the Trail Making Test involve of 25 circles dispersed over a sheet of paper. In Part A, the circles are numbered 1 – 25, and the subject should draw lines to attach the numbers in ascending order. In Part B, the circles comprise both numbers (1 – 13) and letters (A – L); as in Part A, the subject draws lines to join the circles in a rising pattern, but with the extra task of alternating between the numbers and letters (i.e., 1-A-2-B-3-C, etc.). The subject should be coached to join the circles as rapidly as possible, without lifting the pen or pencil from the paper. Note the time of patient as he or she attaches the "trail." If the subject makes an error, point it out immediately and allow the patient to correct it. Errors affect the subject's score only in that the correction of errors is comprised in the achievement time for the task. It is needless to continue the test if the subject has not accomplished both parts after five minutes have passed.

Oral and Written Word Fluency: It measures of executive functioning. A number of words are set to the subject and his/her articulatory is checked both verbally and while inscription.

Prospective Memory Screening Test: It is the measure of training and remembrance for future tasks. Prospective memory is a form of memory that comprises remembering to achieve a scheduled action or intention at the suitable time [14]. Prospective memory

tasks can be used in a variable ways to measure prospective memory. These tasks can be shadowed by questionnaires about prospective memory.

Paced Auditory Serial Addition Task: It is the measure of continued and raced processing. It is used to evaluate capacity and rate of information dispensation and continued and divided attention [15]. The subjects are publicised a number every 3 seconds and are queried to add the number they just caught with the number they caught before. This is a stimulating task that includes attention, working memory and arithmetic capabilities.

Continuous Performance Task: It is the measure of sustained attention/focus and treating speed. It is also called the quantitative behaviour test. Subjects are available with a repetitive, uninteresting task and must uphold their emphasis over a period of time in order to reply to targets or constrain response to foils. Test may use symbols, numbers or sounds but the idea of task is same. Although the tests may differ in terms of length and type of stimulus used, the basic nature of the tests remains the same. Clients are offered with a boring, "tedious" task and must maintain their emphasis over a period of time in order to answer to marks or inhibit response to foils. Tests may use numbers, symbols or sounds, but the basic task has the same concept.

Neo Personality Inventory: It is a measure of personality characters. This was intended to deliver a general description of normal personality applicable to clinical, therapy and educational circumstances. It consists of 240 personality substances and a validity item. All items were designed to be easily read and understood.

Cognitive Failures Questionnaire: It is a self-report measure of cognitive abilities. The questions are about minor faults which everybody makes from time to time, but some of which happen more often than others. The questions are like 'Do you read something and find you haven't been thinking about it and must read it again?'

1.4.1.2 The Psychology Experiment Building Language (PEBL)

PEBL offers a simple programming language tailor-made for creating and conducting many standard experiments [16]. These experiments are used for performing cognitive assessment. Some of these tests are described below:

Digit Span Test: The digit span test or memory test is the longest list of items that a person can repeat back in correct order immediately after presentation on 50% of all trials. It is also a component of cognitive ability tests. In Digit Span, the subject will see a series of digits presented in a box at the top of the screen and the task will be to remember these numbers in sequence. After a brief period of time, the numbers will disappear and you will key in your response. For example, if the subject saw the string of digits “28659”, he/she would enter “28659” with the keypad and hit “OK.” The digit strings will increase in length with each trial and the subject will continue the task until you make a mistake.

Go/No-Go Test: In general go/no go testing refers to a pass/fail test principle using two boundary conditions. The test is passed only when the Go condition is met and also the No go condition fails. This test was developed to assess response inhibition in a rapid computerized assessment format. Subjects learn to discriminate between two response alternatives (right or left mouse button, or screen presses directly on the stimuli). Subjects are asked to respond and pick the correct choice, based on which stimulus is filled with green color “go” stimulus, while the other stimulus is blank. On some trials, however, one of the stimuli is colored red, which is a signal not to respond at all (“no-go” trial). The frequency of “go” stimuli relative to “no-go” stimuli is 80%, which maintains a bias and tendency to respond on every trial. Key dependent measures include both reaction times for all “go” responses, and error frequencies, the most important of which are “false alarm” errors (i.e., a response to a “no-go” stimulus). The test adapts to the subject’s rate of performance, maintaining a maximum pace of administration.

Matrix Rotation Test: The test describes how the mind recognizes objects in the environment. The subject is shown a square matrix with a pattern and he/she is instructed to remember that pattern and then a second matrix appears. He/she is now instructed to compare both the patterns in his/her mind. If the pattern is rotated 90

degrees (either left or right), the subject has to press the left shift key on the keyboard otherwise the right shift key has to be pressed.

Muller-Iyer Test: The Muller-Iyer Test is an optical illusion consisting of a stylized arrow. The Arrow has two arrow heads and it appear as two arrows. The subject has to compare which arrow has longer length and the corresponding key has to be pressed. The lines appear to be same and that is why it is called an illusion test.

Spatial Cueing Test: The test includes 50 trials. It is required to respond to a stimulus dimension, overshadowed by spatial location. At the beginning of each trial, a fixation cross appears, accompanied by a left arrow ([<+]), a right arrow ([+>]) or both ([<+>]). The stimulus 'X' will appear after a short time span either to the left or right of the fixation area. The arrow will usually tell you where the stimulus will appear (75% of the time the stimulus will appear in the direction of the arrow). The subject's goal is to fixate 'X' without moving the eyes and pressing key 'A' as soon as he/she sees the stimulus.

1.4.1.3 Bhatia's Battery for Performance Test of Intelligence

This is another kind of cognitive battery consisting of many tests to measure the cognitive abilities. **Poonam Dhaka** et. al. used this battery to evaluate the impact of light-sound stimulation on intelligence in teenagers [17]. Some of these tests are described below:

Koh's Block Design Test: This test consists of 10 designs from the original 17 designs from the Koh's test. The time for first five designs is 2 minutes and for the remaining five the time is 3 minutes. The card with a variety of colored designs are shown to the test taker and he/she is asked to reproduce them using a set of colored blocks. The performance is based not just on the accuracy of the drawings but also on the examiner's observation of behaviour during the test, including such factors as attention level, self-criticism, and adaptive behaviour.

Alexander Pass-along Test: All the designs of the original test are included in this test and consist of certain blocks of red and blue color. The subject has to arrange the blocks according to the card shown to him/her. The first four of these have to be completed in 2 minutes and the rest of the four have to be completed in 3 minutes.

Pattern Drawing Test: This test comprises of eight patterns of increasing difficulty from first to eighth. In this test, the subject has to make the figures as shown in the card without repeating on lines and without lifting the pencil. The time for the first four cards is 2 minutes and for the rest four cards it is 3 minutes.

Immediate Memory Test: This test has a close relation with mental development or general intelligence. It starts with two letters and then increases accordingly. Firstly the investigator speaks out the word and then the subject. There are three alternative sets of letters. If failure is recorded in the first set, try the second and the third alternative sets. If failure is recorded in all the three alternatives the failure is recorded and the task is stopped. The same steps are to be followed in reversed sounds.

Picture Construction Test: This test consists of five graded subjects. In these subtests there are number of pieces and the subjects have to put the pieces together to form the picture. The time for first two pictures is 2 minutes and the rest of the three pictures in 3 minutes. Individual administration of this test takes less than one hour. Maximum 95 marks can be obtained in the complete test. Maximum marks for 1st, 2nd, 3rd, 4th and 5th test are 25, 20, 20, 15, and 15 respectively.

1.4.1.4 Neurocognitive Test Battery

This is another way for performing cognitive assessment [18]. The tests of neurocognitive test battery are explained as follows:

Letter Cancellation Test: This test concentrates on visual scanning, response speed and sustained attention. A series of English letters are presented to the subject, and he/she is instructed to cancel out specific letters. The score is the time taken by subject

to actually perform this task. In addition, the numbers of different errors (omissions and commissions) done by the subject are also counted.

Trail Making Test:

Part A: This test assesses visuo-motor speed and attention. The subject is taught to draw a straight line to connect 25 successive circles. The score is the time taken by the subject to complete the task.

Part B: In addition to visuo-motor speed and attention, it requires the patient to shift strategy and hence, is a sensitive measure of executive function as well. In this the subject is instructed to connect 25 numbered and lettered circles by alternating between the two sequences. The score is the total time taken by the patient to complete the task.

Ruff Figural Fluency Test: This test assesses on the non-verbal fluency of a subject, which is an indirect measure of subject's capability to form a strategy to complete a given task. The subject is offered with a sheet of paper on which 40 boxes are present. The objective is to draw unlike patterns in these boxes by joining dots existing in these boxes in a stated period of time. The score is based on total number of dissimilar patterns, and number of perseverations. The revolutions were also noted in this test along with Patterns and Perseverations as Rotations are considered to be the hallmark in the strategic approach.

Digit Span:

Digits Forward: measures instant verbal memory span. In the test, subjects must repeat back sequences of digits of increasing length read out by the examiner. The score is maximum number of digits that the patient can recall.

Digits Backward: In addition to auditory attention and short-term retentive capacity this test also assesses the ability to manipulate information in the verbal working memory (and hence is sensitive measure of executive function). The subject has to repeat the sequences of numbers of increasing digit length in reverse order to what was said by the examiner. The score is the maximum number of such digits that the patient is able to reverse.

1.4.1.5 Cognitive Drug Research (CDR) Computerized Assessment System

The CDR system includes a number of measures that are specific to particular aspects of attention, working memory and long-term memory [19]. The battery comprises of the following tests:

Word Presentation: A series of 15 words is presented sequentially for one second each with an inter-stimulus interval of one second. The words are a mix of one two and three syllables.

Immediate Word Recall: The computer demonstration counts down sixty seconds during which time participants write down as many of the words from the list as possible. Recall is scored for number of correct words, and errors (words that are not presented in the list).

Picture Presentation: Twenty photographs are presented, with a stimulus duration of 2 s each, and inter stimuli interval of 1 second.

Simple Reaction Time: The word Yes is presented in the centre of the screen. The participant has to press the Yes button as quickly as possible. There are 50 trials and the inter trial interval varies randomly between 1 and 2.5 s. The reaction time is recorded in milliseconds.

Digit Vigilance: A number is displayed constantly to the right of the screen. A series of 240 digits is presented one at a time in the centre at a rate of 80 per minute; 45 match the constantly displayed digit. The participant has to press the Yes button as quickly as possible every time the digit in the centre matches the one constantly displayed. Accuracy of response (%), reaction time (ms), and number of false alarms are recorded.

Choice Reaction Time: Either the word Yes or the word No is presented in the centre of the screen. The participant has to press the Yes or No button as appropriate and as quickly as possible. There are 30 trials (25 “Yes” and 5 “No”) and the intertrial interval varies randomly between 1 and 2.5 s. Accuracy (%) and reaction time (ms) are recorded.

Spatial Working Memory: A schematic picture of a house is presented for 5 s. The house has nine windows in a 3×3 pattern, 4 of which are illuminated. A series of 36 presentations of the same house in which just one window is illuminated follow, and the participant has to respond Yes if the window was one of the four lit in the original presentation, or No if it was not. Sixteen of the stimuli require a Yes response and 20 a No response. Reaction time and accuracy are recorded and a sensitivity index calculated.

Memory Scanning: Five digits are presented singly at the rate of one every second for the participant to remember. A series of thirty digits is then presented. For each, the participant must press Yes or No according to whether the digit is thought to be one of the five presented initially. Fifteen stimuli require a Yes response and 15 a No response. This is repeated three times using a different 5 digits on each occasion. Reaction time is recorded and a sensitivity index calculated.

Delayed Word Recall: The computer counts down 60 s during which time participants free recall as many of the words from the list as possible. Recall is scored for number of correct words; and errors (words not presented in the list).

Word Recognition: The 15 words initially presented for the word recall are presented again in random order interspersed with 15 new words. The participant presses Yes or No each time to signal whether or not the word was from the original list. Reaction time and accuracy are recorded and a sensitivity index calculated.

Picture Recognition: The 20 pictures presented earlier are shown again in random order interspersed with 20 similar new ones. The participant signals recognition by pressing the Yes or No button as appropriate. Reaction time and accuracy are recorded and a sensitivity index calculated.

1.4.2 Physiological Assessment

The physiological parameters like ElectroEncephaloGraphy (EEG), ElectroCardioGraphy (ECG), Galvanic Skin Resistance (GSR), Heart Rate Variability (HRV), etc. are taken into account for the purpose of performing cognitive assessment experimentation. Cognitive assessment can also be done by acquisition of cognitive signals. These parameters relate to various cognitive abilities that are to be assessed and enhanced. EEG is conventionally used to detect pathological conditions like epilepsy [20-24], but nowadays it is also being used to detect and quantify emotions [25-29]. EEG is record of neural activity, and it is acquired in a non-invasive manner by placing electrodes over the subject [8]. The signal of EEG is conditioned by denoising and features are extracted from frequency bands of different ranges like alpha, beta, theta, delta and gamma [21, 22, 25]. For emotional detection or for diagnosing any pathological condition like epilepsy, the features extracted from EEG frequency bands are given to a related classifier, that may be rule based, nearest neighbour classifiers, or more advance technique like Support Vector Machine (SVM) [30].

How is Cognitive Enhancement different from Training

To answer this question, consider, for instance, a football player who practices daily for 6 hours to increase his performance on field. The player thus undergoes through a task which is related to his game. As he practices daily, his performance on the field gets better or enhanced. Scientifically, if some physiological parameters, say, EEG are checked before and after training and it is observed that some features of EEG, for instance, alpha power and beta power increase/decrease after the player has practised for long, then it can be stated that the player has been trained well. On the contrary, if the same player is exposed to an unrelated task, i.e., having no relation to his game, daily for some time, and enhancement is observed on the field then it is called cognitive enhancement. This unrelated task can be identified by observing the features of the physiological parameters. The unrelated task for training should be chosen in such a way that the same parameters in that should increase/decrease as of the field game. Hence, suppose EEG rhythms of the player are recorded while he plays football and these rhythms are then analysed to give certain value of some predefined bands of EEG – alpha, beta, theta, delta and gamma. These signals are then again analysed after the player undergoes through the unrelated task. If it is observed that the same parameters

which were considered earlier now increase or decrease, then it is said that the player has undergone cognitive enhancement.

A classical example of cognitive enhancement is making soldiers play hard in playground thereby improving their performance in the battlefield. Apart from building physical stamina during field practice, the neuromuscular coordination, the response time, visuo-spatial attention, etc. are some of the cognitive abilities that enhance. The cognitive abilities are much needed in battlefield. No wonder it is said that “the more you sweat in peace, the less you bleed in war”. Hence proving that the best soldiers are made in playgrounds. Also, recently it has been reported that gamers make good surgeons. Gaming can help increase hand-eye coordination, which strengthens surgical skills.

The following discussion relates various parameters of physiological EEG signals to various cognitive abilities:

1.4.2.1 EEG features for Emotions

Ian H. Gotlib, Charan Ranganath and J. Peter Rosenfeld made their research on physiological activities in the prefrontal region of brain to relate depression and cognitive functioning [31]. They evaluated the asymmetry in prefrontal region using power in the alpha band. According to the research, left frontal hypoactivation is related to depression. In study 1, they computed Davidson’s formulations by observing differences in frontal EEG alpha asymmetry among currently depressed, previously depressed, and never depressed subjects. As expected, currently and previously depressed subjects showed left frontal hypoactivation relative to never depressed controls. In study 2, relations among the frontal EEG asymmetry were computed in response to negative mood induction procedure, attentional processing.

Dan Nie et al. recognised emotions while the subjects watched movies related to positive and negative emotions [32]. EEG signals were acquired during the procedure. The feature of EEG taken into account for positive and negative emotions is energy of various bands- alpha, beta, theta, delta and gamma. As per the research, the energies of

delta and gamma does not affect emotions. It is also observed that energy for positive emotions increases and for that of negative emotions it decreases.

Irene Winkler et al. classified emotions as positive and negative using asymmetry index [33]. The researchers presented some pictures to the subjects acquiring the EEG signals simultaneously and finally analysed signals using ‘frontal EEG asymmetry’. It is also suggested that left frontal activity indicates positive emotions while right frontal activity is related to negative emotions. The degree of activation is inferred from the spectral power in alpha band, with lower values in alpha power being associated higher degree of activity.

1.4.2.2 EEG features for Attention

Andrzej Wróbel focussed on the beta activity to study visual attention [34]. The researcher stated that in the cat, cortico-geniculate feedback has a potentiation mechanism having beta frequency which activates thalamic cells and this may lower the threshold for visual information transmission. The study also showed that enhanced beta activity is observed during attentive visual behaviour. Beta bursting activity spreads to all investigated visual centres, including the lateral posterior and pulvinar complex and higher cortical areas.

S.P. Kelly et al. computed EEG alpha power in a sustained attention task [35]. Alpha activity in various regions of brains were computed during the attention task. It was observed that in two of three subjects average power in the alpha band was related to stimulus presentation. This pointed towards short-term attentional processes. Thus, the alpha power is expected to decrease while engaged in an attention task.

