VYSOKÉ UČENÍ TECHNICKÉ V BRNĚ

BRNO UNIVERSITY OF TECHNOLOGY

FAKULTA ELEKTROTECHNIKY A KOMUNIKAČNÍCH TECHNOLOGIÍ
ÚSTAV BIOMEDICÍNSKÉHO INŽENÝRSTVÍ

FACULTY OF ELECTRICAL ENGINEERING AND COMMUNICATION
DEPARTMENT OF BIOMEDICAL ENGINEERING

EVENT FIXATION RELATED POTENTIAL DURING VISUAL EMOTION STIMULATION

DIPLOMOVÁ PRÁCE
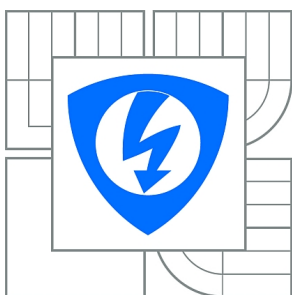MASTER'S THESIS

AUTOR PRÁCE   Bc. VERONIKA MIČÁNKOVÁ
AUTHOR

BRNO 2015

VYSOKÉ UČENÍ TECHNICKÉ V BRNĚ

BRNO UNIVERSITY OF TECHNOLOGY

FAKULTA ELEKTROTECHNIKY A KOMUNIKAČNÍCH TECHNOLOGIÍ
ÚSTAV BIOMEDICÍNSKÉHO INŽENÝRSTVÍ

FACULTY OF ELECTRICAL ENGINEERING AND COMMUNICATION
DEPARTMENT OF BIOMEDICAL ENGINEERING

EVENT FIXATION RELATED POTENTIAL DURING VISUAL EMOTION STIMULATION

KOGNITIVNÍ EVOKOVANÉ POTENCIÁLY A FIXACE OČÍ PŘI VIZUÁLNÍ EMOČNÍ STIMULACI
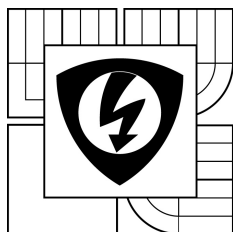
DIPLOMOVÁ PRÁCE
MASTER'S THESIS

AUTOR PRÁCE   Bc. VERONIKA MIČÁNKOVÁ
AUTHOR

VEDOUCÍ PRÁCE   Ing. TOMÁŠ POTOČŇÁK
SUPERVISOR

BRNO 2015

BRNO UNIVERSITY
OF TECHNOLOGY

Faculty of Electrical Engineering and Communication

Department of Biomedical Engineering

Diploma thesis

Master's study field
Biomedical and Ecological Engineering

Student: Bc. Veronika Mičánková
Year of study: 2

ID: 140201
Academic year: 2014/15

TITLE OF THESIS:

Event Fixation Related Potential During Visual Emotion Stimulation

INSTRUCTION:

1) Familiarize yourself with the measurement and signal processing of electroencephalogram (EEG) and electrooculogram (EOG). 2) Study the issues of event fixation related potential during visual emotional stimulation, focus on the differences between static and dynamic visual stimulation. 3) Process the literature review of mentioned issues. 4) Study the effects of eye movements on the EEG signal in the practical measurement. 5) Participate in the development of the new function of event fixation related potential software. 6) Write down a study of the results achieved.
The thesis will be developed in the context of study abroad at the University of Grenoble.

REFERENCE:

[1] TRAUTMANN-LENGSFIELD S. A.; DOMÍNGUEZ-BORRAS, J.; ESCERA, C.; HERRMANN, M.; FEHR, T.: The Perception of Dynamic and Static Facial Expressions of Happiness and Disgust Investigated by ERPs and fMRI Constrained Source Analysis, PLoS ONE, Vol. 8, No. 6, 2013.
[2] SÖRNMO, L.; LAGUNA, P.: Bioelectrical signal processing in cardiac and neurological applications, Boston: Elsevier Academic Press, 2005.

Assigment deadline: 9. 2. 2015

Submission deadline: 31.7.2015

Head of thesis: Ing. Tomáš Potočňák
Consultant: Anne Guérin-Dugué; Gelu Ionecu

prof. Ing. Ivo Provazník, Ph.D.
Subject Council chairman

ABSTRAKT

Cílem této diplomové práce je najít a popsat souvislost mezi fixací očí v emočně zabarveném stimulu, kterým je obrázek či video, a EEG signálu. K tomuto studiu je třeba vyvinout softwarové nástroje v prostředí Matlab k úpravě a zpracování dat získaných z eye trackeru a propojení s EEG signály pomocí nově vytvořených markerů. Na základě získaných znalostí o fixacích, jsou v prostředí BrainVision Analyzeru EEG data zpracovány a následně jsou segmentovány a průměrovány jako evokované potenciály pro jednotlivé stimuly (ERP a EfRP). Tato práce je vypracována ve spolupráci s Gipsa-lab v rámci výzkumného projektu.

KLÍČOVÁ SLOVA

EEG, kognitivní evokované potenciály (ERP), EOG, vizuální emoční stimulace, fixace očí, emoce

ABSTRACT

This diploma thesis is a part of a ongoing research project concerning new joint technique of eye fixations and EEG. The goal of this work is to find and analyze a connection between eye fixation in a face expressing an emotion (static or dynamic). For this study certain software developments need to be done to adjust fixation data in Matlab and connect them to EEG signals with newly created markers. Based on the obtained information on fixations, EEG data are processed in BrainVision Analyzer and segmented to obtain ERPs and EfRPs for each stimuli.

KEYWORDS

EEG, Event related potential (ERP), Event fixation Related Potential (EfRP), emotional visual stimulation, EOG, eye tracking, emotion

MIČÁNKOVÁ, V. *Event Fixation Related Potential During Visual Emotion Stimulation*. Brno: Vysoké učení technické v Brně, Fakulta elektrotechniky a komunikačních technologií, 2015. 62 s. Vedoucí diplomové práce Ing. Tomáš Potočňák.

Prohlášení

Prohlašuji, že svou diplomovou práci na téma "Event Fixation Related Potential During Visual Emotion Stimulation" jsem vypracovala samostatně pod vedením vedoucího diplomové práce a s použitím odborné literatury a dalších informačních zdrojů, které jsou všechny citovány v práci a uvedeny v seznamu literatury na konci práce.

Jako autorka uvedené diplomové práce dále prohlašuji, že v souvislosti s vytvořením tohoto projektu jsem neporušil autorská práva třetích osob, zejména jsem nezasáhl nedovoleným způsobem do cizích autorských práv osobnostních a jsem si plně vědom následků porušení ustanovení § 11 a následujících autorského zákona č. 121/2000 Sb., včetně možných trestněprávních důsledků vyplývajících z ustanovení § 152 trestního zákona č. 140/1961 Sb.

V Brně dne ….……….   ………………………………

                                                              (podpis autora)

Poděkování

Tímto bych chtěla poděkovat vedoucímu mé diplomové práce, panu Ing. Tomáši Potočňákovi, za zaštítění mé práce na ÚBMI, za cenné odborné a organizační rady a smysl pro humor. Dále bych chtěla poděkovat vůbec za onu možnost vyjet na výzkumnou stáž v rámci diplomové práce. V souvislosti s tím také patří poděkování mé rodině, která mě nejen morálně, ale i finančně podpořila. A proto se i zde hodí poděkovat mému partnerovi, který při mně stál a neustále mne motivoval.

Acknowledgment

I would like to thank my tutor Anne Guerin for this opportunity to work on this experiment in the international scientific environment and for her professional scientific aid and leadership. I would like thank Emmanuelle Kristensen not only for the will to explain the problematics but also for the humor and kindness that surrounded her everywhere. Finally, I want to thank the collegues from the laboratory for the perfect atmosphere that was always there along with the support and aid.

V Brně dne …………….   …………………………………

(podpis autora)

Table of Contents

Table of Figures

Table of Tables

Introduction

This diploma thesis is a part of research internship in Gipsa-Lab at the University of Joseph Fourier in Grenoble, France. It is a part of a longterm research project concerning joint analysis of electroencephalographic (EEG) signals and eye movements, meanwhile these techniques are both usually used seperately. The idea of this technique is to study neuronal responses of people during the experimental tasks which can be quite natural.

A subject of this work is to find a ways to connect these two techniques and get to the core of the brain response on the eye fixations in a emotionally expressed face stimuli. For this experiment a DynEmo database (Chapter 4.2) has been used. Certain utilization of the software had been done up to this point. Data from both techniques have been recorded simultanously and synchronized. Video stimuli have been segmented to the nine regions of interest (ROI) in the face and ocular fixations have been repartioned into each of these ROIs.

First, the theoretical part describes the EEG signal, the source and measuring method. Another researched topic is electrooculography (EOG) along with eye movements and acquisition methods. These provide certain ideas about both mentioned techniques. Finally, event related evoked potentials (ERPs) are characterized, sorted and related to visual and emotional stimulation and concerning studies.

The practical part consists of three main sections: description of the experimental protocol and data sets and description of the work that was done on both ocular fixations and EEG signals. The latter two parts describe further data processing and newly implemented functionalities. The fixations are adjusted in the Matlab environment, EEG signal processiong and extraction of ERPs is done in BrainVision Analyzer.

The practical parts continues where the previous intern Nicole Christoff has left of, and so the ocular fixations for static stimuli are processed the same way as the dynamic ones. Static stimuli − image − is segmented into the very same ROIs and the ocular fixations are repartioned into corresponding ROIs. Both, static and dynamic data are adjusted and statistics on their localization, quantity and durations are done for further characteristics and to allow visually explore the distribution in each of the ROIs as well as the distribution of their durations. These informations help to provide ideas how to proceed to extract event fixation related potentials (EfRPs) from EEG signals and provide conditions for labeling of these events − by localization, length and emotion. They also allow to see mistakes in data mostly sourced in acquisition. The EEG signals are pre-processed first to obtain clean data without the artifacts. The experimental extractions of evoked potentials on a particular onsets are done. The end of this work covers a

comparison between two conditions of the stimuli, static and dynamic resulting from this research design.

1. Overview of EEG

This chapter provides an overview of classification including its concept, structure and commonly used methods of EEG signal classification. It is important to provide such information due to understanding the basics and for further classification of EEG.

1.1 The Origin of EEG Signal

Electroencephalography is a method of recording of electrical activity. It measures voltage fluctuations resulting from ionic current flows within the neurons of the brain. Therefore, it is important to introduce the anatomical and neurophysiological structure of the human brain and also focus on the creation of the electrochemical currents that are picked up by scalp electrodes and that basically form the EEG signal.

1.1.1 Human Brain

The supreme commander of the human body is the brain. It is the central part of the nervous system which govern s the functions of various organs in the body. This section explains the anatomical structures of the brain and its' functions. Further, it focuses on how, why and where the brain generates electrical signal that can then be recorded. This section provides an explanation to understand the creation of local current flows within the brain that can be recorded by EEG.

Brain structures and their functions

Anatomically the brain can be divided into three major parts: cerebrum, cerebellum and brainstem (as illustrated in Figure 1.1).

Cerebrum: is the largest and most conspicuous part of the brain. It is composed of right and left hemispheres. The cerebrum is seat of sensory perception, voluntary motor actions, memory, and mental processes (thoughts, judgment, and imagination). [1]

Each hemisphere can be divided into four lobes:

- **Frontal Lobe** is involved with cognition and other higher mental processes (personality, behavior, emotions, problem solving, planning), motor control, parts of speech (speaking and writing).
- **Parietal Lobe** is responsible for sensation (e.g. pain, touch), sensory comprehension, and recognition, perception of stimuli, orientation and movement.
- **Occipital Lobe** is responsible for visual processing (color, light, movement).
- **Temporal Lobe** is involved in dealing with the recognition of auditory stimuli (understanding language, hearing), perception and memory. [1]

Cerebellum: is located at the lower back of the head under the cerebrum and is also divided into two hemispheres. The cerebellum is one of the sensory areas of the brain that is responsible for essential body functions such as muscular coordination, fine motor control, muscle tone, posture; some involvement in emotion, language, and spatial perception. [1]
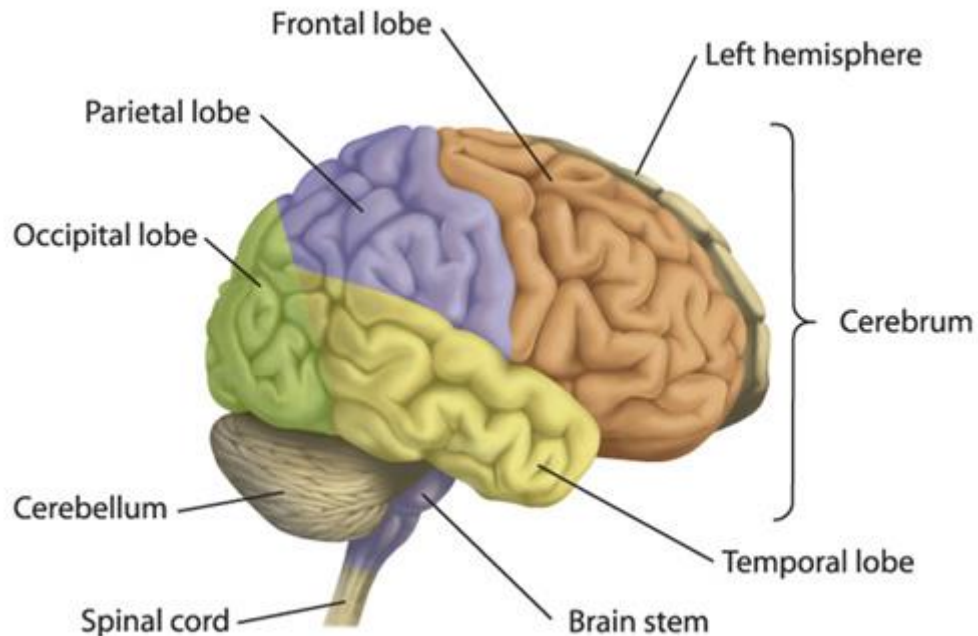
Figure 1.1: Anatomical areas of the brain (source [2])

Brain stem: is located at the bottom of the brain and connects the cerebrum to the spinal cord. The brain stem is the main control panel of the body. It controls vital functions of the body, including breathing, consciousness, movements of the eyes and mouth, and the relaying of sensory messages (heat, noise etc.), heartbeat, blood pressure and hunger. Ten of twelve cranial nerves originate in the brainstem. [3]

Neurophysiology of brain

The primary functional unit of the brain is a nerve cell called neuron. There are about 100 billion neurons in a human brain. Neurons consist of three parts: cell body, axon and dendrites (Figure 1.2). The electrochemical aspect lets them transmit electrical signals and pass message along to each other over long distances. [3], [4]

The **cell body** contains the nucleus which provides the information on what to do. As shown in Figure 1.2 several processes emerge from the cellular body of the nerve cell. According to their function, these processes can be divided into two types:

- **Dendrites** are thin, short structures that extend out of the cell body and usually branch out somewhat like a tree. Dendrites serve as the main apparatus for receiving input from other nerve cells.
- **Axon** is a special extension that arises from cell body and travels for distance. The axon carries nerve signal away from the soma. Some are surrounded by a fatty insulation material called myelin, which enables electrical signal to travel at higher speed. Near its end, the axon divides into branches that have specialized swellings called terminals. The dendrite of one neuron receives the message sent from presynaptic terminal in a form of neurotransmitter chemical of another neuron. This communication is possible through the action potential. [6], [7]
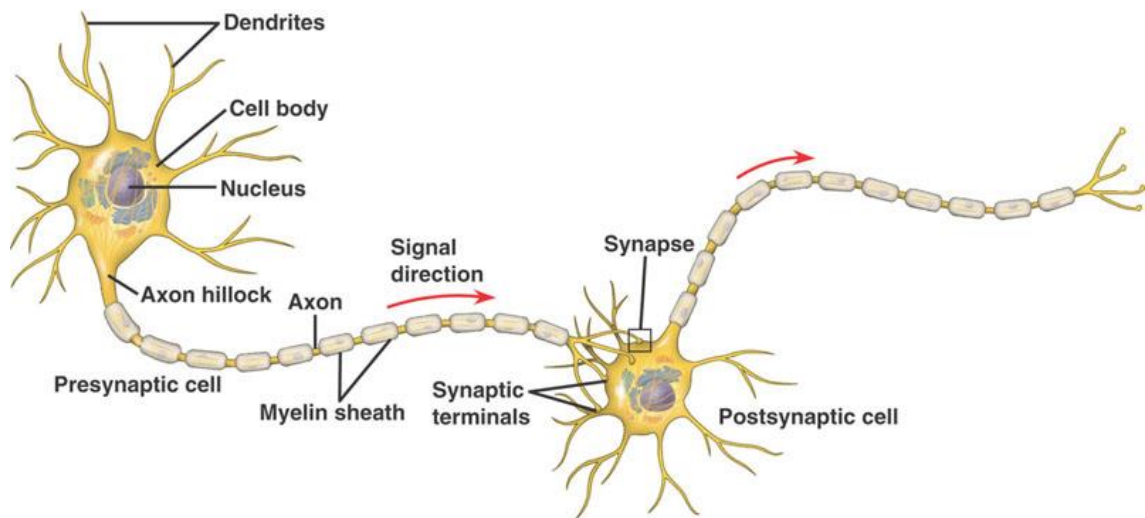
Figure 1.2: A simple structure of neurons and inter-neuron communication system (source [5])