Kridsakon Yaomane et al. presented a research to find appropriate locations of brain for detecting EEG signals during attention tasks [36]. Three experiments were constructed for this purpose. All 3 experiments made the examiners focus on the specific task to stimulate attention. The locations found for detecting Alpha wave were AF3 and F7. The suggested locations for detecting Beta wave were FC6 and F8. It was

also shown that Alpha wave in the relaxation state was higher than Alpha wave in the attention state and Beta wave in the attention state was higher than Beta wave in the relaxation state.

1.4.2.3 EEG features for Working Memory

Allison Bell analysed the theta waveforms of EEG signal during a working memory task [37]. The research considered a hypothesis- does eye closure increase theta wave amplitude and performance level during a working memory task. The EEG data analysis indicates no significant correlation between increased theta wave amplitude and eyes opened and eyes closed tasks.

Joshua Jacobs et al. studied that memory retrieval and decision making in correlation with theta activity [38]. During retrieval, power of left-parietal theta oscillations increased in relation to how well a test item was remembered, and theta in central regions correlated with decision making. The study also showed how these oscillatory dynamics complemented event-related potentials.

Ole Jensen and Claudia D. Tesche showed that frontal theta activity in humans increases in a working memory task [39]. The research showed brain oscillations in the theta band are involved in tasks related to working memory. The activity in the theta band increased with the number of items retained in working memory. The results suggested that theta oscillations generated in frontal brain regions play a significant role in working memory tasks.

Features of another physiological parameters can also be considered:

CAI Jing et al. recognized emotions considering features of ECG. The automatic location of P-QRS-T wave was performed by use of discrete wavelet transform (DWT). The researchers stated that it is feasible to recognize emotions with the features of ECG [40].

Tanu Sharma et al. studied emotions taking features of many physiological parameters like ECG, HRV, GSR, etc. While experiencing the emotion, there are also physiological

changes taking place in the human body, like variations in the heart rate (ECG/HRV), blood volume pulse (BVP), breathing rate (BR), brain waves (EEG), skin conductance (GSR), temperature and muscle tension. It was concluded that GSR represents the emotional state of the person [41].

1.5 Interventions

A diseased brain's activity is corrected by use of medicines. On the other hand, activity of a healthy brain can be enhanced using some non-invasive or invasive interventions. Interventions are the procedures used for cognitive enhancement. Interventions are of many types such as meditation, color, odour, music, virtual reality, etc.

1.5.1 Meditation

Meditation is usually defined as a state that is experienced when the mind dissolves and is free of all thoughts. In the ancient period, Meditation is a pure spiritual aspect which is helpful to achieve an enlightened personality. In the present scenario, meditation was proved to have more concern with health, consciousness, intellect and self-realization. Meditation is helpful in reducing anxiety, stress and depression, improving psychological health, memory and intelligence, self-concept, problem solving effectiveness, academic performance etc. [42].

1.5.2 Color

By using colors we can enhance cognitive levels. Considering the example of a class of students. If a teacher uses chalks of different colors on the board, the students can be expected to become more attentive. Hence increasing the cognitive abilities [43].

1.5.3 Odor

Odor can be used for cognitive enhancement. Smell is often our first response to stimuli. It alerts us to fire before we see flames. Different odors are given to subjects, some having good fragrance and some having bad. Good fragrances are like fragrance of flowers, fruits etc. Bad fragrances are like fragrance of garbage etc. After some time cognitive level is checked whether it is improved or not [44].

1.5.4 Music

Music can also be used in cognitive enhancement. Music is of different types like classical, folk, etc. People listening to music for sufficient amount of time can be expected to have better cognitive levels [45].

1.5.5 Electroencephalography (EEG) and Neuro-feedback

Biofeedback is a self-intervention. EEG biofeedback is use an intervention for cognitive enhancement. EEG biofeedback is known as Neuro-feedback. Biofeedback is a treatment technique in which people are trained to improve their health by using signals from their own body. Specialists in many different fields use biofeedback to help their patients cope with pain. Biofeedback machines are used to detect a person's internal bodily functions, this information may be valuable for both patients and therapists use to gauge and direct the progress of treatment. [46].

1.6 Cognitive Enhancement

Cognitive enhancement (CE) is a technology. It targets at heightening detailed class of cognitive functions, information-processing functions and physical comprehension of human brain. Modern day CE is unusual because of its function “level of granularity”. Level of granularity expose us with a technology that impacts the core realizers of certain cognitive functions. Enhancement is typically used to depict interventions intended to progress human functioning beyond what is necessary to sustain or restore good health .Enhancement alter physical or mental characteristics in individuals. Many neuropsychiatric illnesses arise on a spectrum that embraces normal levels of functioning. This raises the question: if medications can mend cognition in people with cognitive impairment, what can they do for normal healthy people? This questions

points to what is cognitive enhancement. Cognitive enhancement may be defined as the intensification or addition of core capabilities of the mind through enlargement or escalation of internal or external information processing systems. There are different techniques to perform cognitive enhancement.

Some of them are described as follows:

1.6.1 Conventional

“Conventional” means of cognitive enhancement can be education, mental techniques, neurological health, and external systems.

1.6.1.1 Education

Education and training, as well as the use of external information processing devices, may be labelled as “conventional” means of enhancing cognition. They are frequently well recognised and accepted. Whatever we learn at school comes under this category. For example, abacus is used as a cognitive enhancement technique. The abacus, also called a counting frame, is a calculating tool that was in use centuries before the acceptance of the written modern numeral system and is still widely used by merchants and traders. Abacus is a mechanical calculation device used to store numbers during mental calculations. The beads are slid up or down on various rods to simplify the mathematical processes like addition, subtraction, multiplication, division etc. Many children trained on this technique are able to do calculations faster than those done with the help of electronic calculator.

1.6.1.2 Enriched Environment

This is another method for performing cognitive enhancement. There are various methods for providing such kind of environment. For example, learning or gaining knowledge about something provides enriched environment. Learning refers to gaining knowledge about something new. It can be learning some musical instrument or new games like archery, football, etc. The environment and life experiences affect the health and structure of your brain. A research study from January of 2012 published in the British Medical Journal found that cognitive function begins to decline as early as age

45, which is much earlier than previously thought. The researchers, led by Archana Singh-Manoux from the Centre for Research in Epidemiology and Population Health in France, found that lifestyle choices that lead to cardiovascular health made during middle age greatly impact cognitive function as we age. Animal studies have found that enriched environments can induce important changes in the brain, including enhanced functioning and development in areas related to cognitive capacity, learning, memory, and resilience. Depending on the design of the study, the results might include more neurons, longer dendrites, more connections, heavier brains, greater brain mass, more intra- and intercortex connectivity, and enlarged capillaries. Changed brains can be contrasted with a control group and measured in many ways.

1.6.1.3 Mental Training

Mental training and visualization techniques are widely practiced in elite sport (Feltz and Landers 1983) and rehabilitation (Jackson et al. 2004), with apparently good effects on performance. Users vividly imagine themselves performing a task (running a race, going to a store), repeatedly imagining every movement and how it would feel. A likely explanation for the efficacy of such exercises is that they activate the neural networks involved in executing a skill at the same time as the performance criteria for the task is held in close attention, optimizing neural plasticity and appropriate neural reorganization. General mental activity—“working the brain muscle”—can improve performance (Nyberg et al. 2003) and long-term health (Barnes et al. 2004), while relaxation techniques can help regulate the activation of the brain (Nava et al. 2004). It has been suggested that the Flynn-effect (Flynn 1987), a secular increase in raw intelligence test scores by 2.5 IQ points per decade in most western countries, is attributable to increased demands of certain forms of abstract and visuospatial cognition in modern society and schooling, although improved nutrition and health status may also play a part (Neisser 1997; Blair et al. 2005). On the whole, however, the Flynn effect seems to reflect a change in which specific forms of intelligence are developed, rather than an increase in general fluid intelligence.

1.6.2 Unconventional

Unconventional means are like drugs, implants, direct brain-computer interfaces, these tend to evoke moral and social concerns.

1.6.2.1 Drugs

Drugs can also be used for cognitive enhancement. Cognitive abilities (memory, attention, concentration) can be improved by drugs such as nootropics. Nootropics work by improving the brain's oxygen supply, by stimulating nerve growth, or by altering the availability of the brain's supply of neurochemicals (neurotransmitters, enzymes, and hormones). Some of the commonly used nootropics drugs for enhancing memory are almonds, ginger, tulsi, amla, etc.

1.6.2.2 Gene Therapy

Gene therapy or gene modification is a technique which inserts genes directly into cell. It is used to cure or prevent disease instead of using drugs or surgery. They are useful in enhancing cognitive abilities as well. In rats and mice it has been demonstrated that gene modification enhances memory. NR2A subunit of NMDA (N-Methyl-D-aspartic acid) is linked with low plasticity of brain (or neuroplasticity is the ability of brain to change based on new experience). While normal animal is maturing, synthesis of NR2B is replaced by NR2A, hence memory is low in adult animals [47].

1.7 Electroencephalogram (EEG)

Electroencephalography (EEG) is the recording of electrical activity along the scalp. EEG measures voltage variations resulting from ionic current flows within the neurons of the brain. In clinical backgrounds, EEG refers to the recording of the brain's spontaneous electrical activity over a short period of time, usually 20–40 minutes, as recorded from multiple electrodes placed on the scalp. Diagnostic applications usually emphasize on the spectral content of EEG, that is, the sort of neural oscillations that can be observed in EEG signals. In neurology, the foremost diagnostic application of EEG is in the case of epilepsy, as epileptic activity can create clear abnormalities on a standard EEG study. A secondary clinical use of EEG is in the diagnosis of coma, encephalopathies, and brain death. A third clinical use of EEG is for studies of sleep

and sleep disorders where recordings are typically done for one full night, sometimes more. EEG used to be a first-line method for the diagnosis of tumors, stroke and other focal brain disorders,[3] but this use has decreased with the advent of anatomical imaging techniques with high (<1 mm) spatial resolution such as MRI and CT. Despite limited spatial resolution, EEG continues to be a valuable tool for research and diagnosis, especially when millisecond-range temporal resolution (not possible with CT or MRI) is required.

Derivatives of the EEG technique include evoked potentials (EP), which includes averaging the EEG activity time-locked to the presentation of a stimulus of some sort (visual, somatosensory, or auditory). Event-related potentials (ERPs) refer to averaged EEG responses that are time-locked to more complex processing of stimuli; this technique is used in cognitive science, cognitive psychology, and psychophysiological research.

1.7.1 Basic Principles of EEG

The electrical activity of neurons in the brain yields currents that reach the surface of the scalp. EEG provides a non-invasive method of recording the voltage differences of these scalp potentials. These potentials are generated by both cerebral sources and unwanted non-cerebral artifacts which tend to be exaggerated during movement. The EEG signal is communicated from the scalp electrodes to a differential amplifier in order to intensify the microscopic potentials severely attenuated by their passage through the skull. This signal is continuously sampled at a high rate (typically 256 Hz but often more) to provide a high temporal resolution. An analogue band-pass filter is used to filter the raw EEG signal and typically possesses a lower cut-off of 0.5 Hz and a higher cut-off of 50 Hz. The 50 Hz filter helps eliminate electrical noise originating from 50/60 Hz mains power. These filters also shake the processing of nearby frequencies so care must be taken to ensure the cut-off frequencies do not lie too close to the frequencies under investigation. The default cut-offs pose no problems in the sports sciences as the low to mid-range frequencies (e.g. 4–20 Hz) are normally those of interest.

After amplification and filtering, the EEG signal is (in modern digital systems) relayed to a computer where it can be managed as continuous data and, if looked-for, its spectral parameters compared with some criterion measure. This is the approach adopted by EEG-biofeedback training in sports and other performance domains which rewards desirable changes in specific frequency bands. A substitute method is the study of event-related potentials (ERPs). These typically comprise of data epochs of short duration replicating the cortical response to an external stimulus. In order to offset data noise, many ERPs (often hundreds) are averaged to deliver a good signal-to-noise ratio.

The typically wave like appearance of the EEG signal reflects the rhythmic activity of underlying synaptic processes. This rhythmicity is thought to reflect the synchronized activity of large neuronal assemblies possibly driven by thalamic pace-maker cells; although the simplicity of this interpretation has been questioned. Anatomically distinct cortical areas produce a variety of different rhythms which are observed as a composite EEG signal. Fourier spectral analysis is typically used to decompose this signal into its constituent frequency bands and to compute the amplitude of each band. These bands have been historically categorized as delta (<4 Hz), theta (4–8 Hz), alpha (8–12 Hz) and beta (13–30 Hz), although alternative classifications have also been employed. Slower waves such as delta are typically associated with sleep while faster beta waves are associated with wakefulness and mental activity. Alpha has been linked to a 'relaxed focus or mental readiness. An increase in alpha activity is often the goal of EEG-biofeedback training aiming to improve sporting performance through increasing the user's ability to remain focused thereby filtering out distracting stimuli, thoughts or emotions. In addition to spectral analysis, more complex analytical techniques have been developed including source localization methods such as low resolution electromagnetic tomography, or LORETA, which aim to identify the original sources of cortical oscillations.

1.7.2 Frequency Bands of EEG

The EEG is usually labelled in terms of rhythmic activity and transients. The rhythmic activity is divided into bands by frequency. These frequency bands are an issue of

nomenclature (i.e., any rhythmic activity between 6–12 Hz can be described as "alpha"), but these designations arose because rhythmic activity within a certain frequency range was noted to have a certain distribution over the scalp or a certain biological significance. Frequency bands are typically extracted using spectral methods (for instance Welch) as employed for illustration in freely obtainable EEG software such as EEGLAB toolbox.

Most of the cerebral signal detected in the scalp EEG falls in the range of 1–20 Hz. EEG signals are composed of dissimilar oscillations. These rhythms have distinctive properties in terms of spatial and spectral localization. There are 6 conventional brain rhythms:

- Delta (0.5-4 Hz) □ Theta (4-8 Hz)
- Alpha (8-12 Hz)
- Beta (12-30 Hz)
- Gamma (>30 Hz)

Delta rhythm: Delta is the frequency range up to 4 Hz. It tends to be the maximum in amplitude and the gentlest waves. It is seen generally in adults in slow wave sleep. It is also seen ordinarily in babies. It may occur focally with subcortical lesions and in general allotment with diffuse lesions, metabolic encephalopathy hydrocephalus or deep midline lesions. It is usually most prominent frontally in adults and subsequent in children.

Theta rhythm: Theta is the frequency range from 4 Hz to 7 Hz. Theta is seen normally in young children. It may be seen in sleepiness or arousal in older children and adults; it can also be seen in meditation. Excess theta for age signifies abnormal movement. It can be seen as a focal interruption in focal subcortical lesions; it can be seen in universal allocation in diffuse disorder or metabolic encephalopathy or deep midline disorders or some occurrences of hydrocephalus. On the contrary this range has been linked with reports of meditative, relaxed and creative states.

Alpha rhythm: Alpha is the frequency range from 8 Hz to 12 Hz. Hans Berger named the first rhythmic EEG activity he saw as the "alpha wave". This was the "posterior basic rhythm" (also called the "posterior dominant rhythm" or the "posterior alpha rhythm"), seen in the posterior regions of the brain on both sides, higher in amplitude on the dominant side. It develops with closing of the eyes and with relaxation, and mental application or attenuates with eye opening. The posterior basic rhythm is actually slower than 8 Hz in young children (therefore technically in the theta range).

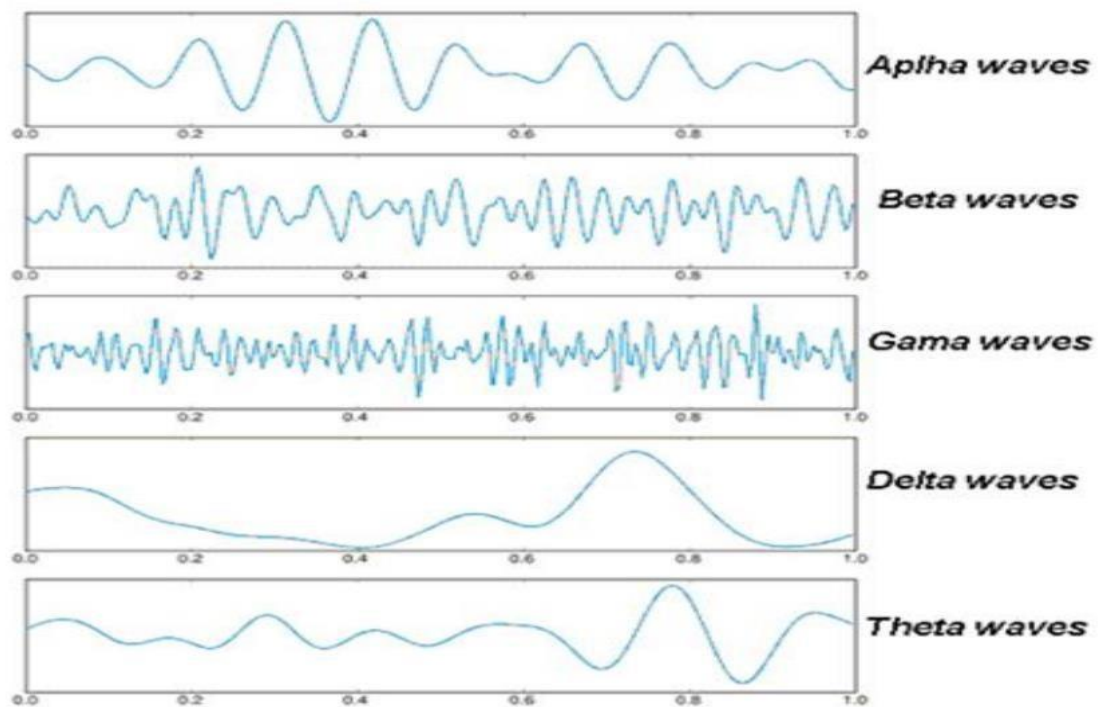


Figure 1.1: Brain rhythms

Beta rhythm: Beta is the frequency range from 12 Hz to about 30 Hz. It is seen usually on both sides in symmetrical distribution and is most clear frontally. Beta activity is closely associated to motor behaviour and is generally attenuated during active movements. Low amplitude beta with multiple and varying frequencies is regularly connected with active, busy or anxious thinking and active attentiveness.