Within a single neuron, information is conducted via electrical signaling. When a resting neuron is stimulated, the flow of ions across the neuronal cell membrane appears which leads to different distribution of ions alongside the cell membrane resulting in ionic charge; a voltage is generated on both sides of the cell membrane of the neuron. This signal is transmitted via a neurotransmitter sent through the synapse to another neuron creating a postsynaptic potential (PSP). [6], [8]

Pyramidal neurons of the cortex are spatially aligned and perpendicular to the cortical surface. This alignment of membrane potential creates dipoles between the cell body and apical dendrites (Figure 1.3). Those PSPs summate in the cortex and extend to the scalp surface where they are recorded by EEG. APs don't have such potential field distribution and are much shorter so they don't contribute significantly to either scalp or intracranial EEG recordings. The voltage generated by a single cell, is too small to measure with present day technology, so there needs to be large population of active neurons for measuring the electrical activity of the brain. [6], [8]
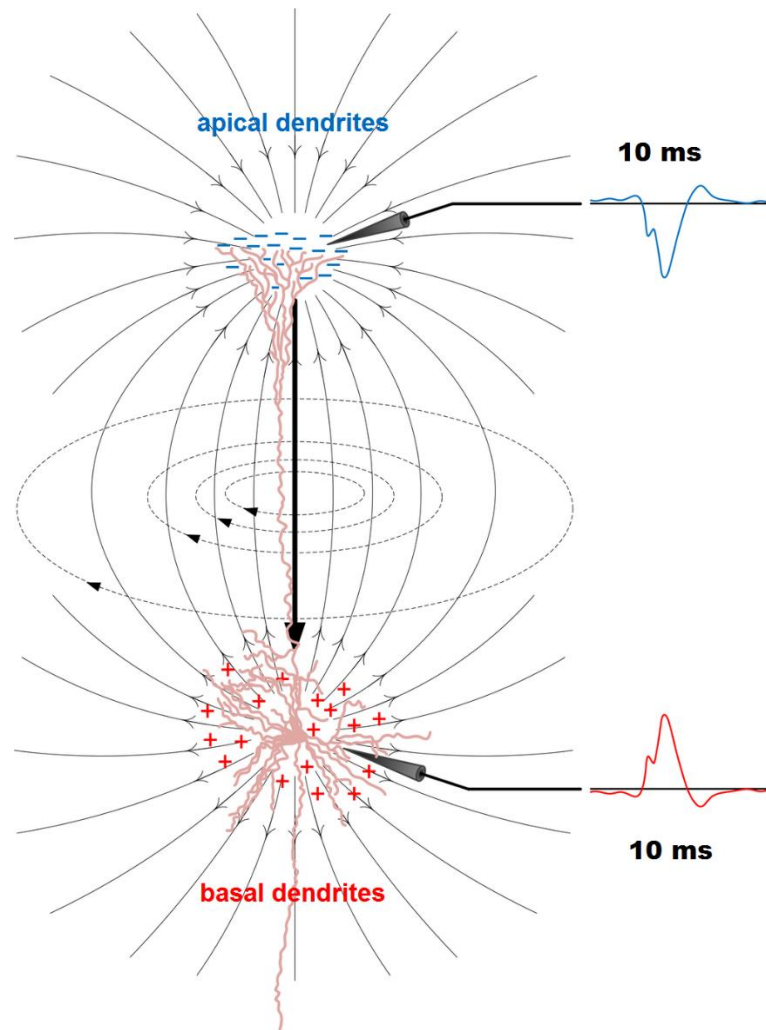
Figure 1.3: A cortical pyramidal cell, showing the current flow contributing to the surface EEG (source [9])

Cerebral cortex is a layer about 2 to 3 mm thick covering the surface of the hemispheres and it contains 14 to 16 billion neurons. One of the types of neurons is a pyramidal cell. They are the only cerebral neurons whose fibers leave the cortex and connect with other parts of CNS. Due to its surface position, the electrical activity of the cerebral cortex has the greatest influence on EEG recording. [1], [3]

1.2   Electroencephalography

Electroencephalography (EEG) is the measurement of electrical activity produced by the brain. Depending on where the signal is measured, there are two types of EEG: scalp and intracranial. Scalp EEG is measured by small electrodes places on the scalp with good mechanical and electrical contact. As for intracranial EEG, special electrodes are implanted in the brain during the surgery. EEG measured directly from the cortical surface by use of subdural electrodes is called electrocorticogram (ECoG). The amplitude of a signal measured by scalp EEG ranges typically from a few microvolts to 100 µV and

a frequency content ranging from 0.5 to 30-40 Hz in a "normal" adult (depends on mental state and age). [3], [10]

Electrode positions are standardized and usually adhere to the international 10-20 system. The goal is to sample the surfaced of the scalp evenly. The numbers 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, as shown in Figure 1.4. Individual electrodes are designed by a convenient nomenclature indicating brain hemisphere (odd numbers = left, even numbers = right) and general cortical zone (F = frontal, C = central, T = temporal, P = parental, O = occipital). [11], [12]
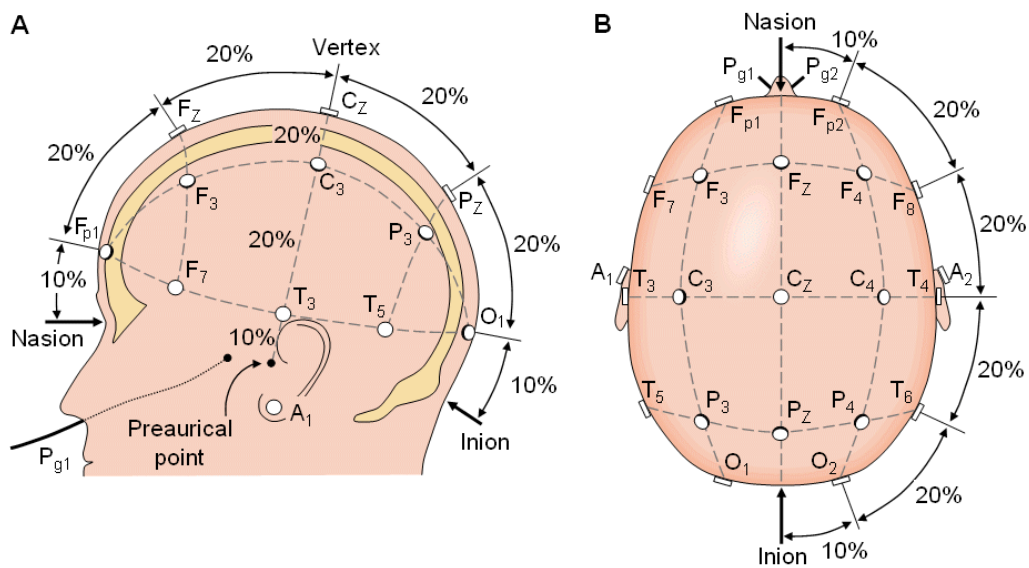
Figure 1.4: The 10-20 electrode placement system (Source [7])

The placement of the electrodes is referred to as a montage. The EEG can be monitored with the following montages:

- **Bipolar montage:** each voltage recording represents the difference in potential between two active adjacent electrodes. The entire montage consists of a series of these channels.
- **Referential montage:** each voltage recording represents the difference between a certain active electrode and a chosen reference electrode. A popular reference is "linked ears" which is basically a mathematical average of electrodes attached to both earlobes.
- **Average reference montage:** As a reference signal is used the average of sum of all the outputs of all amplifiers.

- **Laplacian montage:** Each voltage recording represents the difference between an active electrode and a weighted average of the surrounded electrodes. [3], [11], [13]
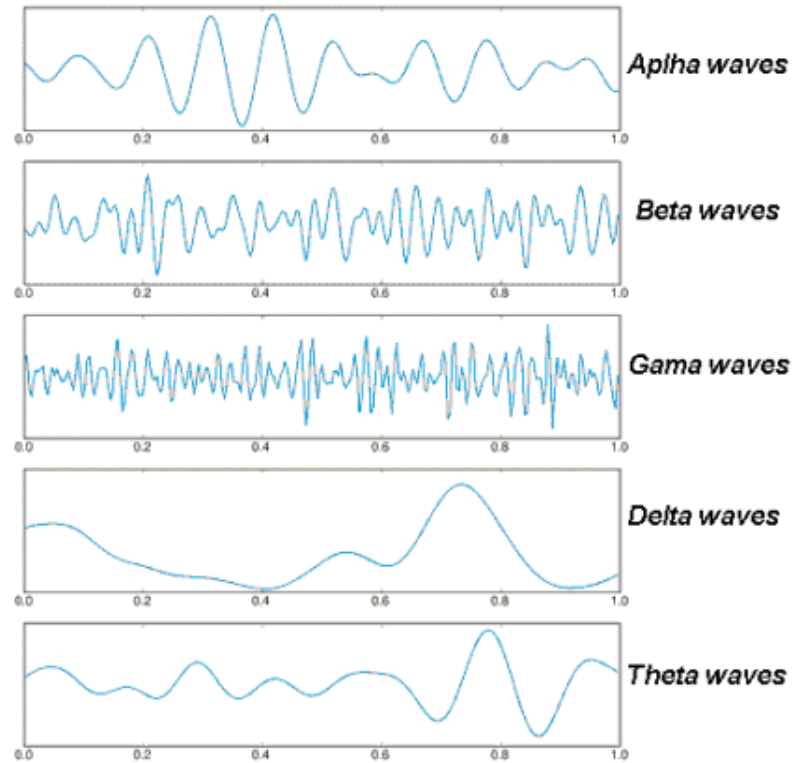
Figure 1.5: Rhythmic activity of the brain (source [14])

Rhythms of the EEG signals

The collective electrical activity of the cerebral cortex is usually referred to as a rhythm due to its repetitive behavior. These rhythms can be classified into five different frequency bands (Figure 1.5).

- **Delta band** is the frequency band up to 4 Hz and has large amplitude. It is mainly seen in deep sleep.
- **Theta band** consists of frequencies between 4 Hz and 7 Hz. This activity can be observed with drowsiness or meditation.
- **Alpha band** is usually defined by term "relaxed wakefulness" and contains the frequencies between 8 Hz and 13 Hz. It is seen when people are awake, and is known to be more apparent when eyes are opened.
- **Beta band** contains frequencies between 14 Hz and 30 Hz. This band is apparent with active thinking or concentration.

- **Gamma band** contains frequencies from 30 Hz and up. This wave is sometimes defined as having a maximal frequency around 80 Hz. It is associated with various cognitive and motor functions. [10], [12], [13]

Electrical signal in the EEG that are originated from non-cerebral origin are called artifacts, EEG data is almost always contaminated by such artifacts. Their amplitude can be largely relative to the size of amplitude of the cortical signals of interest. This is one of the reasons why it takes considerable experience to correctly interpret EEGs clinically. [15]

1.3 Overview of EEG signal processing and classification

It is important to develop methods for the detection and objective quantification of signal characteristics to facilitate visual interpretation. But first, the cancellation of noise and artifacts is important issue and prerequisite for the reliable subsequent signal analysis. [10]

1.3.1 Signal preprocessing

The aim of signal preprocessing is simply to remove noise and prepare the raw signal for further processing and analysis. The most important signal preprocessing techniques used are signal filtering and resampling, baseline fluctuation removal, signal segmentation, detection of artifacts, and various averaging techniques. [11]

High pass filters are used for low frequency removal (f < 0.1 Hz), while low pass filters remove high frequency noise (EMG activity, f > ±70 Hz). The exact frequency values may vary due to used method. To eliminate power-line noise, a notch filter can be used (f = 50 Hz for Europe). There are many approaches to remove baseline fluctuation, such as applying median filter, wavelet decomposition, the cubic-spline method, etc. In some cases, analyzing all EEG channels may be too complex, so averaging over all channels is performed. This can be used to detect artifacts. [11], [16]

1.3.2 EEG artifacts

Wide variety of artifacts can occur in EEG, some can be easily identified, while others may closely mimic the brain activity and are very difficult to distinguish, even by a well-trained electroencephalographer. By the origin of those artifacts, we can divide them into two groups: of physiological or technical origin. The latter can be reduced highly by proper attachments of electrodes. But it is impossible to avoid the influence of artifacts of physiological origin.

- **Eye movement and blinks**: Eye movement produces electrical activity (EOG) which is clearly visible in EEG. The strength of the signal depends on the proximity of the electrode to the eye and the direction of eye movement. More

about EOG and its characteristics in chapter 2.3. It is practical to acquire EOG signal with two reference electrodes positioned near the eye. The signal acquired is correlated with the EOG in the EEG and is used for artifact cancellation.

- **Muscle activity:** This artifact is caused by electrical activity of contracting muscles. It is usually encountered while patient is swallowing, frowning, chewing, talking, sucking, etc. Spectral properties of the EMG are overlapping with beta activity in 15-30 Hz range. It is hard to get a reference signal containing only EMG activity which would be useful for the artifacts' cancellation.

- **Cardiac activity**: The repetitive, regularly occurring waveform pattern which characterizes the normal heartbeat helps to reveal presence of this artifact, but the spike-shaped ECG waveforms are sometimes mistaken for epileptiform activity. [10]

1.3.3 Signal processing and classification
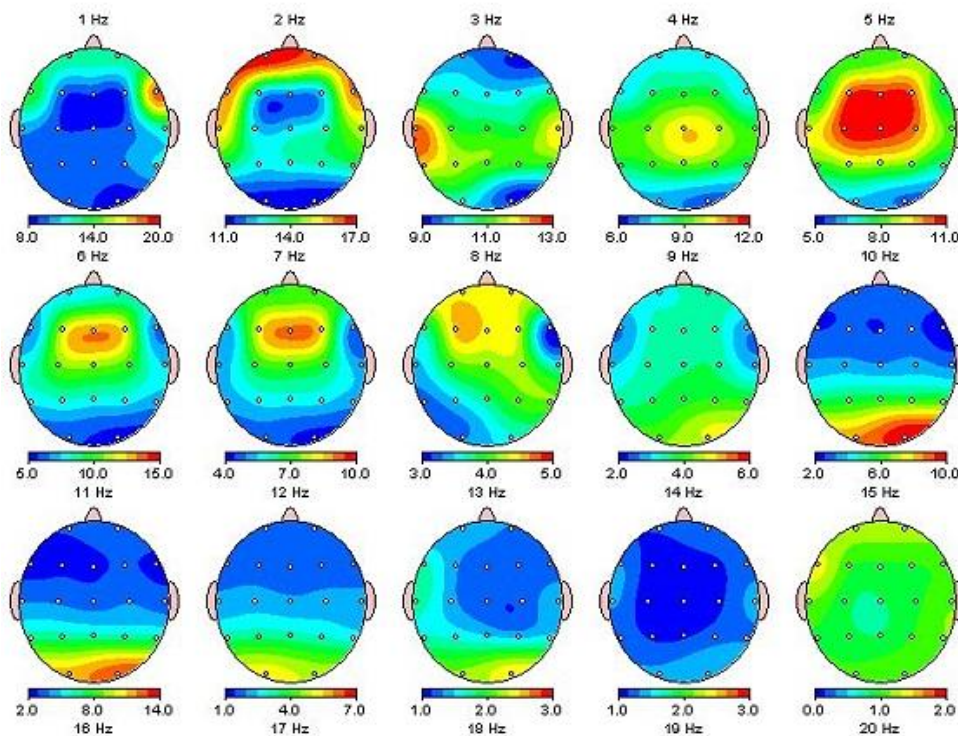
Figure 1.6: Brain topography (source [17])

The conventional EEG representation consists of simple graphs, with time set out horizontally and voltage value set vertically. These graphs are usually interpreted by a visual inspection by neurophysiologist. The brain activity is classified into different classes using knowledge and experience. Neurologists sometimes use the results of the EEG spectral analysis or topographical mapping (2D or 3D). These maps display information about the measured potential at all EEG electrodes for a single time span.