Rhythmic beta with a dominant set of frequencies is associated with a variety of pathologies and drug effects, especially benzodiazepines. It may be inattentive or condensed in areas of cortical damage. It is the dominant rhythm in patients who are attentive or anxious or who have their eyes open.

Gamma rhythm: This rhythm concerns mostly frequencies above 30 Hz. This rhythm is well-defined as having a maximal frequency around 80 Hz or 100 Hz. It is allied to various cognitive and motor functions. It displays during cross-modal sensory processing (perception that combines two different senses, such as sound and sight). It is also shown during short-term memory matching of recognized objects, sounds or tactile sensations. A decrease in gamma-band activity may be linked with cognitive decline, especially when related to the theta band; however, this has not been computed for use as a clinical diagnostic measurement.

Comparison of EEG bands			
Band	Frequency (Hz)	Location	Normally
Delta	up to 4	frontally in adults, posteriorly in children; high-amplitude waves	• adult slow-wave sleep • in babies • Has been found during some continuous-attention tasks^[39]
Theta	4 – 7	Found in locations not related to task at hand	• young children • drowsiness or arousal in older children and adults • idling • Associated with inhibition of elicited responses (has been found to spike in situations where a person is actively trying to repress a response or action).^[39]
Alpha	7 - 14	posterior regions of head, both sides, higher in amplitude on non-dominant side. Central sites (c3-c4) at rest	• relaxed/reflecting • closing the eyes • Also associated with inhibition control, seemingly with the purpose of timing inhibitory activity in different locations across the brain.
Beta	15 - 30	both sides, symmetrical distribution, most evident frontally; low-amplitude waves	• alert/wo • active, busy, or anxious thinking, active concentration
Gamma	30 – 100+	Somatosensory cortex	• Displays during cross-modal sensory processing (perception that combines two different senses, such as sound and sight)^{[40][41]} • Also is shown during short-term memory matching of recognized objects, sounds, or tactile sensations
Mu	8 – 13	Sensorimotor cortex	• Shows rest-state motor neurons.^[42]

Table 2: Comparison of EEG bands

1.7.3 Recording Methods

EEG measurement consist the attachment of electrodes to standardized positions on the scalp. These electrodes are usually made of highly conductive silver or silver chloride (Ag/AgCl) although other metals such as tin, gold and platinum are also used. Non-metallic material such as carbon fibre can also be employed to allow compatibility with other neuro imaging devices such as MRI. Electrodes are attached to the skin using conductive adhesive with impedances usually kept below 5 kilo ohms. Prior to attaching the electrodes the skin is usually prepared with an abrasive paste such as Nu-Prep to reduce skin impedance. The number of active electrodes can range from one, which is sufficient for neurofeedback training, to multiple electrodes necessary for source localization with the number of electrodes typically varying from 20 to 128. Electrode placement is standardized to aid interpretability from one laboratory to another.

1.7.3.1 International 10/20 System:

Electrodes are generally placed according to a standard system called the 10-20 international system. This system has been originally considered for 19 electrodes, however, extended versions have been developed to deal with a larger number of electrodes.

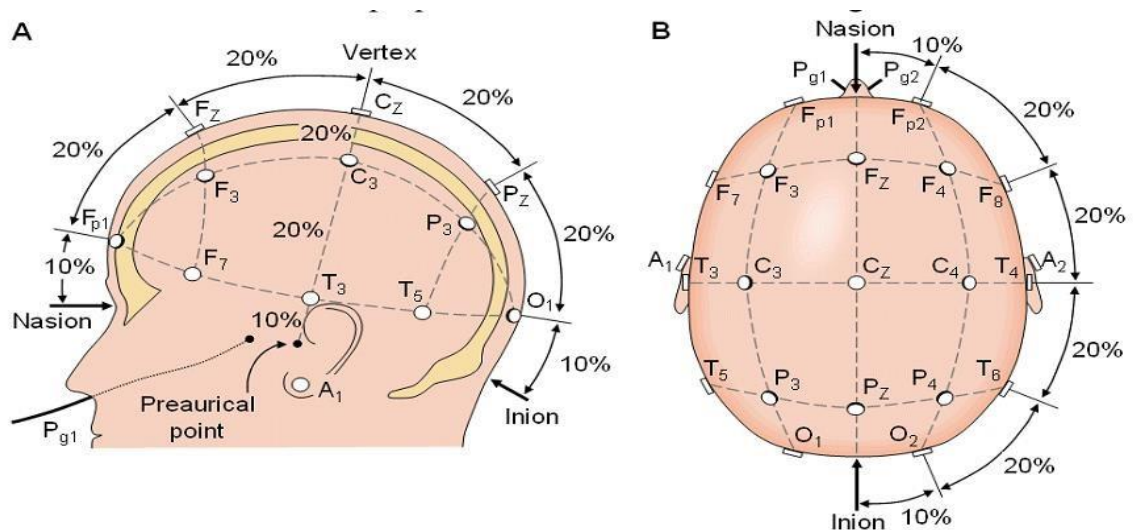


Figure 1.2: 10-20 Placement

The 10-20 system or International 10-20 system is an internationally renowned technique to designate and apply the location of scalp electrodes in the EEG experiment. This method was established to confirm standardized reproducibility so that a subject's readings could be linked over time and subjects could be compared to each other. This system is based on the association between the site of an electrode and the underlying area of cerebral cortex. The "10" and "20" refer to the fact that the actual distances between adjacent electrodes are either 10% or 20% of the total front-back or right-left distance of the skull.

Each location has a letter to identify the lobe and a number to recognize the hemisphere location. The letters F, T, C, P and O stand for frontal, temporal, central, parietal, and occipital lobes, respectively. Note that there exists no central lobe; the "C" letter is only used for identification purposes only. A "z" (zero) refers to an electrode placed on the midline. Even numbers (2, 4, 6, and 8) refer to electrode positions on the right hemisphere, whereas odd numbers (1, 3, 5, and 7) refer to those on the left hemisphere.

1.7.3.2 Source of EEG activity

The brain's electrical charge is maintained by billions of neurons. Neurons are electrically charged (or "polarized") by membrane transport proteins that pump ions across their membranes. Neurons are constantly exchanging ions with the extracellular milieu to maintain resting potential and to propagate action potentials. Ions of alike charge repel each other, and when many ions are pushed out of many neurons at the same time, they can thrust their neighbours, who push their neighbours, and so on, in a wave. This process is known as volume conduction. When the wave of ions influences the electrodes on the scalp, they can push or pull electrons on the metal on the electrodes. Since metal conducts the push and pull of electrons easily, the difference in push or pull voltages between any two electrodes can be measured by a voltmeter. Recording these voltages over time gives us the EEG.

Scalp EEG activity displays oscillations at a variety of frequencies. Several of these oscillations have characteristic frequency ranges, spatial distributions and are associated with different states of brain functioning (e.g., waking and the various sleep

stages). These oscillations represent synchronized activity over a network of neurons. The neuronal networks underlying some of these oscillations are understood (e.g., the thalamocortical resonance underlying sleep spindles), while many others are not (e.g., the system that generates the posterior basic rhythm). Research that measures both EEG and neuron spiking finds the relationship between the two is complex, with a combination of EEG power in the gamma band and phase in the delta band relating most strongly to neuron spike activity.

1.7.4 Artifacts

1.7.4.1 Biological Artifacts: Electrical signals detected along the scalp by an EEG, but that initiate from non-cerebral origin are called artifacts. EEG data is almost always tainted by such artifacts. The amplitude of artifacts can be quite huge compared to the size of amplitude of the cortical signals of interest. This is one of the reasons why it takes significant experience to correctly interpret EEGs clinically.

Some of the most common types of biological artifacts include:

- Eye-induced artifacts (includes eye blinks, eye movements and extra-ocular muscle activity)
- ECG (cardiac) artifacts
- EMG (muscle activation)-induced artifacts

The most protuberant eye-induced artifacts are caused by the potential difference between the cornea and retina, which is quite large compared to cerebral potentials. When the eyes and eyelids are completely still, this cornea-retinal dipole does not affect EEG. However, blinks occur several times per minute, the eyes movements occur several times per second. Eyelid movements, occurring mostly during blinking or vertical eye movements, elicit a large potential seen mostly in the difference between the Electrooculography (EOG) channels above and below the eyes. An recognised clarification of this potential regards the eyelids as sliding electrodes that short-circuit the positively charged cornea to the extra-ocular skin.

1.7.4.2 Environmental Artifacts: In addition to artifacts generated by the body, many artifacts originate from outside the body. Movement by the patient, or even just settling of the electrodes, may cause electrode pops, spikes originating from a momentary change in the impedance of a given electrode. Poor grounding of the EEG electrodes can root noteworthy 50 or 60 Hz artifact, depending on the local power system's frequency. A third source of possible interference can be the presence of an IV drip; such devices can cause rhythmic, fast, low-voltage bursts, which may be confused for spikes.

1.7.4.3 Artifact Correction: Recently, independent component analysis techniques have been used to correct or remove EEG contaminants. These techniques challenge to "unmix" the EEG signals into some number of underlying components. There are many source separation algorithms, often assuming various behaviors or natures of EEG. Regardless, the principle after any particular method usually allow "remixing" only those components that would result in "clean" EEG by nullifying (zeroing) the weight of unwanted components. Fully automated artifact rejection methods, which use independent component analysis (ICA), have also been established [48-51][8].

CHAPTER 2 EMOTIONS: EFFECTS ON ELECTROENCEPHALOGRAPHY

Cognitive abilities are closely related to emotions. In the research, cognitive assessment has been carried out taking emotions into account. Emotions play an important role in cognition. The effect of odor is studied on different emotions. Certain parts of EEG are affected by different emotions. As per the previous researches, these parts and features have been observed.

Dan Nie et al. recognized emotions using EEG while the subjects watch videos related to distinguished emotions. The study finds the relationship between EEG signals and human emotions. EEG signals are used to classify two kinds of emotions, positive and negative. Features from original EEG data are extracted using a linear dynamic system approach to correct these features. An average test accuracy of 87.53% was obtained by using all of the features together with a support vector machine. EEG data in this study were recorded from 3 women and 3 men aged around 22 years of age. Several movie clips of 4 minutes each were shown to the subjects. These clips were related to romantic, musical, war, disaster and landscape films. The signals of the EEG data were visually checked. Then energy of each channel and each band was computed and it was shown that energy for positive emotion increases as compared to the negative ones [52].

Irene Winkler et al. considered the asymmetry index. The researchers studied the problem of classifying the EEG signals utilizing the “frontal EEG asymmetry” phenomenon. This was done while presenting pictures to the subjects related to different emotions. It was suspected that brain activity is related to emotions. Also, left frontal activity indicates a positive or approach-related emotion, whereas higher right frontal activity indicates a negative or withdrawal-related emotion. The degree of activation is concluded from the spectral power in the alpha band, with lower values in alpha power being associated with a higher degree of activity. Alpha asymmetry indices were then computed by subtracting the natural logarithm of left-sided alpha power from the natural logarithm of right-sided alpha power (Asymmetry

Index = $\ln[\text{right alpha}] - \ln[\text{left alpha}]$). Assuming an inverse relationship between alpha power and cortical activation, a more positive asymmetry index reflects a greater relative left hemispheric activity [53].

Ian H. Gotlib, Charan Ranganath and J. Peter Rosenfeld made their research on physiological activities in the prefrontal region of brain to relate depression and cognitive functioning. They evaluated the asymmetry in prefrontal region using power in the alpha band. According to the research, left frontal hypo activation is related to depression. In study 1, they computed Davidson's formulations by observing differences in frontal EEG alpha asymmetry among currently depressed, previously depressed, and never depressed subjects. As expected, currently and previously depressed subjects showed left frontal hypo activation relative to never depressed controls. In study 2, relations among the frontal EEG asymmetry were computed in response to negative mood induction procedure, attentional processing [54].

Sander Koelstra et al. classified emotions aroused during music videos. Correlations between users' self-assessments of arousal and valence and the frequency powers of their EEG activity were presented. For EEG, an average (maximum) classification rate of 55.7% (67.0%) for arousal and 58.8% (76.0%) for valence was obtained [55].

Yuan-Pin Lin et al. recognized emotions while listening music. Support vector machine was employed to classify four emotional states (joy, anger, sadness, and pleasure) and obtained an averaged classification accuracy of $82.29\% \pm 3.06\%$. 26 subjects were considered in the study. EEG dynamics were considered while the subjects listened to music. The identified features were primarily derived from electrodes placed near the frontal and the parietal lobes [56].

Anirban Basu and Anisha Halder used facial expressions and EEG signals in their study for emotion recognition. Five subjects are requested to watch particular videos for exciting five different emotions in their mind. The facial expressions and EEG signal of subjects are logged by a good quality camera and EEG machine respectively while watching the movie clips. 16 numbers of Kalman Filter coefficients and power spectral density were computed next [57].

CHAPTER 3 ODOR FOR COGNITIVE ENHANCEMENT

3.1 Introduction

Cognitive Enhancement refers to the procedure by which the abilities or capacities of a healthy brain can be improved further through improvement of processing system of brain. The dictionary meaning of enhancement says “enhancement is to raise to a higher degree”. Thus enhancement can be done by using some kind of interventions like music, odor, meditation, brain wave entrainment. In this research, we use odor as an intervention. Olfaction plays a very important role in extending or amplifying the core capacities of the mind.

Many neuropsychiatric illnesses occur on a spectrum that includes normal levels of functioning. This raises the question: if medicines can recover cognition in people with cognitive deficiency, what can they do for normal healthy people? This questions points to what is cognitive enhancement. The process of cognitive enhancement needs some interventions. In this research, we are concentrating on odor as an intervention. After carrying out cognitive assessment by certain techniques, the next step is to carry out the process of cognitive enhancement using some sort of intervention [58]. We use the odor of lemon in this research. How important smell is in determining what we do and do not like? Many researchers have worked in this concern.

3.2 Olfaction

Olfaction or olfactory perception is the sense of smell. This sense is facilitated by dedicated sensory cells of the nasal cavity of vertebrates, which can be reflected equivalent to sensory cells of the antennae of invertebrates. In humans, olfaction happens when odorant molecules bind to full sites on the olfactory receptors. These receptors are used to observe the occurrence of smell. They come together at the glomerulus, a construction which conveys signals to the olfactory bulb (a brain assembly above the nasal cavity and beneath the frontal lobe). Many vertebrates, comprising most reptiles and mammals, have two distinct olfactory systems—the main

olfactory system, and the accessory olfactory system (used mainly to detect pheromones). For air-breathing animals, the main olfactory system identifies instable chemicals, and the accessory olfactory system notices fluid-phase chemicals. Olfaction and taste are forms of chemoreception. The chemicals that arouse the olfactory system at very low concentrations are called odorants.

3.3 How brain detects odor

Smell is first response to stimuli. It alarms us to fire before we realise flames. But although smell is a simple sense, it's also at the front of neurological investigation. Scientists are still determining how humans pick up odorants, understand them and process them as smells.

Smell, like taste, is a chemical sense professed by sensory cells called chemoreceptors. When an odorant arouses the chemoreceptors in the nose that perceive smell, they permit electrical impulses to the brain. After that the brain construes patterns in electrical activity as exact odors and olfactory feeling becomes insight - something we can distinguish as smell. The only other chemical system that can quickly identify, make sense of and memorize new molecules is the immune system.

But smell, more so than any other sense, is also closely related to the parts of the brain that process emotion and associative learning. The olfactory bulb in the brain, which sorts sensation into perception, is part of the limbic system - a system that comprises the amygdala and hippocampus, structures vital to our behavior, mood and memory. This link to brain's emotional center makes smell an appealing edge in neuroscience and behavioral science.

3.4 How the sense of smell works

The sense of smell is a chemical sense. They are called chemical senses because they notice chemicals in the environment, with the alteration being that smell works at intensely larger distances than that of taste. The process of smelling goes more or less like this:

- Vaporized odor molecules moving in the air touch the nostrils and melt in the mucus (which is at the start of each nostril).
- Under the mucus, in the olfactory epithelium, dedicated receptor cells called olfactory receptor neurons perceive the odor. These neurons are proficient of noticing thousands of different odors.
- The olfactory receptor neurons convey the information to the olfactory bulbs, which are situated at the back of the nose.
- The olfactory bulbs has sensory receptors that are a part of the brain which send messages directly to: the most primitive brain centers where they effect emotions and memories, and
- “Higher” centers where they adjust conscious thought (neo-cortex).
- These brain centers recognise odors and access memories to remind us about places, people, or events connected with these olfactory sensations [59].

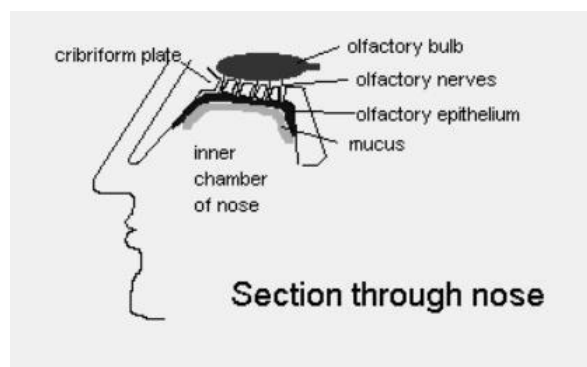


Figure 3.1: Section through nose

3.5 Effects of different odors

Hironobu Kamimura et al. considered both psychological and physiological parameters to explore the effects of odors on human body during a footbath. The study used two odors: lemon and hinoki on human body while the subjects took footbath. The subjects were 10 healthy college students. The researchers divided the experiment into two parts. The first part was the baseline period of 5 minutes. In this part the subjects simply remained seated. During the second period the subjects continued to remain seated with their feet immersed in a footbath for 11 minutes. At the same time the subjects were exposed to different odors. Lemon was used as ‘pleasant’ odor and Hinoki

was used for the odor termed 'Japanese bath'. The results of our experiments showed that the use of both lemon and Hinoki odors significantly increased body temperature (36 degree). Using Graphical modelling a correlation was observed between the use of different odors and subjects' impressions of the heat of the water in the footbath. Use of both the pleasant and Japanese bath odors showed a prominent effect on the subjects' physiological and psychological presentation. Particularly *at 36 degree Hinoki odor has a good amount of relationship to physiological parameter, at 40 degree lemon odor has a nice relationship with physiological parameter* [60].

The same authors **Hironobu Kamimura** et al. studied the effects of lavender and peppermint odors on human body at 36° C and 40° C. The study was carried out while the subjects took footbath. The subjects were 12 healthy college students. First of all, baseline was taken for 5 minutes during which the subjects remained ideal. During the second period the students continued to remain seated and immersed their feet in a footbath for 11 minutes. At the same time the students were exposed to different odors. Peppermint was used as a 'refreshing' odor and lavender was used a 'relaxing' one. The results of the research showed that the use of peppermint resulted in a notable increase in energy expenditure as compared with the absence of odors. On the other hand, lavender resulted in a significant decrease on energy expenditure and O₂Hb: cerebral blood flow. Thus, *lavender odor affected the Parasympathetic nerve system, while peppermint had an inverse effect on the sympathetic nerve system. At 40°C the lavender odor also showed a prominent effect on the subjects' physiological and psychological performances* [61].

Hidenori Tanaka et al. studied the effects of lavender during a cognitive task. It was explored whether the auditory cognitive processes affect mental stress of listener. Some pre-experiments were conducted before the main one. The pre-experiments were made to achieve "time responses of secretory immunoglobulin A (s-IgA) in response to stimuli. The main experiment was to observe the response of salivary sIgA during repetitive auditory cognitive task and the effect of odor (lavender) on the response. 10 healthy subjects were asked to perform the task in which subjects must continuously respond to a particular auditory stimuli amongst three kinds of stimuli, three times repeatedly being exposed to the odor of lavender. After each task, it follows 3 minutes interval with no

task. Before and after each task, saliva samples were collected. As a result, *s-IgA secretion rate enlarged during the repetitive cognitive task in odorless state. In odor condition, the average value of s-IgA secretion rate was always more than that during the repetitive task without odor* [62].

T. Hongratanaworakit and G. Buchbauer et al. observed human behaviour and physiological reactions to inhalation of sweet orange oil. The main objective of the research was to investigate the effects of this fragrance compound on physiological parameters as well as self-evaluation in healthy human subjects following inhalation. Physiological parameters recorded were breathing rate, blood pressure, skin temperature, and heart rate. Self-evaluation was measured in terms of attentiveness, alertness, calmness, mood, relaxation, and energy. Furthermore, the fragrance was rated in terms of pleasantness, intensity, and effect. *Sweet orange oil caused noteworthy growths in heart rate as well as in subjective alertness, which are likely to signify a stimulating effect of the oil.* These findings deliver scientific proof for the use of sweet orange oil in aromatherapy for the relief of mild forms of depression and stress in humans [63].

Hiroshi Yamada et al. researched on the performance and physical responses during an attention shift task with grapefruit and skatole odor presentation. Performance and physiological responses while execution of an attention shift task were compared between grapefruit odor, skatole, odorless air presentation. Ten male students participated in this experiment. They performed 15 min digit detection task three times which required quick attention shift. During the task, 1 min odor was presented three times. EEG and near infrared spectroscopy were supervised through the experiment. Also, it presented physiological values of oxy-Hb, deoxy-Hb and beta wave component. *The number of correct responses and reaction time were better in both grapefruit and skatole presentation than in odorless air. While grapefruit presentation, oxy-Hb increased that indicated activated brain function, also it was observed only in grapefruit presentation at left forehead. Increased beta wave component that reflects relaxation, was found in grapefruit presentation at F4 (left middle forehead), while decreased beta in skatole presentation.* These findings suggest grapefruit acts as an activator, while skatole as a sedative [64].

Takayuki Koike et al. studied the effects of odorant presentation on changes in cognitive interference and brain activity during a counting stroop task. Cognitive task for longer duration increases subject's psychological loadings because of extracting ordered answer from visual stimuli. The present study examined how sporadic odorant presentation during cognitive task donates to cognitive function and statement of psychological loadings. Ten subjects were instructed to perform counting stroop task that repeatedly counts the pieces of digits displayed on a monitor. The task consisted three tasks that the digits and the number were consisted (task1), nonconsisted (task2), and both the former tasks combined (task3). The duration of each task was four minutes, and thus subjects totally performed the tasks for 12 minutes. Four kinds of odorant stimuli (non-odor, lemon, peppermint and skatole) were used in this study and each odor was presented after beginning of each task for one minute. Behavioral results, rate of content of alpha, beta, delta and theta waves from EEG, and oxygenated haemoglobin concentration (ΔO_2Hb) were measured and compared between each odor condition. Behavioral results, the reaction time and the percentage of questions answered correctly, ΔO_2Hb in right hemisphere related to pleasant emotion, and rate of content of alpha wave were significantly increased when peppermint and skatole were presented. The findings indicated that intermittent odor presentation induced pleasant emotion and increased cognitive function and state of concentration, regardless of odors [65].

Rob W. Holland, Merel Hendriks and Henk Aarts observed the non-conscious effects of odors. Three studies discovered whether odor can influence people's cognition and conduct without their being consciously aware of the stimulus. In two studies, it was verified and established that when participants were unremarkably exposed to citrus-scented all-purpose cleaner, the mental convenience of the performance concept of cleaning was enhanced, as was indicated by faster identification of cleaning-related words in a lexical decision task and higher frequency of listing cleaning-related activities when describing expected behavior during the day. Finally, a third study recognised that the simple exposure to the scent of all-purpose cleaner caused participants to keep their direct environment cleaner during an eating task. Awareness checks showed that participants were ignorant of this influence [66].

Anne L. James explored the effects of odor on Compliance and Willingness to Volunteer. The study aimed on the effects of lavender and peppermint ambient odor on compliance and volunteerism. Sixty undergraduate students contributed by answering a questionnaire that had been saturated or not saturated with odor. Helping behavior was judged by the participants' willingness to take part in a brief telephone survey and to mail back food labels. Noteworthy results were obtained for odor on both compliance and willingness to volunteer. As a result, *the peppermint group to be significantly more compliant and willing to volunteer than the lavender group and significantly more willing to volunteer than the no odor group* [67].

Mark Moss et al. used the aromas of peppermint and ylang ylang. This study provides indication for the impression of the aromas on aspects of cognition and mood in healthy contestants. One hundred and forty-four volunteers were randomly consigned to conditions of ylang-ylang aroma, peppermint aroma, or no aroma control. Cognitive performance was calculated using the Cognitive Drug Research computerized assessment battery and mood scales were completed before and after cognitive testing. *Peppermint was found to enhance memory whereas ylang-ylang impaired it, and elongated processing speed.* In terms of subjective mood peppermint increased alertness and ylang-ylang decreased it, but meaningfully increased calmness. These results offer support for the contention that the aromas of essential oils can yield significant and characteristic effects on both subjective and objective assessments of aspects of human behaviour [68].

Jean-Louis Millot et al. studied the effects of odors on reaction times of humans. The research equated the reaction times of subjects between ambient odor conditions both pleasant and unpleasant and a no odor condition. *The results showed that the reaction time in simple tasks (responses to visual or auditory stimulation) expressively decreased in the ambient odor conditions compared with the no odor condition* [69].

Hiroaki Tsujimoto et al. predicted the feeling of subject under odor condition using physiological information. In this study, the researchers have measured an EEG activity of a subject who was exposed to odor. The influence of the odor stimulation by a chaotic

analysis and a frequency analysis was computed. The affection of odor stimulation could be observed even if the subject did not consciously feel the odor.

The results showed that in the preferred odor stimulation the chaotic value of EEG data decreased slowly but it of the un-preferred odor stimulation dispersed. The change of the feeling of subject by the odor stimulation was also explored and the feeling of subject by the more suitable several explanatory variates selected from physiological information could be predicted [70].

Ashkan Yazdani et al. observed the EEG alterations during pleasant and unpleasant odors. In this research, electroencephalogram (EEG) of five participants during perception of unpleasant and pleasant odor stimuli were analysed. The regions of the brain cortex that are active during discrimination of unpleasant and pleasant odor stimuli were also found. *It was shown that classification of EEG signals during perception of odor scan reveal the pleasantness of the odor with relatively high accuracy* [71].

Tatsuya Iwaki and Mika Noshiro studied the EEG Activity over Frontal Regions during Positive and Negative Emotional Experience. It has been shown that frontal EEG activity has potential for estimating emotional state. Fifteen university students partook in both the image and odor stimulus periods. They were coached to adjust a dial to rate their subjective emotional intensity during the period between the onset of image/odor presentation and the offset of a blank screen presentation. Standard 21 channel electroencephalograms were acquired and analysed. After that laterality, coherence and frequency fluctuation of the alpha band of frontal EEG signals were compared amongst control, pleasantness and unpleasantness conditions. *The results indicated that both the laterality model and the frequency fluctuation model were able to estimate emotional state from frontal alpha band EEG activity.* However, the sensory modality of the stimulation influenced the laterality of frontal cortical activity, as indicated by a difference in the laterality index between the image and odor sessions [72].

Hironobu Kamimura et al. studied the effects of pleasant and unpleasant odor on recovery period after moderate exercise by different types of breathing. The subjects were nine healthy college students. The experiment was divided into three sessions. The

first was the baseline period of six minutes. During this part, the subjects remained seated. During the second period the subjects exercised for twelve minutes on an exercise bike. In the final period, the subjects were seated again during which time they were exposed to a number of different odors. Students' breathing was also verified and checked, the breathing divided into either students' natural breathing cycle, or inhalation through the nose and exhalation through the mouth. Odors rated 'pleasant' by the students did not result in any changes in their respiratory metabolism. However, exposure to unpleasant odors resulted in significant change in the respiratory metabolism during the recovery period. *The results of the experiment suggest that the exposure to an unpleasant odor, combined with breathing in through the nose and out through the mouth, had a notable effect on the student's respiratory metabolism* [73].

H.Tsujimoto et al. analysed EEG signals stimulated by pleasant and unpleasant odors. In this study, EEG activity of a subject who was exposed to the odor was measured and the influence of the odor stimulation by a chaotic analysis and a frequency analysis was computed. It could be considered to be measurable the affection of odor stimulation even if one is not conscious the odor. *The results showed that in the case of the pleasant odor stimulation the chaotic value of EEG data decreased slowly with a time but it of the unpleasant odor stimulation dispersed* [74].

CHAPTER 4 PROBLEM DEFINITION

As per the previous researches, many odors have been used for the purpose of cognitive enhancement. In our research, we make use of the odor of lemon. There has been very less work done using this odor. This intervention of smelling the odor has been provided to healthy engineering students to enhance their cognitive abilities. As per our knowledge, very less work has been carried out with engineering students in this regard. Moreover, it is important to mention that this is a sort of pilot study which tries to verify what previous researchers have stated. For instance, it has been notified that asymmetry index and powers of various bands of the physiological EEG signals increase in case of happy emotions. Hence, in this research we focus on enhancement in cognitive abilities, viz., different emotion states- happy and sad. Not much work has been done taking emotions and odor together into consideration. Moreover, the study involves short-term meditation as the subjects undergo through the process of odor for 15 days. The present research on healthy engineering students shall therefore focus on:

- (i) to verify the changes in EEG rhythms during tasks involving two different emotions, that are, happy and sad.
- (ii) to explore the effects of odor of lemon on cognitive enhancement of emotions.

CHAPTER 5 PROPOSED METHOD

Any cognitive enhancement technique involves application of suitable intervention. Pre and post-intervention cognitive assessment is made to confirm the cognitive enhancement achieved, if any. The protocol proposed for this research involves the following:

5.1 Participants

All the participants shall be engineering students from undergraduate or postgraduate level. Before the experiment, all participants shall be given a detailed, written summary of the experimental procedures. None of the participants shall have any neurological or psychiatric disorders or previous head injury that might affect the experiment. It shall be confirmed that all subjects had normal or corrected normal vision and normal hearing. All experiments shall be conducted in the Laboratory of Thapar University.

5.2 Preparation of participant for EEG

Participants shall sit on a comfortable armchair in the front of monitor. They shall be explained about complete procedure, that is, hardware (EEG system), data acquisition, and all the tests to be carried out, as a result of which subject shall become familiar with the experiment. The scalp of subject shall be prepared by light abrasion to remove dead cells. Details of data acquisition using BioPac MP150 are explained in Chapter 6.

5.3 Baseline data acquisition

The EEG data as the baseline shall be taken by making the subject seated calmly for 2 minutes with eyes opened and no movements in the body.

5.4 Tests for pre-intervention cognitive assessment

As a part of pre-intervention cognitive assessment, the subject shall be made to watch videos of two different emotions of his/her choice- one of happy and another of sad emotion. The videos shall be picked up from the internet. EEG data shall be acquired while the subject watches the videos.

5.5 Intervention

The odor of lemon is used as a part of intervention. The subject shall be provided with an aroma lamp and aroma oil of lemon. The aroma shall be inhaled by the subjects for 15 days for one hour daily.

5.6 Tests for post-intervention cognitive assessment

As a part of pre-intervention cognitive assessment, the subject shall be made to watch videos of two different emotions of his/her choice- one of happy and another of sad emotion. The videos shall be picked up from the internet. EEG data shall be acquired while the subject watches the videos.

5.7 Statistical analysis of data

Statistical analysis of data shall be done using one tail paired type t-test. The t-Test shall be used to test the null hypothesis that the means of two populations are equal. For testing statistical significance of data either one tailed or two-tail test shall be computed. Depending on whether one trend is considered in extreme or both trends are considered equally likely one tail or two tail test shall be considered respectively. Type of t-Test, that is, whether it is type one, type two or type three shall depend on whether data is paired, homoscedastic or unequal respectively. It shall return the value of “p” i.e. probability associated with the t-Test.

5.8 Signal Processing and feature extraction

The pre and post data required shall be analysed and then compared to observe the changes due to training. The raw data acquired shall be filtered initially. The frequency range shall be selected between 0.5 to 30 Hz as this covers almost whole range of an EEG signal. This shall be followed by Independent Component Analysis (ICA) of the signal. ICA shall be used for finding underlying factors or components from multivariate (multi-dimensional) statistical data. The eye artifacts and muscle artifacts shall be removed from the resulting signal. This procedure shall be carried out using EEGLAB toolbox. The final data thus obtained shall be analysed using frequency analysis. This frequency analysis shall be done using Wavelet transform.

Different ranges of EEG signal- alpha (α), beta (β), theta (θ) shall be computed by programming in MATLAB. Power of all the components shall be calculated individually.

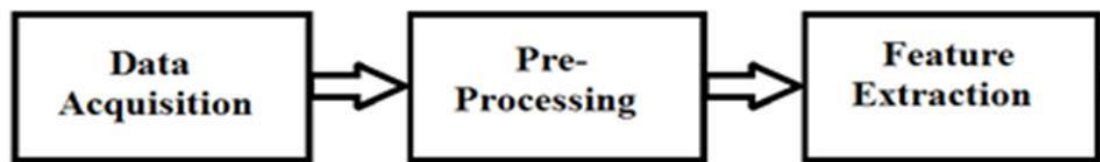


Figure 5.1: Flow chart for signal processing

For computing physiological results, the parameters like asymmetry index shall be computed and then compared. Alpha asymmetry indices can be computed by subtracting the natural logarithm of left-sided alpha power from the natural logarithm of right-sided alpha power (Asymmetry Index = $\ln[\text{right alpha}] - \ln[\text{left alpha}]$). A more positive asymmetry index reflects a greater relative left hemispheric activity.

Details of components of signal processing are explained in Chapter 6.