Variable values are spatially interpolated and mapped to corresponding colors (Figure 1.6). [16], [18]

Frequency domain

The basic transform used in EEG signal processing is Fourier Transform (FT), which converts signal from time domain to frequency domain. It is one of the oldest and the most used methods for EEG analysis. For digital analysis, discrete Fourier Transform (DFT) is used. This transformation decomposes the EEG signal into a voltage by frequency called the complex spectrum. Power spectrum, where power is the square of FFT's amplitude weighted by coefficient number, is represented by spectral graph where amplitude at each frequency is shown. (Figure 1.7). [16]

Non-parametric methods are based on fast FT computing. There are two power spectra: absolute power spectra and relative EEG spectra which can be computed to compensate a variation in amplitude of EEG. These appear depending on many different physiological, anatomical and physical properties. Parametric methods require an approximation of convenient parameters from the acquired data for signal analysis. The most used models are autoregressive model and prediction error model. [10], [16]
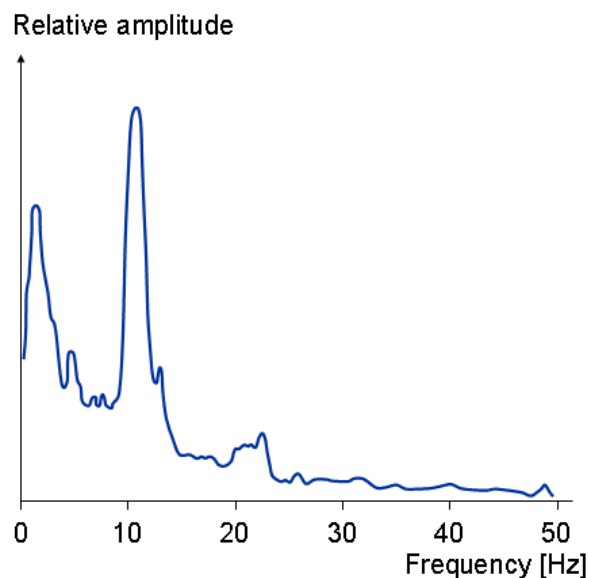
Figure 1.7: Frequency spectrum of normal EEG (source [19])

Time-frequency domain

Time-frequency analysis compensates for the inability of spectral analysis to say when in time different frequencies occur. It is important for processing non-stationary signals. One useful tool to analyze a signal changing in time is spectrogram. First the signal is windowed by window of certain length. The outcoming spectrogtram time or frequency resolution is dependent on window length overlap and number of FFT coeficients chosen to be counted. The power spectral density (PSD) is computed and all resulting spectra are

sorted in 3D orthogonal system with time, frequency and PSD axis. Spectrogram has 2D or 3D mode of the display, in 2D signal power at certain frequency is represented with color of chosen colormap. [16], [20]

Wavelet transformation (WT) is a time-scale analysis and it is capable to represent local characteristics in time and frequency domains. WT-based methods can better localize the signal components in time-frequency space. In other words, it is a convolution of a signal with a single wavelet function localized at different times and with different sizes. Each wavelet coefficient represents the activity of the signal at a particular time and frequency range, offering an ideal representation of time varying patterns in the signal, which has advantages in stationary signal analysis with better time and frequency resolution. On the other hand working with model wavelets result in appearance of redundant data. [16], [20], [21]

2. Eye movement and scene exploration

This chapter provides overview information about eye movements, parameters that are evaluated as well as the principles of two major methods to measure and detect eye movements and fixations. It is important to provide these information to understand the following chapters as well as the experiment itself.

2.1 Human eye movement

The purpose of eye movements is to fixate static or dynamic object in the field of view so that it is projected into the fovea. Eye movement is controlled by 3 pairs of antagonisticaly working muscles that are innervated by the third, fourth, and sixth cranial nerves (Figure 2.3). There are four basic types of eye movements:

- **Saccades**: Rapid, ballistic movements of the eyes that abruptly change the point of fixation. Saccades can be elicited voluntarily, but occur reflexively whenever the eyes are open, even when fixated on a target. The average duration of a saccade is from 30 to 120 ms.
- **Smooth pursuit movements**: In contrast to saccades, these movements are slower, designed to keep a moving stimulus on the fovea. These movements are under voluntary control in the sense that the observer can choose whether or not to track a moving stimulus.
- **Vergence movements**: These movements align the fovea of each eye with targets located at different distances from the observer. These movements are disconjugate.
- **Vestibulo-ocular movements**: Stabilizating eyes movements (compensating for head movements). These reflex responses prevent visual images from slipping on the surface of the retina as head position varies. [22], [23]

Fixation also refers to the point between any two saccades, during which the eyes are relatively stationary and virtually all visual input occurs. Average duration of fixation ranges from 200 to 250 ms during free will observation. Figure 2.1 shows the asymetric distribution of fixations. Most frequent fixation duration is about 200 ms, few are shorter than 100 ms or longer than 400 ms. [24], [25]
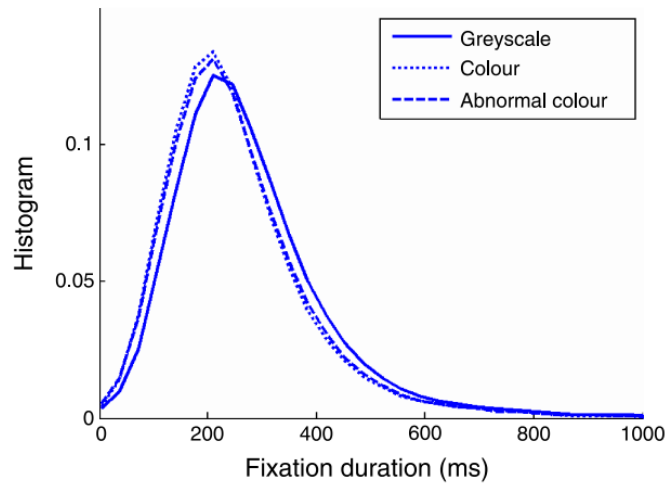
Figure 2.1: Distribution of fixation durations for three stimulus conditions (source [24])

2.2 Eye tracking

The device that is used to measure eye movements is commonly called eye tracker. The most widely used apparatus for measurement of the point of regard is the video-based combined pupil and corneal reflection eye tracker. [26]
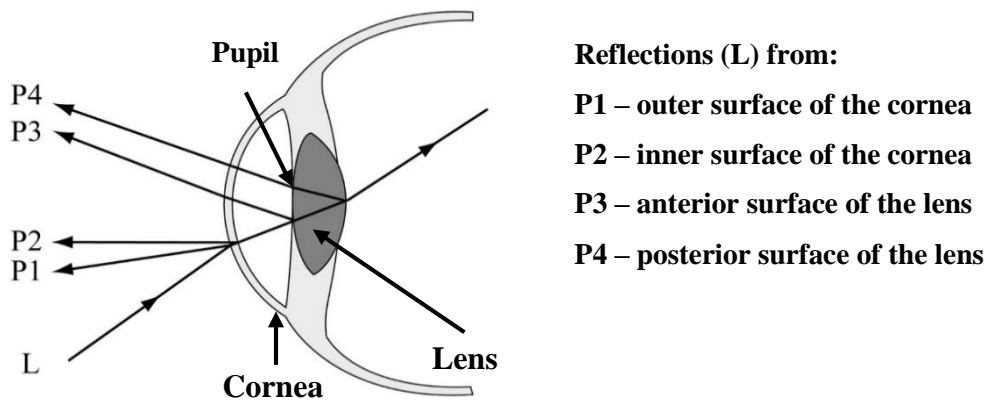
Figure 2.2: Structures of eye and 4 Purkinje images (source [59])

When infrared light is shone into the subject's eye, several reflections occur on the boundaries of the lens and cornea, these are called Purkinje images (Figure 2.2). When the eye moves, the position of glint (first Purkinje image) and the centre of the bright-eye (reflection from retina) change and so the direction of gaze can be calculated from these positions. Problems associated with this technique are primarily those of getting a good view of the eye and head movement which can put the eye out of focus. [27], [28]

2.3 Electrooculography

In 1848 Emil du Bois-Reymond observed that the cornea of the eye is electrically positive relative to the back of the eye, cornea-retinal standing potential. The movement of the eyes produces a shift of this electrical potential which can be recorded by electrodes placed around the eyes. The measuring electrodes are placed as shown in Figure 2.5. Horizontal eye movements are generally recorded with an electrode placed at the outer edge of each eye (resulting signal is shown in Figure 2.4). Vertical eye movements are recorded with the electrodes above and below the eye. EOG can be used to record eye movements up to ±70°. [19], [23]
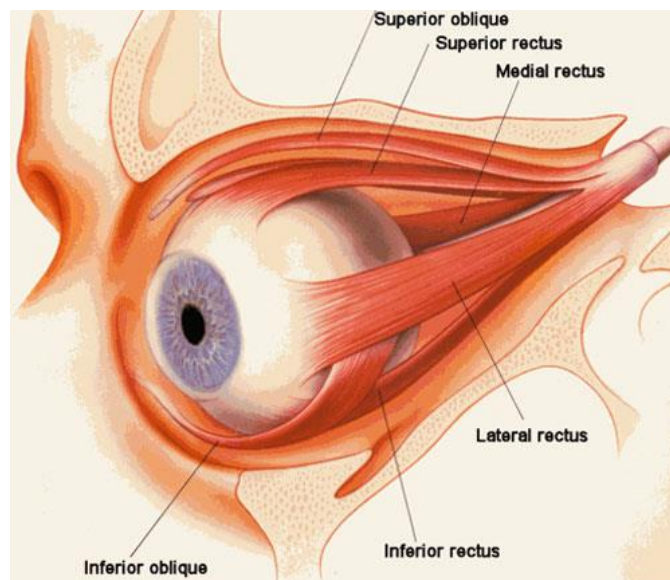
Figure 2.3: Extraocular muscle anatomy (source [60])