5.9 Comparison of EEG data acquired during pre and post-intervention procedures

The EEG data acquired during both procedures is compared to know how much the cognitive abilities have been enhanced. Values asymmetry indices are compared.

CHAPTER 6 IMPLEMENTING THE PROPOSED METHOD

6.1 Data Acquisition

EEG data is recorded using BIOPAC MP150 system having 10 channels. The electrodes are placed according to international 10-20 system. EEG data is acquired while the person watches the videos during pre and post-intervention procedures. The sampling rate at which data is acquired is 500 Hz.

6.1.1 BioPac MP150 System

EEG data was acquired using MP150 BioPac system. The MP System (MP150 or MP36R) is a complete data procurement system that includes both hardware and software for the attainment and analysis of life science data. The MP System (MP150 or MP36R) is used for data acquisition, storage, analysis and retrieval. The MP System is a computer-based data acquisition system that performs many of the same functions as a chart recorder or other data viewing device, but is bigger to such devices in that it transcends the physical limits commonly encountered (such as paper width or speed). The MP data acquisition unit (MP150 or MP100) is the heart of the MP System. The MP unit takes incoming signals and converts them into digital signals that can be processed with the computer.



Figure 6.1: MP150 BioPac system

The MP150 high-speed data acquisition system employs the very modern in Ethernet technology. The MP150 is compliant with any Ethernet (UDP) ready PC running Windows or Macintosh. This next generation product takes full advantage of cutting edge technology. Access multiple MP150 devices located on a local area network and record data to any computer connected to the same LAN. Record multiple channels with variable sample rates to maximize storage efficiency. Recording is done at a speed up to 400 KHz (aggregate).

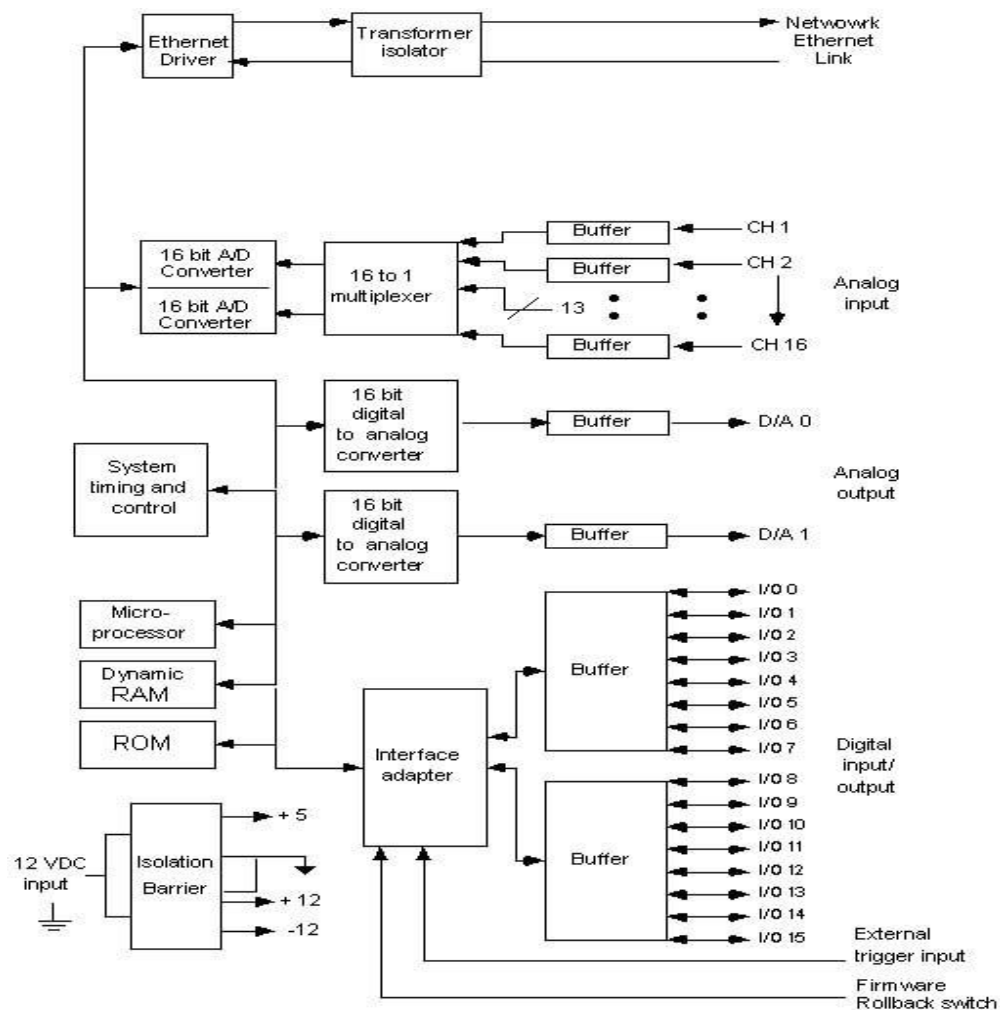


Figure 6.2: MP150 Block Diagram

The MP150 has an internal microprocessor to control the data acquisition and communication with the computer. There are 16 analog input channels, two analog output channels, 16 digital channels that can be used for either input or output, and an external trigger input. The digital lines can be programmed as either inputs or outputs and function in 8 channel blocks. Block 1 (I/O lines 0 through 7) can be programmed as either all inputs or all outputs, independently of block 2 (I/O lines 8 through 15).

EEG data was recorded using 11 electrodes (10 channels) placed in accordance with complete international 10-20 system with linked ear lobe reference electrode. Data was recorded at a sampling rate of 1000 sample per second and sampling rate of 500 Hz of each channel. Out of these eleven electrodes one is ground electrode. Conductivity of electrodes with scalp is made using gel. Impedance of each electrode is compared with

reference to ground of cap and is set up approximately below 10 K Ω . Electrodes from which data is recorded are darkened in figure 5.

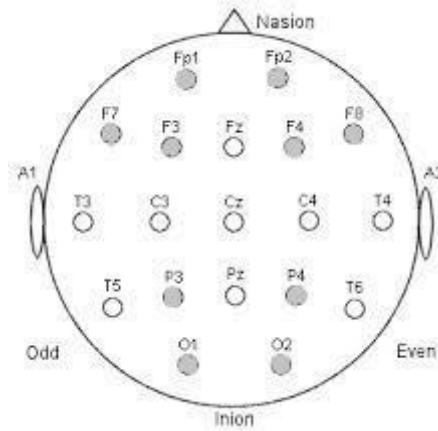


Figure 6.3: Marked electrodes for recording

The Biopac MP150 system is provided with a software for acquisition of signals named AcqKnowledge. **AcqKnowledge** software is used for feature extraction. AcqKnowledge software not only makes data collection easier, but also performs analyses quickly and easily that are impossible on a chart recorder. Easily edit data, cut and paste sections of data, perform mathematical and statistical transformations, and copy data to other applications (such as a drawing program or spreadsheet) for reports and publication. The MP System (MP150 or MP36R data acquisition unit) with AcqKnowledge 4 is compatible with Windows 7 or Vista OS or Mac OS X 10.410.6. AcqKnowledge uses the familiar point-and-click interface common to all Windows and Macintosh applications. Complex tasks such as digital filtering or fast Fourier transformations are now as easy as choosing a menu item or clicking the mouse. There is inbuilt notch filter in MP150 which is used for signal conditioning [75].

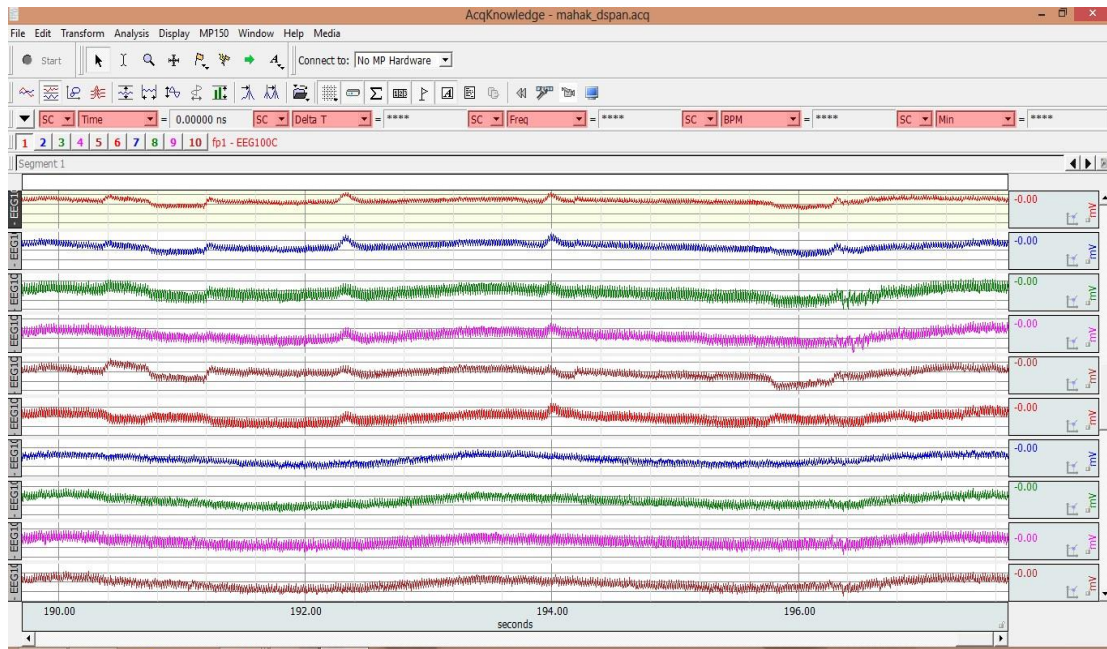


Figure 6.4: Window of AcqKnowledge acquiring EEG signals

6.2 Signal processing and Data Analysis

Various steps of signal processing and data analysis are described as follows:

6.2.1 Software used for data analysis: MATLAB and EEGLAB Software

6.2.1.1 MATLAB

MATLAB is a software built for numerical calculation and visualization. It provides a collaborative environment with hundreds of built-in functions for practical computation, graphics and animation. It also provides easy extensibility with its own high-level programming language. The name MATLAB stands for MATrixLABoratory.

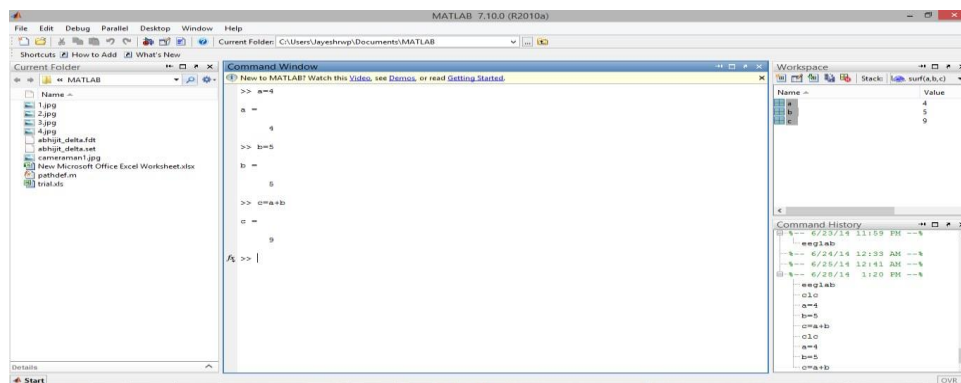


Figure 6.5: The MATLAB environment consisting of the MATLAB desktop

MATLAB's built-in functions offer excellent tools for data analysis, signal processing, linear algebra computations, numerical solution, optimization of normal differential equations (ODE's), quadrature, and numerous other sorts of scientific computations. There are numerous functions for 2-D and 3-D graphics, as well as for animation. The user however is not limited to the built-in functions, he can inscribe his own functions in the MATLAB language.

There are also several optional toolboxes accessible from the developers of MATLAB. These toolboxes are collection of functions written for special applications such as symbolic computation, image processing, signal processing, control systems, neural networks, etc. [76].

6.2.1.2 EEGLAB

EEGLAB is an interactive MATLAB toolbox for processing EEG, EMG and other electrophysiological data employing independent component analysis (ICA), artifact rejection, time/frequency analysis, event-related statistics, and several useful modes. First developed on Matlab 5.3 under Linux, EEGLAB runs on Matlab v5 and higher under Linux, UNIX, Windows, and Mac OS X (Matlab 7+ recommended).

EEGLAB provides an interactive graphic user interface (GUI) permitting users to adaptably process their high-density EEG and other dynamic brain data using independent component analysis (ICA) and/or time/frequency analysis (TFA). EEGLAB also combines extensive tutorial and help windows, plus a command history function that eases users' transition from GUI-based data examination to construction and running batch or custom data analysis scripts. EEGLAB offers a large number of methods for picturing and modelling event-related brain dynamics, both at the level of individual EEGLAB datasets and/or across a collection of datasets brought together in an EEGLAB 'study set' [77].

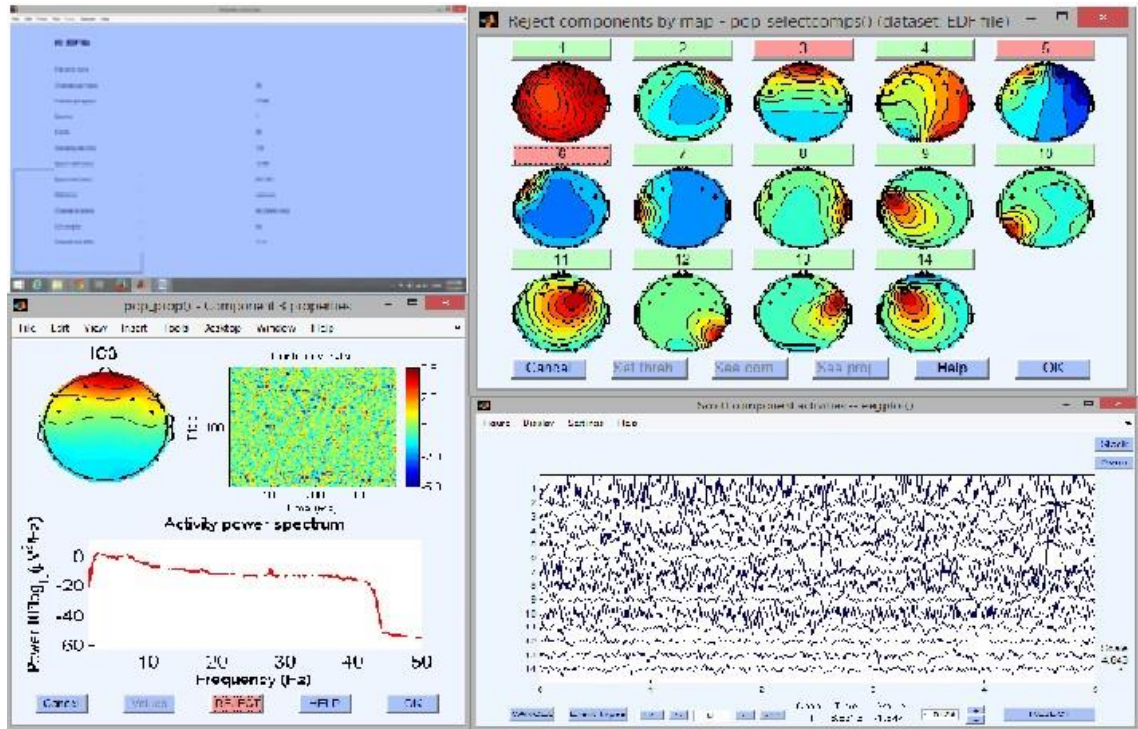


Figure 6.6: EEGLAB windows

Artifacts and Noise Removal

The EEG signal is small compared to the amplitude of common artifacts (eye, muscle, mains power frequency radiation). Clean signals are dependent on low scalp/electrode impedance, differential amplifiers, and filtering. Several kind of noises exist in the signal. These noises may arise due 50 Hz power line interference, movement or breathing by the subject. To remove noises, a filter is used first. The research makes use of window sinc FIR filter available in EEGLAB. Next, ICA is applied for artifact removal [78].