The amplitude of EOG signal ranges between 50 to 3500 µV and its frequency components go from 0 to 100 Hz. There are only few difficulties with the EOG. One can be that a patient may find it difficult to make standard eye movement and compensates it with head movement. This problem can be overcome by providing a solid head rest. As EOG requires use of electrodes there might occur a DC drift on the baseline of the signal over time which can be eliminated with well attached electrodes and good amplifiers. The EMG also occurs as a parasite signal acquired during the acquisition. [23], [29], [30]

The EOG can be used for a wide variety of applications. Monitoring and recording the EOG signal can help to detect stages of sleep, to diagnose certain eye disease; EOG can help control specialized software, it can be used as a reference signal for the EEG etc. As for this study we are going to use is for detecting eye fixation. [19]

30°

[μV]
200

100

0

-100

Time [s]

Eyes moving 30° to the right

-15°

[μV]
100

0

-100

Time [s]

Eyes moving 15° to the left
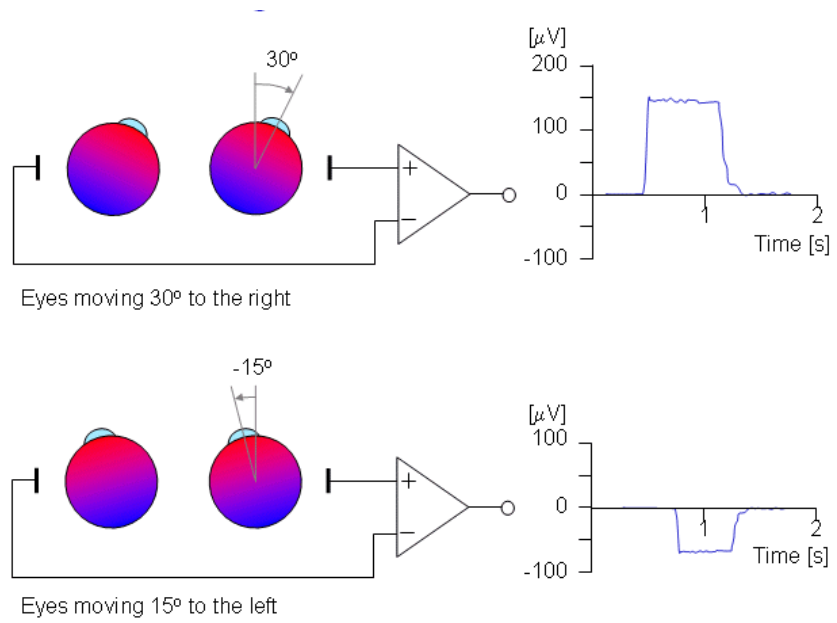
Figure 2.4: EOG signal generated by horizontal movement of the eyes (source [19])

A

Vertical

Ground lead

Positive
lead

Negative
lead

B

Ground lead

Positive
lead

Negative
lead

Horizontal

Right side

Left side
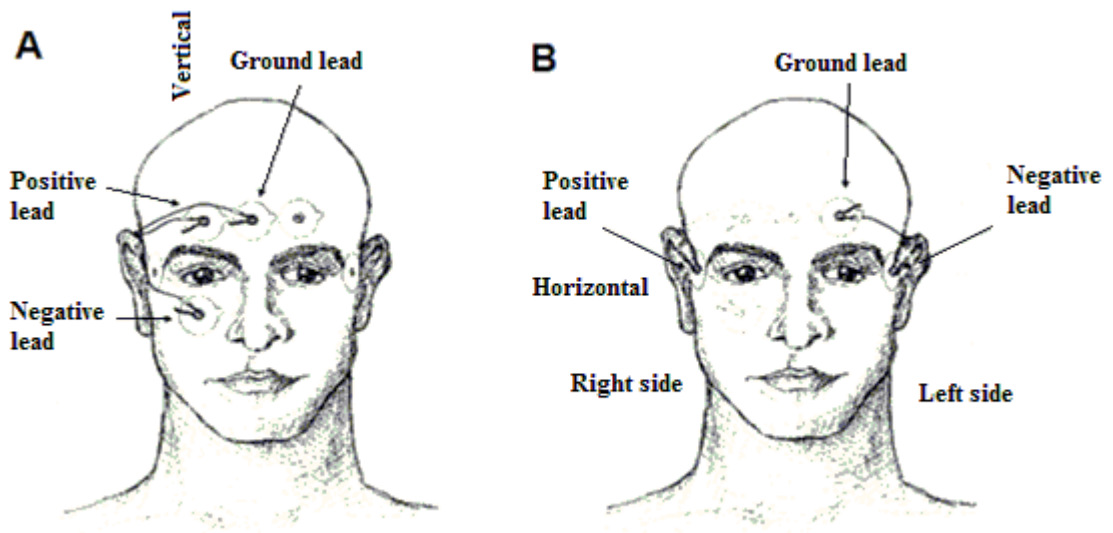
Figure 2.5: EOG signal measuring (source [31])

3. Event Fixation Related Potential

EEG as a general method for studying human brain function includes ways of determining the reaction of the brain to a variety of stimuli. Event-related potentials (ERPs) are a specialized form of EEG and may be interpreted as a subset of sensory (visual, auditory, somatosensory) evoked potentials (EPs). [11], [32]

3.1 Extraction of Event Related Potentials

ERPs are usually defined in time domain but the basic problem of analysis is detecting this activity within much larger ongoing or background activity. The common way of extracting ERPs from EEG can be done by filtering and averaging the signal as shown in Figure 3.1. The assumption is that measured signal consists of the sum of ongoing brain activity and a stimulus-related response that is independent from the ongoing activity. Also, the response is considered invariant over repeated stimulation. An event of interest is being repeatedly presented to a subject and these EEG epochs (time-locked to the stimuli) are then used to calculate average. [11], [33]
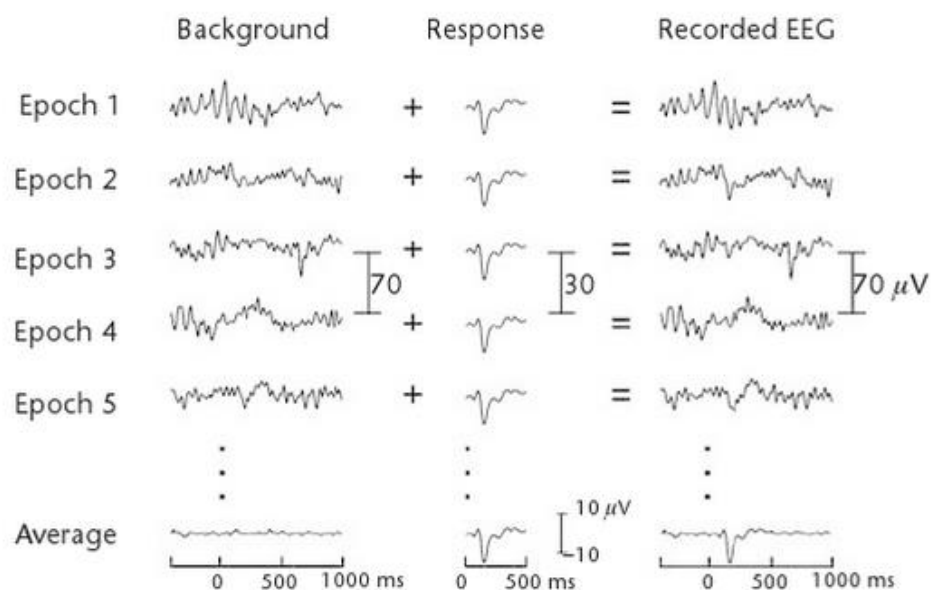
Figure 3.1: Additive ERP model (source [33])

On contrary this method is limited by a loss of information related to trial-by-trial changes. These can be systematic (e.g. decrese in amplitude or latency with trial number that could be related to learning or memory process) or unsystematic (e.g. trial-to-trial variability that correlates with perceptual performance). [21]

Few strategies to perform single trial analyses have been proposed. One method is to identify wavelet coefficients obtained using wavelet transformation, correlated with the average evoked responses and then reconstruct denoised single-trial traces with use

17

of these coefficients. Another method requires defining an instantaneous phase and then evaluating if there is a preferred phase at which the neurons fire, or a trial-by-trial correlation between the phases at different recording sites, etc. Another approach is to predict on a trial-by-trial basis the stimulus eliciting a particular response using decoding algorithms. [21], [34]