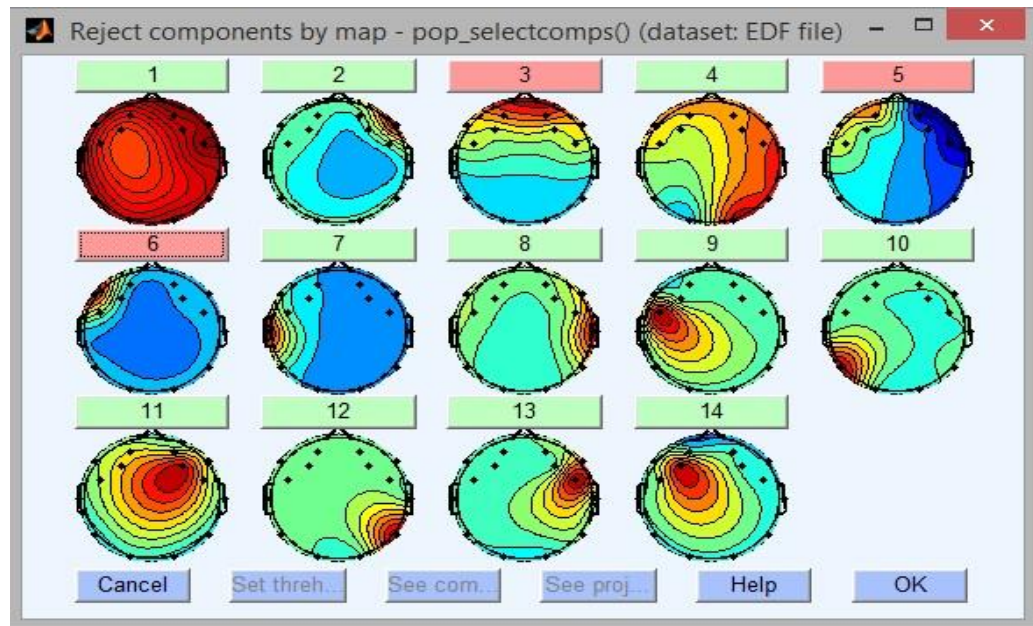


Figure 6.7: Topography before removal of artifact: 3, 5 and 6 is artifact

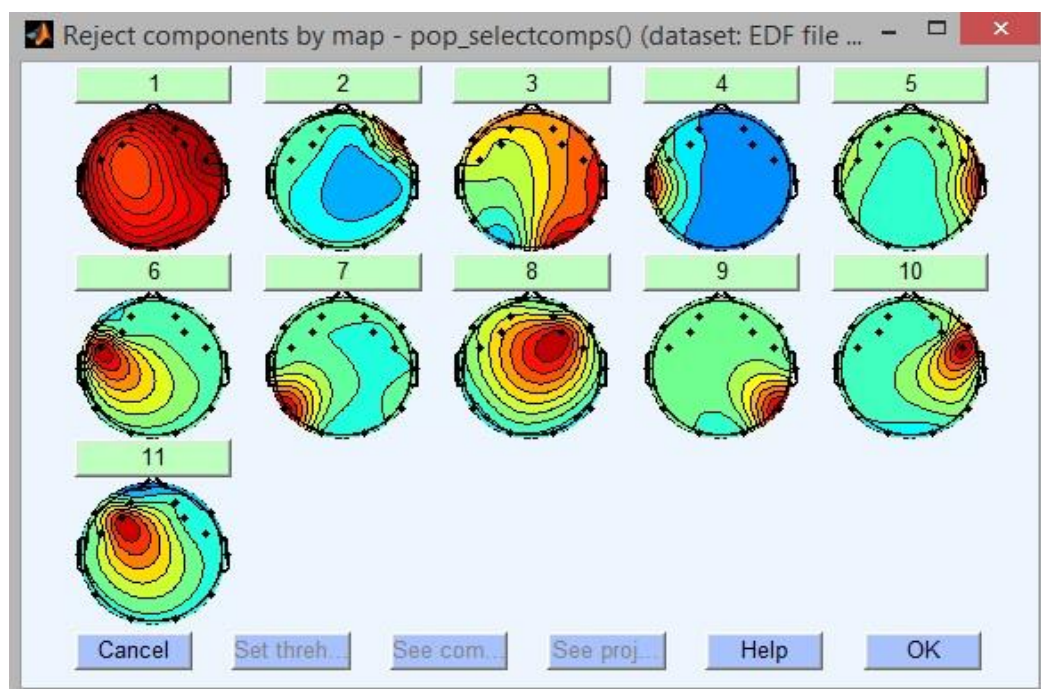


Figure 6.8: Topography after removal of artifact by running ICA

6.2.2 Steps for Signal Processing

6.2.2.1 Pre-processing: Filtering of data (Band Pass Filter)

EEGLAB software is used for carrying out signal processing. For filtering the signal, bandpass filter is used which is selected from window sinc FIR filter and required range of the filter is set, that is, 2 to 43 Hz. The order of the filter is taken to be 212. A low pass filter helps to pass only low frequency signals and similarly a high pass filter passes high frequency signals, so instead of employing both, a band pass filter is used which passes the required band of signals. A band pass filter filters a Band Pass filters without distorting the input signal or introducing extra noise that are 3dB below the maximum centre or resonant peak while attenuating or weakening the others outside that range. It is the combination of low pass and high pass filter where lowpass filter is followed by the high pass filter.

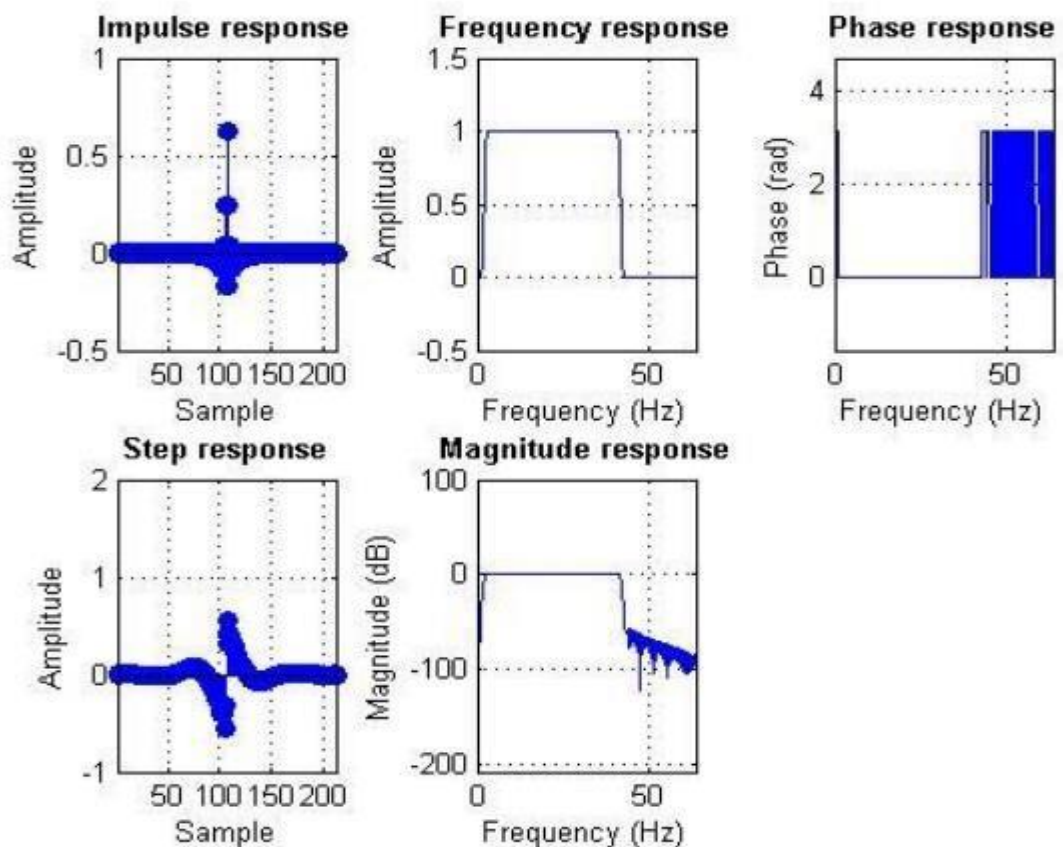


Figure 6.9: Filter response plot

6.2.2.2 Independent Component Analysis

Independent component analysis (ICA) is an essential part of signal processing used for separating multivariate signal into its subcomponents which are additive in nature. Thus, it is a method for finding underlying factors or components from multivariate (multi-dimensional) statistical data. ICA is different from other methods as it finds the components that are both statistically independent and non-Gaussian. Independent Component Analysis (ICA) is a computational method for separating a multivariable signal into additive subcomponents supposing the mutual statistical independence of the non-Gaussian source signal.

Origin of ICA

Imagine that you are in a room where two people are speaking simultaneously. You have two microphones which are held at different locations. The microphones give you two recorded time signals, which can be denoted by $x_1(t)$ and $x_2(t)$, with x_1 and x_2 the amplitude, and t the time index. Each of these recorded signal is a weighted sum of speech signals emitted by the two speakers, which we denote by $s_1(t)$ and $s_2(t)$. We could express this as linear equation:

$$x_1(t) = a_{11}s_1 + a_{12}s_2$$

$$x_2(t) = a_{21}s_1 + a_{22}s_2$$

Where a_{11} , a_{12} , a_{21} and a_{22} are some parameters that depend on the distances of the microphones from speakers. Two speech signal $s_1(t)$ and $s_2(t)$ can now be estimated, using only the recorded signals $x_1(t)$ and $x_2(t)$. This is called the cocktail-party problem.

Definition of ICA

To define ICA, we make use of ‘latent variables’ model. Assume that we observe n linear mixtures $x_1, \dots, x_n$ of n independent components

$$x_j = a_{j1}s_1 + a_{j2}s_2 + \dots + a_{jn}s_n, \text{ for all } j$$

In the ICA model, we assume that each mixture x_j and each independent component s_k is a random variable and not a proper time signal. The observed values $x_j(t)$, e.g., the microphone signals in the cocktail party problem, are then a sample of this random variable. Also it is assumed that both the mixture variables and the independent components have zero mean: If this is not true, then the observable variables x_i can always be centered by subtracting the sample mean, which makes the model zero mean.

Vector-matrix notation can also be used instead of the sums like in the previous equation. Let $\mathbf{x}$ denote the random vector whose elements are the mixtures $x_1, \dots, x_n$, and likewise $\mathbf{s}$ denotes the random vector with elements $s_1, \dots, s_n$. Let us denote by $\mathbf{A}$ the matrix with elements a_{ij} . Generally, bold lower case letters indicate vectors and bold upper-case letters denote matrices. All vectors are understood as column vectors; thus $\mathbf{x}^T$, or the transpose of $\mathbf{x}$, is a row vector. Using this vector-matrix notation, the above mixing model is written as $\mathbf{x} = \mathbf{A}\mathbf{s}$

This equation is called independent component analysis, or ICA model. Sometimes we need the columns of matrix $\mathbf{A}$; denoting them by $\mathbf{a}_j$ the model can also be written as

$$\mathbf{x} = \sum_{i=1}^n a_i \mathbf{s}_i$$

The ICA model is a generative model, which means that it describes how the observed data are generated by a process of mixing the components s_i . The independent components are latent variables, meaning that they cannot be directly observed. Also the mixing matrix is assumed to be unknown. All we observe is the random vector $\mathbf{x}$, and we must estimate both $\mathbf{A}$ and $\mathbf{s}$ using it. This must be done under as general assumptions as possible.

ICA is very closely related to the method called blind source separation (BSS) or blind signal separation. A “source” means here an original signal, i.e. independent component, like the speaker in a cocktail party problem. “Blind” means that we know very little, if anything, on the mixing matrix, and make little assumptions on the source signals. ICA is one method, perhaps the most widely used, for performing blind source separation.

ICA removal using EEG

Severe contamination of EEG activity by blinks, eye movements, heart, muscles and line noise is a serious problem for EEG interpretation and analysis. One of the methods to remove such contaminations or artifacts is ICA. It is assumed that the signals are acquired are mixtures of activities of EEG rhythms and the artifacts.

ICA decomposition

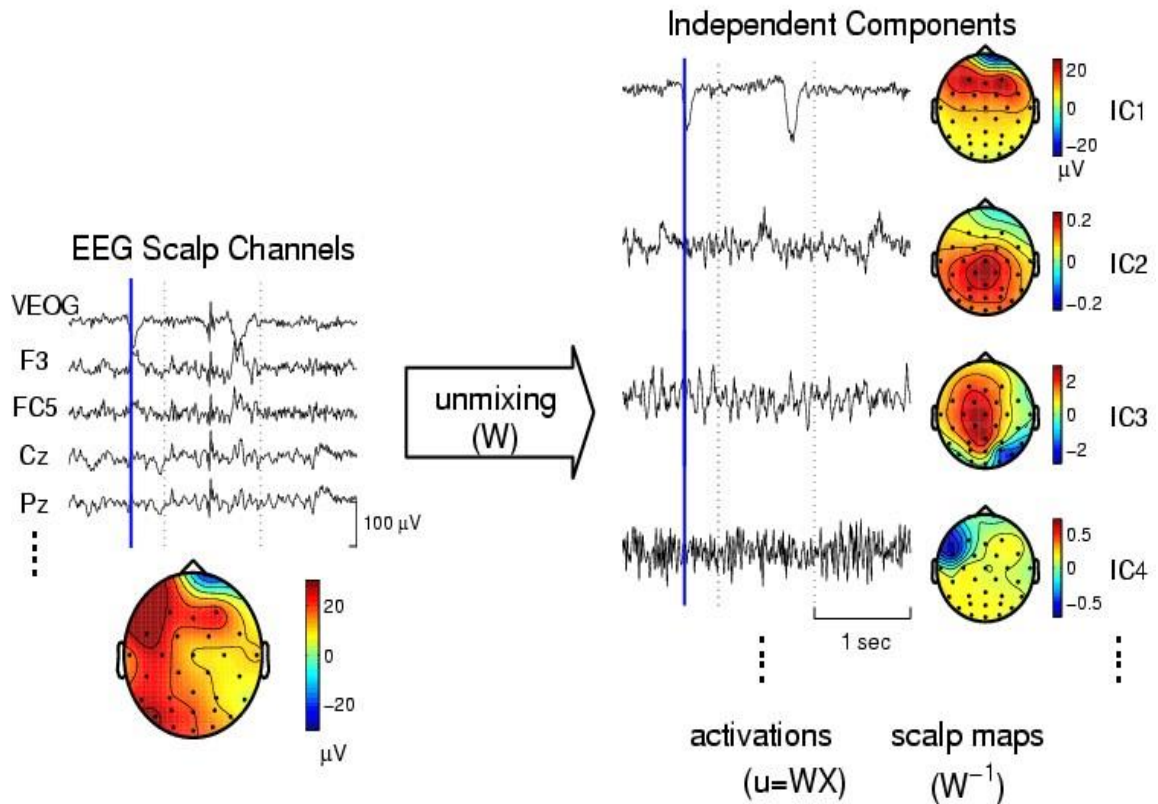


Figure 6.10: Schematic illustration of the procedure of ICA

In EEG analysis, the rows of the input matrix, X , are EEG signals recorded at different electrodes and the columns are measurements recorded at different time points. ICA finds an ‘unmixing’ matrix, W , which decomposes or linearly unmixes the multi-channel scalp data into a sum of spatially and independent components. The rows of the output data matrix, $U = WX$, are time courses of activation of the ICA components. The columns of the inverse matrix, $\text{inv}(W)$, give the relative projection strengths of the respective components at each of the scalp sensors.

The activations the matrix of unmixed component are given by

$$W = \text{weights} * \text{sphere}; \text{Activations} \\ = W * \text{data};$$

and the inverse weight matrix or the mixing matrix is

$$W_{\text{inv}} = \text{inv}(W); \\ \text{Projection} = W_{\text{inv}}(:,i) * \text{activations}(i,:);$$

The projection of the i th component is the outer product of i th row of the component activation, activations ($i,:$), with the i th column of the inverse matrix, $Winv(:,i)$.

Summed Projection of Selected Components

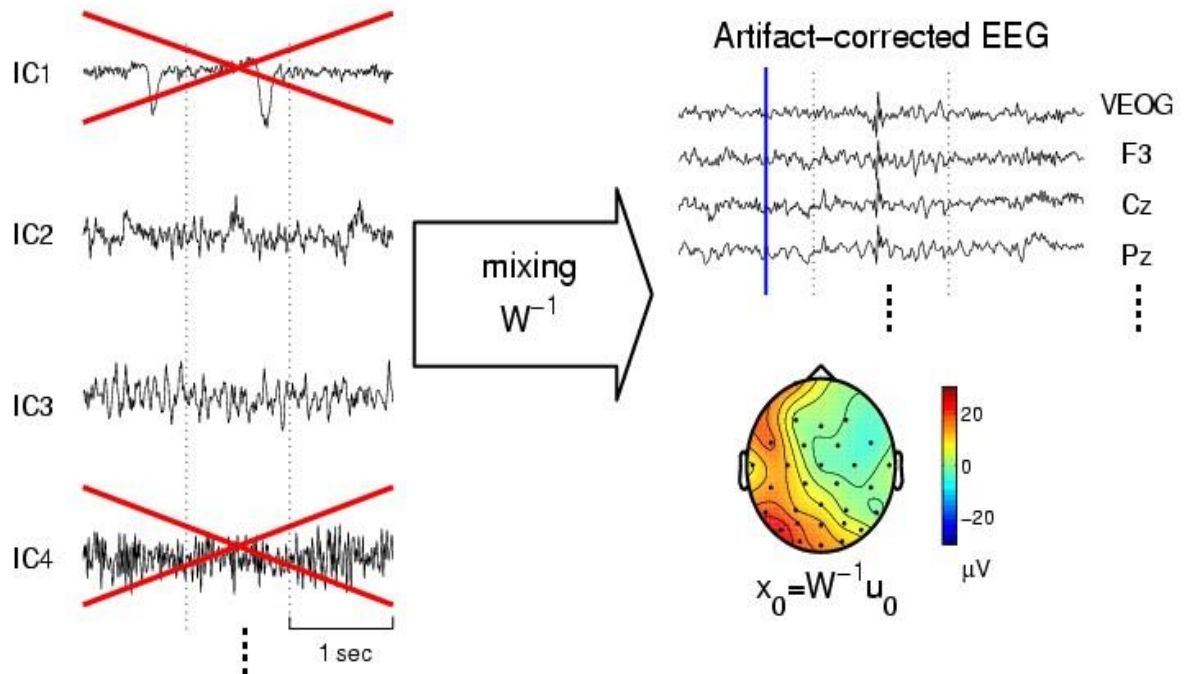


Figure 6.11: Summed projection of selected components in ICA

artifact-free event-related brain signals were obtained by projecting the sum of selected non-artifactual ICA components back onto the scalp, $\text{clean_data} = \text{Winv}(:,a) * \text{activations}(a,:);$

Removing blink and muscle artifacts

The figure below depicts a 3 seconds portion of the acquired EEG and its ICA component activations, the scalp topographies of four selected components, and the artifact-corrected EEG signals which is achieved by removal of four selected EOG and muscle noise components from the data. The eye movement artifact at 1.8 sec in the EEG data is isolated to ICA components 1 and 2 (left middle). The scalp maps (right middle) indicate that these two components account for the spread of EOG activity to frontal sites.

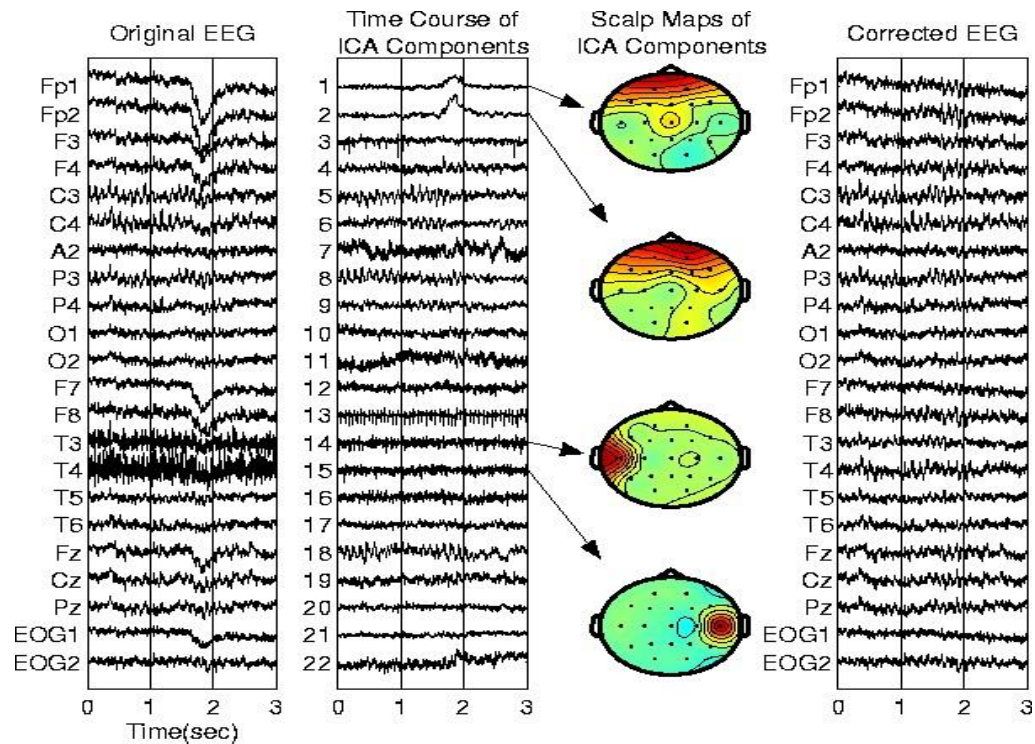


Figure 6.12: Blink and muscle artefact removal by ICA

Eliminating the four artifact components whose scalp maps are shown above, and projecting the remaining components back onto the scalp channels produced artifactcorrected EEG data (right) free of these artifacts [79-80].

6.2.2.3 Wavelet Transform

A wavelet is a waveform of a very limited duration that has an average value of zero. It starts from zero, increases, and then decreases gets back to zero. Wavelets have advantages over traditional Fourier methods which are used for analysing physical situations where the signal contains discontinuities and sharp spikes. Wavelets were developed independently in the fields of quantum physics, electrical engineering, mathematics and seismic geology. Wavelets can be joined, using a "shift, multiply and sum" technique called convolution, with portions of an unknown signal to extract information from the unknown signal. It can be stated that a wavelet is a mathematical function used to divide a given function or continuous-time signal into different scale components. A wavelet transform is the demonstration of a function by wavelets. The wavelets are scaled and translated copies (known as "daughter wavelets") of a finite length or fast-decaying oscillating waveform (known as the "mother wavelet") [81].

The wavelet transform of a signal $f(t)$ at the scale s and position τ is computed by correlating $f(t)$ with a wavelet atom:

$$W_f(\tau, s) = \int_{-\infty}^{\infty} f(t) \varphi_{\tau,s}^*(t) dt$$

$$\text{Where } \varphi_{\tau,s}^* = \frac{1}{\sqrt{s}} \varphi\left(\frac{t-\tau}{s}\right)$$

Where s is positive and defines the scale (1/frequency) and τ is any real number and defines the translation (shift). Wavelet transforms can be classified as

- Discrete wavelet transforms (DWTs)
- Continuous wavelet transforms (CWTs)
- Fast wavelet transform (FWT)
- Wavelet packet decomposition (WPD)

Almost all practically useful discrete wavelet transforms use discrete-time filter banks. These filter banks are called the wavelet and scaling coefficients in wavelets nomenclature. These filter banks may contain either finite impulse response (FIR) or infinite impulse response (IIR) filters [82-83].

Discrete Wavelet Transform

Usually time and frequency domains have been considered for analyses of EEG signals. The discrete wavelet transform (DWT) is an active tool for Time-Frequency analysis of signals. Discrete wavelet transform (DWT) is a spectral analysis technique used for analysing non-stationary signals, and provides time-frequency signals. Wavelet transform is a spectral approximation technique in which any general function can be conveyed as an infinite series of wavelets. The decomposition of the signal results in a set of coefficients are called wavelet coefficients. Decomposition of the signal analysis depends on the high-pass and low-pass filter. Wavelet transform uses a different window size, which allows the wavelet to be stretched or compressed depending on the frequency of the signal. DWT analyses frequency bands with dissimilar resolution by means of multi-level decomposition into a coarse frequency band. This results in

excellent feature extraction from sub-bands of the non-stationary EEG signals. In simple words, a discrete wavelet transform (DWT) is any wavelet transform for which the wavelets are discretely sampled.

Daubechies families

Ingrid Daubechies invented what are called compactly-supported orthonormal wavelets which made discrete wavelet analysis achievable. The names of the Daubechies family wavelets are written in the form dbN, where N is the order, and db the surname of the wavelet. The figure below shows some members of Daubechies family.

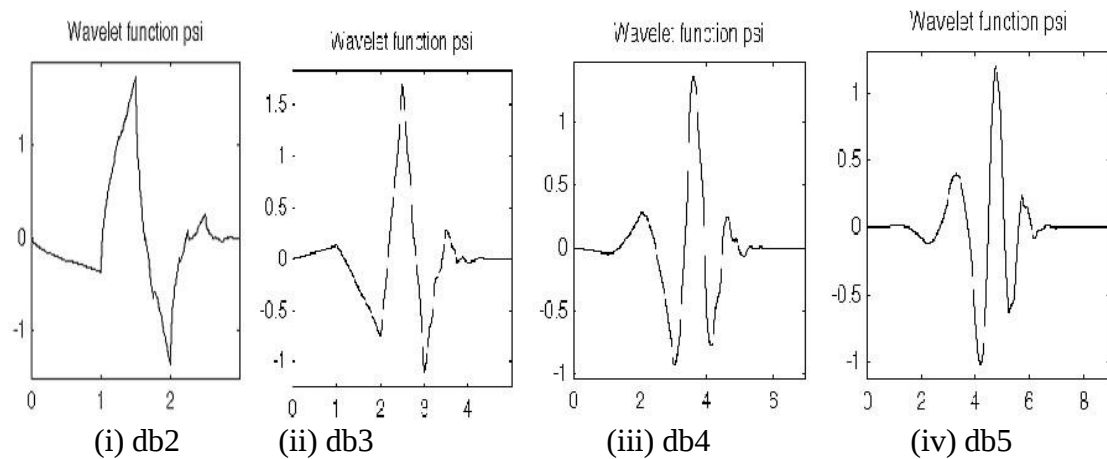


Figure 6.13: Daubechies Family

The research makes use of Daubechies wavelet ‘db4’ which is used to decompose the signal by wavelet decomposition at 5 levels and ‘sqtwolog’ is used to calculate the threshold [84]. From the wavelet coefficient, different frequency bands of EEG are reconstructed as follows: Theta (4-8 Hz) = [4.56 7.125]

Alpha (8-13Hz) = [7.125 12.25]

Beta (13-25 Hz) = [12.25 22.5]

6.2.3 Feature Extraction

The pre and post data required was analysed and then compared to observe the fluctuations due to training. The raw data acquired was originally filtered. The frequency range was designated between 0.4 to 35 Hz as this covers almost whole range of an EEG signal. This is followed by Independent Component Analysis (ICA) of the signal. ICA was used for finding underlying factors or components from multivariate (multi-dimensional) statistical data. The eye artifacts and muscle artifacts were detached from the resultant signal. This procedure was carried out using EEGLAB toolbox. The final data thus obtained was analysed using frequency analysis. This frequency analysis was done using Wavelet transform. Different ranges of EEG signal- alpha (α), beta (β), theta (θ) are computed by programming in MATLAB. Power of all the components are calculated individually. Thereafter, Asymmetry indices are computed.

CHAPTER 7 RESULTS AND DISCUSSION

7.1 Changes in Asymmetry of Brain Wave Rhythms

This section shows the values of asymmetry indices while the subject watches videos of different emotions. Alpha asymmetry indices can be computed by subtracting the natural logarithm of left-sided alpha power from the natural logarithm of right-sided alpha power (Asymmetry Index = $\ln[\text{right alpha}] - \ln[\text{left alpha}]$). A more positive asymmetry index reflects a greater relative left hemispheric activity.

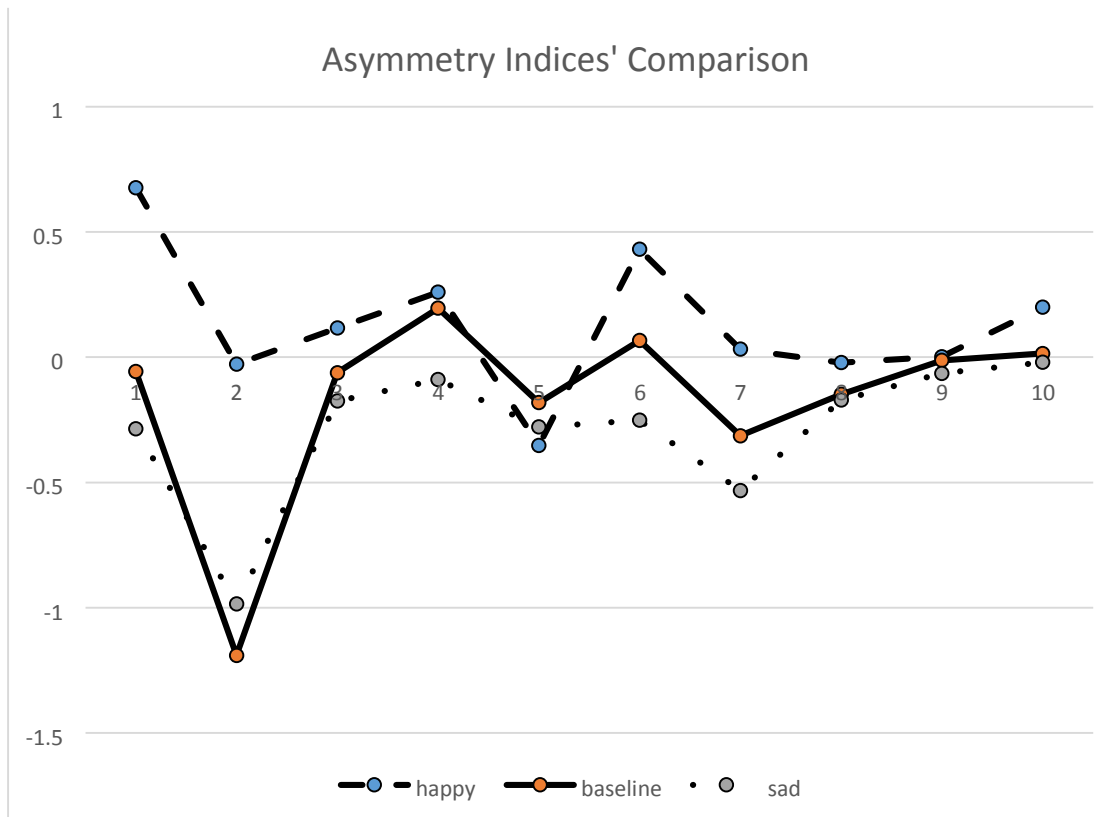


Figure 7.1: Comparison of asymmetry indices

From figure 7.1 it is inferred that for happy emotion the value of asymmetry index is more than that of baseline and sad emotion. Also, the value of sad emotion is less than that of baseline. Hence, the result is as expected. It is also computed statistically using single tailed paired t-test. Result of t-test for happy emotion is $p=0.018458$ and for that of sad is $p=0.020359$.

The graphs for each subject's asymmetry values are shown as follows:

Subject 1:

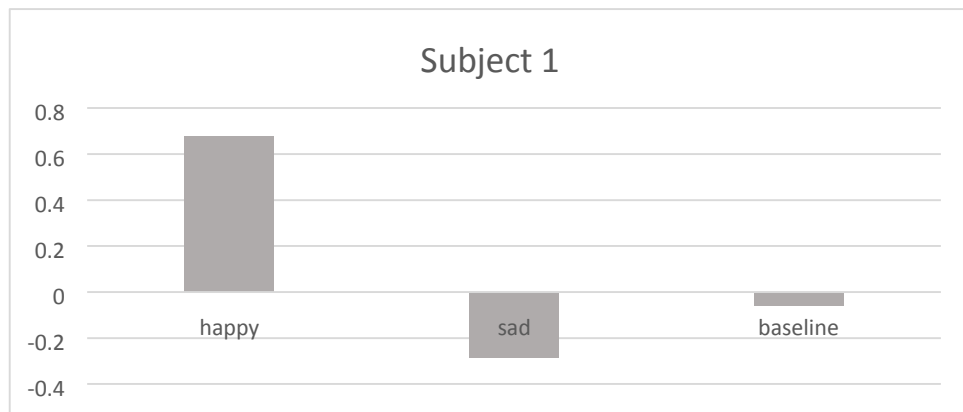


Figure 7.2: Asymmetry indices of subject 1 for happy, sad emotions and baseline

From figure 7.2 it is inferred that for happy emotion the value of asymmetry index is more than that of baseline and sad emotion. Also, the value of sad emotion is less than that of baseline. Hence, the result is as expected.

Subject 2:



Figure 7.3: Asymmetry indices of subject 2 for happy, sad emotions and baseline

From figure 7

.3 it is inferred that for happy emotion the value of asymmetry index is more than that of baseline and sad emotion. But the value of sad emotion is more than that of baseline. Hence, the result is as somewhat expected.

Subject 3:

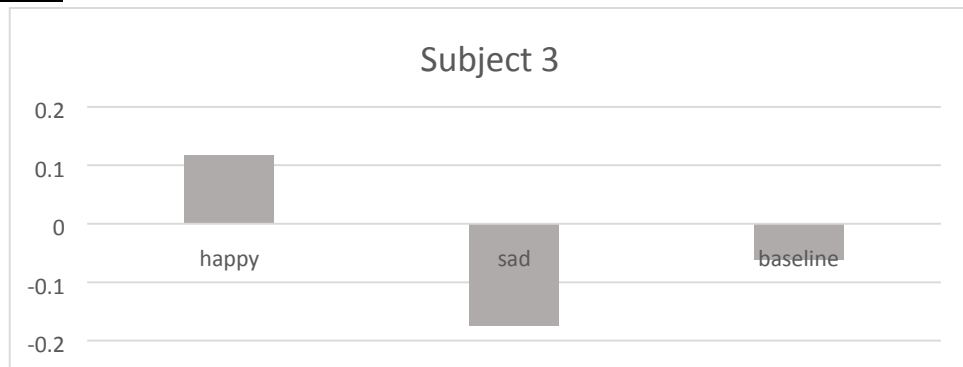


Figure 7.4: Asymmetry indices of subject 3 for happy, sad emotions and baseline

From figure 7.4 it is inferred that for happy emotion the value of asymmetry index is more than that of baseline and sad emotion. Also, the value of sad emotion is less than that of baseline. Hence, the result is as expected.