Analysis of ERPs in frequency domain shows some benefits; considering the signals that cannot be detected in time domain because they occur without a fixed phase or time relation to the trigger, and to ERPs caused by continuous stimuli. Approaches to extract ERPs by these advanced methods, Principal component analysis (PCA), and Independent component analysis (ICA) show many advantages. [11]

3.2   ERPs components

There are two classes of ERPs. The early waves are referred to as sensory ("exogenous"), because they depend mainly on the physical parameters of the stimulus, then the cognitive waves ("endogenous") appear as a reflection to evaluation of the stimulus. These waveforms can be characterized by their latency and amplitude. [32], [35]

ERPs component can be classified by means of their voltage polarity, timing, scalp distribution and response to experimental manipulations. The nomenclature usually indicates the polarity of the wave (P = positive, N = negative, C = polarity is not uniform) and the number can either indicate the latency in milliseconds or the original position of the component in the waveform (Figure 3.2). The most prominent one and mostly studied is the wave **P300** (P3). P300 can be obtained when a subject detects an occasional target stimulus in a regular train of standard stimuli. [35], [36]

Contingent Negative Variation (CNV) is characterized as a sustained potential change during which the surface of the brain becomes electro-negative by about 20 µV. It is a slow negative deviation of EEG which appears in the interval between two stimuli. It is complex endogenous potential that reflects many mental and cognitive activities such as sensation, attention, expectance, stress or discrimination. [32]

Mismatch Negativity (MMN) represents a response of the brain to violations of a rule, established by a sequence of sensory stimuli (typically in the auditory domain). It is evoked even in the absence of attention and can be used as an objective index of sound-discrimination accuracy and auditory sensory memory. [32]

Bereitschaftspotential (BP) also termed readiness potential (RP) represents an anticipatory slow wave in a close relation with movement or another voluntary motor act. Its deficit reflects abnormal motor preparatory processes in the brain. [32], [37]

Sur & Sinha (2009) recognize additional parts of an ERP trace involving P50 wave, N100, P200, N200, N300, N400, P600, etc. [37]
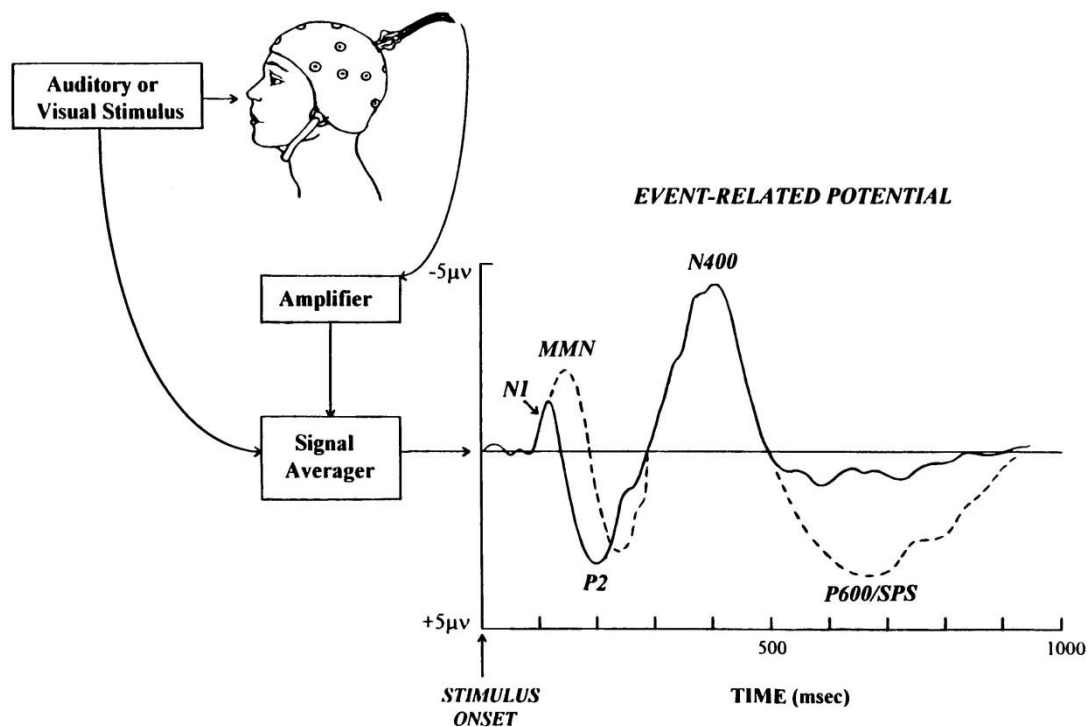
Figure 3.2: Extraction of ERP and its components (source [61])

3.3 The use of ERPs

ERP technique provides a unique and significant tool for experimental psychology. There are many fields of study concerning ERPs. Recording of ERPs from normal subjects has played an important role in study of attention. Also involvement of certain brain areas in certain intentional tasks and an effect of aging were investigated. This method also enables to study abnormalities in subjects with psychological diseases and phobias, as well as studying the memory. As for this work, the most concerning study of ERPs is the one relating emotions. ERPs are frequently used to study emotional responses to either positive or negative stimuli, emotional memory, effects of emotional concent on declarative memory, emotion regulation or emotion processing. [32], [35]

3.4 Eye tracking with EOG and ERP

When exploring a scene, we move our eyes systematically and create sequences of fixations while gathering information in each instance of this sequence. The EOG method has many advantages compared to commercial eye tracking systems. This method is simple, time-efficient and provides a good resolution. The precision of EOG output is within ± 1.5 - 2° angle of gaze. [38]

The methods determine where an individual is fixating at any given moment by monitoring electric field changes generated by eye movements. The origins of this signal

19

were explained in the section 2.3. EOG signal information is mainly contained in low frequencies (< 30 Hz). In order to remove some noise components a low pass filter is required. [30]

3.4.1 Methods

These methods use a certain visual pattern. Subjects are asked to make a certain set of eye movements. The distance and the viewing angles are known. Merino et al. (2010) detect eye movements with an edge analysis. During the eye movements, there are three different stages that can be recognized: the signal rising from „low" level to „high", stabilizating at the „high" level, and fading until the „low" level. The edges are detected through the derivative of the EOG signal. This method shows average hit rate of 94.11%. [30], [38]

Banerjee et al. (2012) present a method using the wavelet transform coefficients and statistical parameters to classify the direction of eye movements. [39]

Joyce et al. (2002) describe a method to track where on screen (x,y coordinates) a subject is fixating. The basics of the method are very similar to previous ones. A subject is asked to make a certain set of eye movements which are then related to the measured potential. The pattern is shown to a subject in some order with the instruction to saccade to the new location of the fixation point. As the subject tracks the pattern, a filter is calculated by associating the changes in the x,y coordinates of the pattern with the recorded changes in the EOG. The quality of the calibration is usually verified by the mean error during the trials. To detect saccades wavelet decomposition is realized. Saccade onsets and offsets appear as sharp peaks in many wavelet levels. The coordinates of the fixation at the time of these are used and everything else in the eye movement sequence is eliminated. Synchronizing the eye movement and EEG data is realized by use of clock signal sent to both of the modalities. [38], [40]

3.5 Emotional stimulation

There are number of ways in which emotions can be recognized. This may be via speech, facial expression, gesture, or a variety of other physical and physiological cues. Two of the more researched methods include speech and face recognition. As for this work focuses more on ERPs related to visual emotion stimulation. [41]

3.5.1 Emotions

There are many definitions of emotion. Some make distinction between feelings and emotions. Two basic models for emotion classification are characterized. Ekman (1999) classifies six emotions: anger, disgust, fear, happiness, sadness and surprise. Plutchik (1962) suggests eight primary emotions: joy, sadness, anger, fear, trust, distrust, surprise, anticipation. [42], [43]

Emotional state of an individual is conveyed by facial expression which is also affected by social communication. In this regard, faces might be an especially salient type of emotional stimulus. Facial recognition also identifies face's gender, age, visual identity, or other socially relevant category. [44], [45]

Nowadays, functional imaging methods are used to study emotion processing. This method provides perfect spatial resolution and reveals brain regions that are involved in the processing of emotional face. ERP method provides better temporal resolution, higher movement tolerance, lower cost of hardware, and mobility. Use of emotional ERP seems to show promising understanding in study of cognitive brain functions. [44], [45]

3.5.2 Visual evoked potential

Visually evoked potential (VEP) is type of ERP and is initiated by brief visual stimuli. VEPs are primarily used to measure the functional integrity of the visual pathways from retina via the optic nerves to the visual cortex of the brain. Commonly used visual stimuli are strobe flash, flashing light-emitting diodes, and time-reversing checkboard pattern. The International Affective Picture System (IAPS) is widely used database of pictures used to study emotion and attention. Smith et al. (2013) focus on the time-course of processing of fearful, angry, happy, sad and neutral faces using the NIMSTIM facial stimulus set. NIMSTIM is large, freely available, full color, and increasingly-used in studies of emotion. [44], [46], [47]

Hajcak et al. (2010) focus on specific ERP components in response to standardized emotional stimuli (IAPS) and set including facial displays of emotion. Some studies present that individuals are more likely to look at unpleasant and pleasant pictures compared to emotionally neutral images (Calvo et al. 2007). The fact that emotional stimuli seem to automatically capture attention may depend on the relatively early detection of emotional compared to neutral information. Figure 3.3 illustrates ERP from a study in which participants were shown pleasant, unpleasant and neutral pictures for 2 sec. [36], [48]

Studies of emotion perception have shown five prominent ERP-components that might be modulated by visual emotional content during static emotional face processing:

- **C1**: is evoked whenever a visual stimulus is presented. It can be either positive or negative with the peak observet around 70 ms range.
- **P1**: first positive component observed around 100 ms. The maximum of it amplitude is over the lateral occipital scalp.
- **N170**: as the studies show, emotional modulation of N170 rather depends on specifications of the experimental setup but it has been shown to be particularly sensitive to faces, encoding of facial features and configurations.