Subject 4:

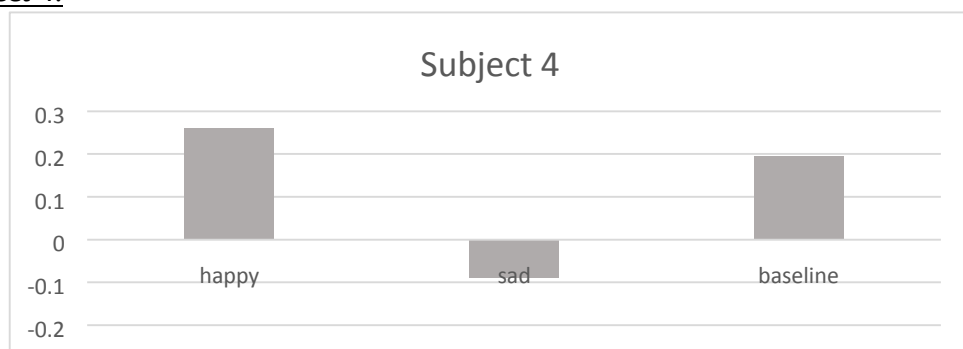


Figure 7.5: Asymmetry indices of subject 4 for happy, sad emotions and baseline

From figure 7

.5 it is inferred that for happy emotion the value of asymmetry index is more than that of baseline and sad emotion. Also, the value of sad emotion is less than that of baseline. Hence, the result is as expected.

Subject 5:

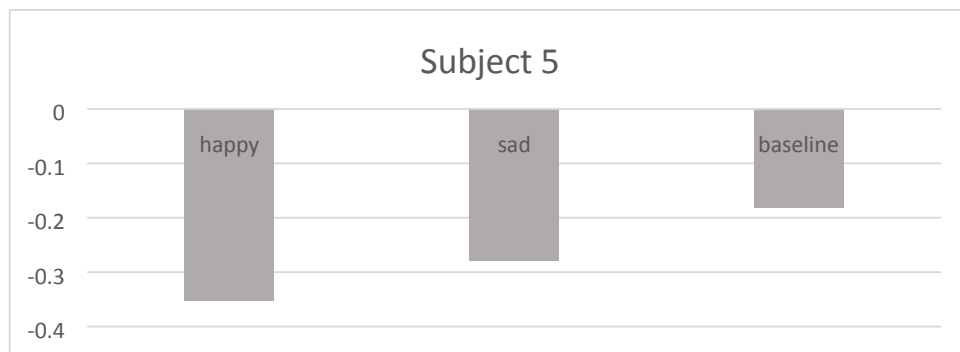


Figure 7.6: Asymmetry indices of subject 5 for happy, sad emotions and baseline

From figure 7.6 it is inferred that for happy emotion the value of asymmetry index is less than that of baseline and sad emotion. Hence, the result is not as expected.

Subject 6:

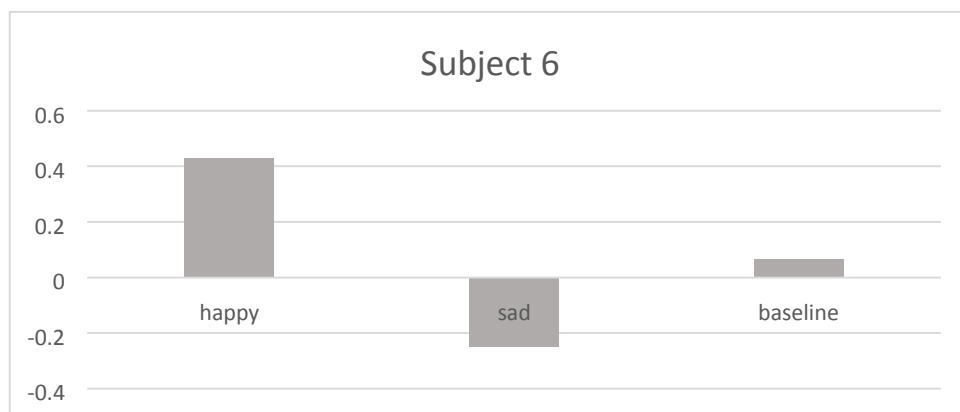


Figure 7.7: Asymmetry indices of subject 6 for happy, sad emotions and baseline

From figure 7

.7 it is inferred that for happy emotion the value of asymmetry index is more than that of baseline and sad emotion. Also, the value of sad emotion is less than that of baseline. Hence, the result is as expected.

Subject 7:



Figure 7.8: Asymmetry indices of subject 7 for happy, sad emotions and baseline

From figure 7.8 it is inferred that for happy emotion the value of asymmetry index is more than that of baseline and sad emotion. Also, the value of sad emotion is less than that of baseline. Hence, the result is as expected.

Subject 8:



From figure 7

Figure 7.9: Asymmetry indices of subject 8 for happy, sad emotions and baseline

.9 it is inferred that for happy emotion the value of asymmetry index is more than that of baseline and sad emotion. Also, the value of sad emotion is less than that of baseline. Hence, the result is as expected.

Subject 9:

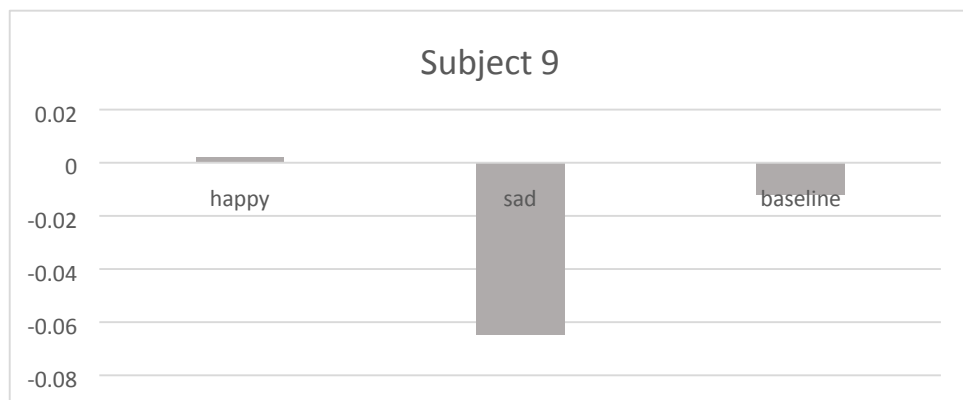
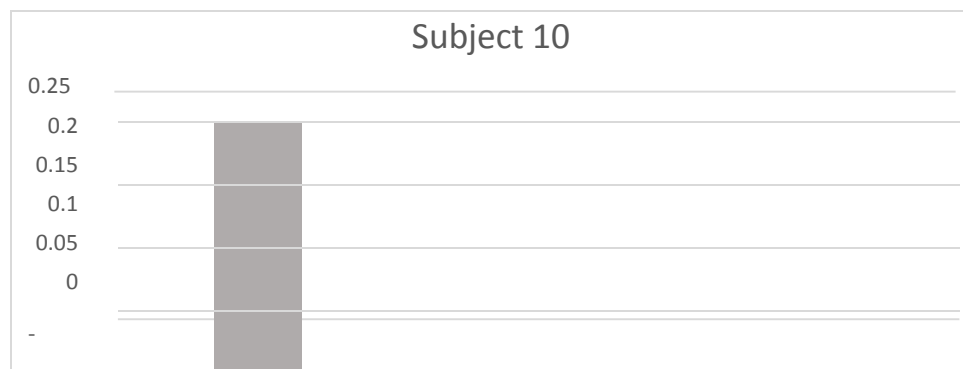


Figure 7.10: Asymmetry indices of subject 9 for happy, sad emotions and baseline

From figure 7.10 it is inferred that for happy emotion the value of asymmetry index is more than that of baseline and sad emotion. Also, the value of sad emotion is less than that of baseline. Hence, the result is as expected.

Subject 10:



From figure 7

Figure 7.11: Asymmetry indices of subject 10 for happy, sad emotions and baseline .11 it is inferred that for happy emotion the value of asymmetry index is more than that of baseline and sad emotion. Also, the value of sad emotion is less than that of baseline. Hence, the result is as expected.

7.2 Cognitive Enhancement using Odor as Intervention

This section shows the values of asymmetry indices while the subject watches videos of different emotions during pre and post procedures.

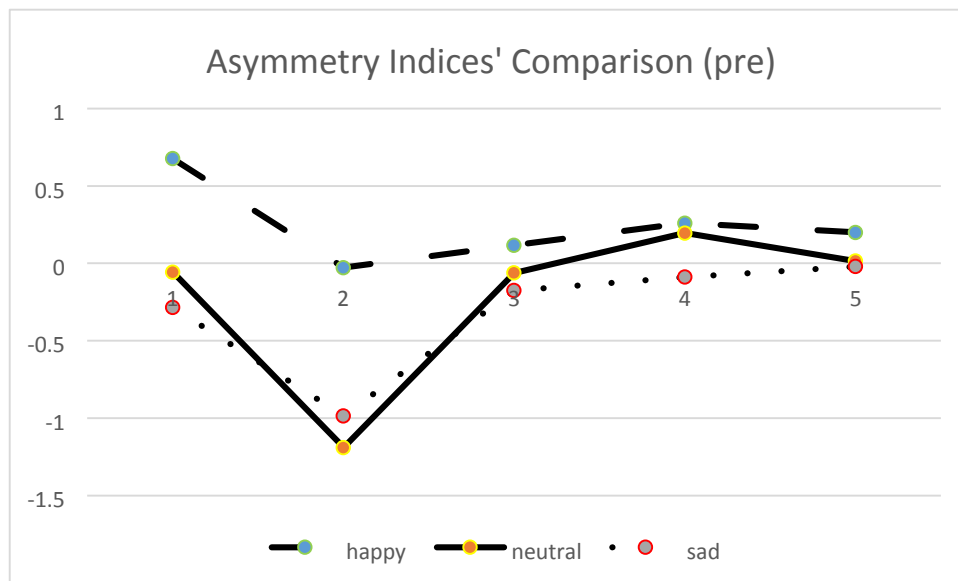


Figure 7.12: Comparison of Asymmetry Indices obtained during pre-intervention

From figure 7.12 it is inferred that for happy emotion the value of asymmetry index is more than that of baseline and sad emotion. Also, the value of sad emotion is less than that of baseline. Hence, the result is as expected. It is also computed statistically using single tailed paired t-test. Result of t-test for happy emotion is $p=0.045541472$ and for that of sad is $p=0.17380686$.

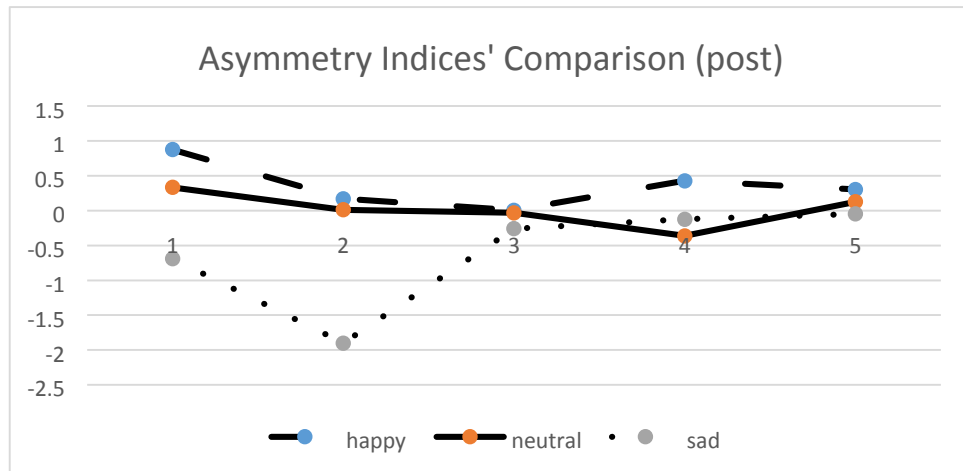


Figure 7.13: Comparison of Asymmetry Indices obtained during post-intervention

From figure 7.13 it is inferred that for happy emotion the value of asymmetry index is more than that of baseline and sad emotion. Also, the value of sad emotion is less than that of baseline. Hence, the result is as expected. It is also computed statistically using single tailed paired t-test. Result of t-test for happy emotion is $p=0.036397$ and for that of sad is $p=0.0902$.

Also, comparison has been made between happy emotions of both pre and post procedures. Similarly, the same has been carried out with sad video.

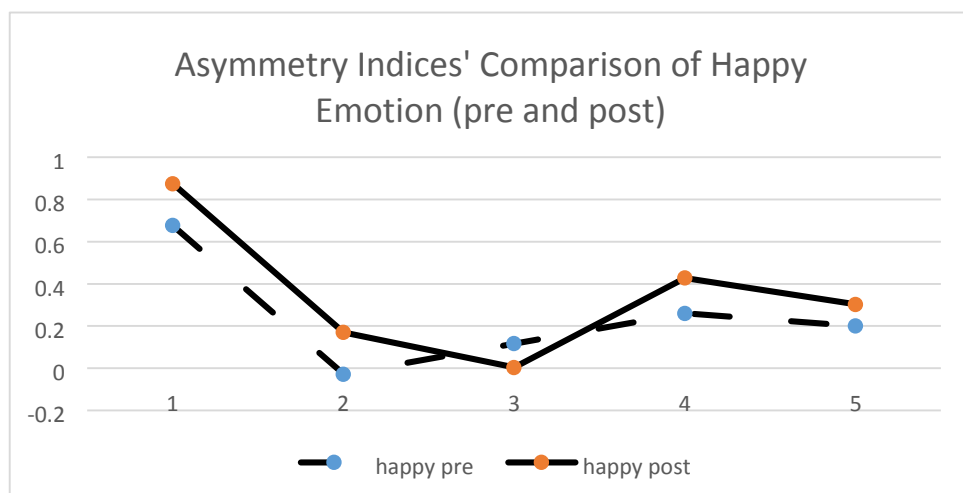


Figure 7.14: Comparison of Asymmetry indices of happy emotion during pre and post-intervention

From figure 7.14 it is inferred that for happy emotion during post-intervention the value of asymmetry index is more than that of during pre-intervention. Hence, the result is as expected. It is also computed statistically using single tailed paired t-test.

Result of t-test is $p=0.066017925$.

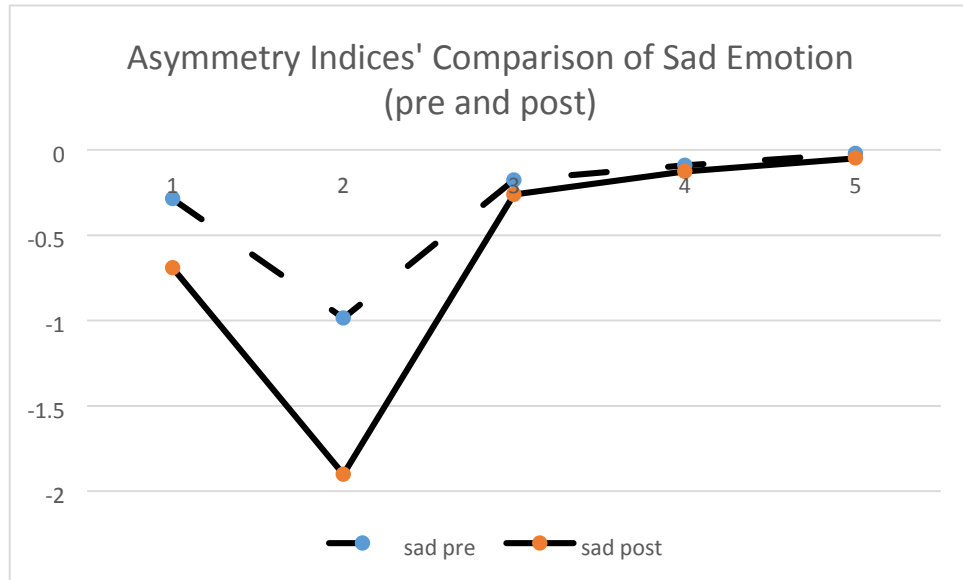


Figure 7.15: Comparison of Asymmetry indices of sad emotion during pre and postintervention

From figure 7.15 it is inferred that for happy emotion during post-intervention the value of asymmetry index is more than that of during pre-intervention. Hence, the result is as expected. It is also computed statistically using single tailed paired t-test.

Result of t-test is $p=0.079923695$.

CHAPTER 8 CONCLUSION AND FUTURE SCOPE

8.1 Conclusion

Human beings emote through various gestures like laughing, smiling, giving a poker face, having grumpy looks, sobbing and crying. They express their emotions of being happy, neutral and sad. Some people acquire the art of mimicking these emotions like, for example, showing the world they are happy when they are actually sad within or vice versa. Cognitive science as effectively broad about the means to know these emotions by studying physiological signals like EEG. This research shows that one parameter, asymmetry index, can reveal a lot about the inner emotional state of a subject being happy or sad. The pilot study indicated that this asymmetry index is positive when the person is happy and is negative when the person is sad.

The subjects were exposed to the odor of lemon for fifteen days for one hour daily and post intervention analysis of asymmetry index on being provided with similar stimulus indicates that subjects show more positive asymmetry index for happy emotion and more negative for sad emotion. It can therefore be concluded that on being exposed to olfactory stimulus of lemon frequently on regular basis the subjects tend to become emotionally more sensitive.

8.2 Future Scope

We plan to increase the number of subjects in near future to carry out this research. Also, there should be one control group which does not involve in any sort of intervention so that the results can be compared easily. Also, the study can involve the effect on other cognitive abilities like motor speed, reaction time, fatigue, etc.

CHAPTER 9 CHECK FOR ORIGINALITY

The dissertation report presented here has been checked for its originality using online plagiarism checker “Paper Rater”, available at http://www.paperrater.com/plagiarism_checker

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