- **EPN** (Early Posterior Negativity): follows the N170, and is a negative deflection at posterior-lateral electrodes between 250 and 350 ms. EPN can be associated with disgust and fear.
- **LPP** (Late Positive Potential): is most prominent over midline centro-pariental regions around 300ms during the attentive processing of both positive and negative emotional facial expressions. It is a positive-going slow wave. It is associated with sustained attention to motivationally-salient visual scenes. [44], [49], [50]
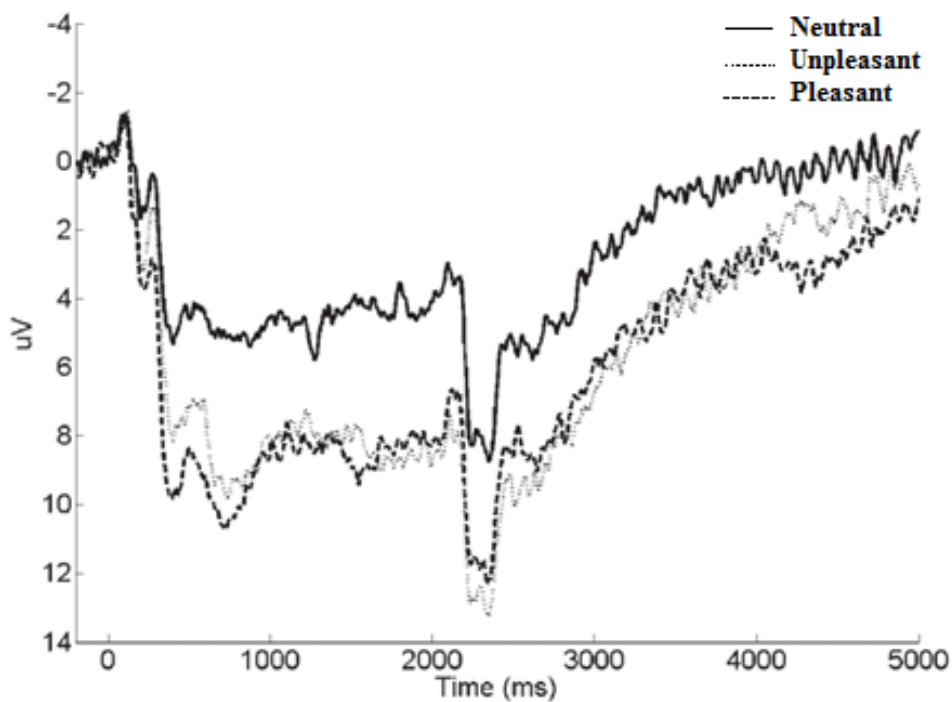
Figure 3.3: ERPs following the presentation of pleasant, neutral and unpleasant pictures (source [36])

Static vs. Dynamic stimulation

Every day, people are confronted with pictures of emotional expressions, but most of the time facial expressions appear in movement and at different intensities. Experimental studies explore the differences in brain activation to static facial displays versus dynamic changes in facial identity or emotional expression. [51]

It has been demonstrated that dynamic expressions provide some form of information that is available only over time (Cunningham & Wallraven, 2009). An experiment conducted by Gold et al (2013) revealed that there is no significant difference in signal between dynamic and static stimulation when the static picture shows a fully expressed emotion. On the other hand, it might appear problematic to keep the exact emotion intact. [51], [52]

ERP analysis by Trautmann-Lengsfelt et al. (2013) shows some differences in ERPs components. As for the static stimulation, LPP component was increased in amplitude. On the other hand, dynamic stimuli induced prolonged and widespread response of LPP. This study supports the view that dynamic facial displays trigger more information due to their changing features triggering continuous evaluation of those faces. [49], [53]

4. Experiment

This chapter summarizes the experiment that was conducted to acquire the oculometric data, EOG data and EEG data. It is described to provide complex idea about the whole study. This was conducted by Nicole Christoff (2014). [54]

4.1 Experimental device and equipment

The experiments were conducted in the hospital Michalon at La Tronche. A test subject is alone in an experiment room and is seated in front of a computer screen. An experimenter controls calibrations of eye trackers, appearance of stimuli and acquisition of EEG signal.

4.1.1 Eye tracker

Eye movements are registered with EyeLink^{TM} 1000 Hz from SR Research. Thanks to the sampling rate 1 kHz, the eye tracker registers information about eye position every 1 ms. It also distinguishes between saccades and fixations based on calculation of the speed between every sample. The eye is filmed with infrared camera and the pupil is detected. Tracker uses the reflection of light beam on the cornea.

Eye tracker allows to track both eyes at the same time but for this experiment one eye is sufficient enough. Before the experiment, the calibration with nine points that appear at the edges, in the center and in the middle of the edges of the screen is done. The subject has to successfully fixate on these points. If the average error is bigger than 1°, it has to be redone.

During the experiment, another calibration called "drifting" is utilized. It ensures that there is not a drift in eye positioning with use of one point in the center of monitor. If the error is bigger than 1°, the main calibration is done again. Drift is planned every 5 stimuli, calibrations every 14 or 19 stimuli.

For every time stamp, size of papillae and the horizontal and vertical positions of eye are registered. Eye tracker data is saved in file format *.edf* (eye data file). It contains information about position and concerning time stamps spent there, along with initialization and end of fixation and saccades. The blink information is provided as well.

4.1.2 EEG and EOG

EEG signal from the head surface is continuously registered at 1000 Hz (registering system EEG BrainAmp – Brain Recorder) with head cap with 64 active electrodes (electrode system 10-20) – green and yellow (Figure 4.1) with the reference (blue) on FCz and the ground (black) at AFz. For reference 4 mastoid electrodes are added. Three sizes of caps are available for the best results: 54 cm, 56 cm and 58 cm.

The registered data is saved in *.eeg for the raw EEG signal, *.vhdr for the header information and *.vmrk for the triggers.

EOG signals are registered along with EEG signal. Four electrodes are used to acquire EOG signal. To get the vertical EOG (VEOG), one is placed above and one below the left eye. For horizontal EOG (HEOG), two are places next to the outer corners of both eyes. Fifth electrode – ground, is placed at scapula.

Figure 4.1: Positioning of 64 used electrodes (source [54])

4.2 Experimental protocol

The subjects to this study were 18 healthy people aged from 20 to 31. All the subjects had corrected or normal sight. The final data were taken from 17 subjects, 11 men and 6 women. Stimuli for this study were videos carefully chosen from DynEmo database. DynEmo is a video database containing dynamic and authentic emotional facial expressions (EFE) of annoyance, astonishment, boredon, cheerfulness, disgust, fright, curiosity, pridy, moved, and shame. The afffective state of the EFE is identified both by the expresser and by observer. It consists of 358 EFE videos of ordinary people recorded in natural conditions. [55]

The subject explores the visual scene of emotional expression of faces in two sets of presentation: 2 seconds for (static - EFE) picture and 5 seconds for (dynamic - EFED) video. Subjects are told to observe the visual scene carefully. The protocol is divided into two sessions – static and dynamic and the order is balanced for all the subjects. At the beginning of each session there is a part of learning (3 test stimuli). The order of all the stimuli (images/videos) is random and each stimuli appears just once.

4.2.1 First session

To maximalize the expected results, 48 distractors were added to 70 stimuli (24 neutral, 12 happiness, 12 surprise, 10 fear, 12 disgust). Distractors are stimuli that have not been selected as a valid emotional trigger. Sum of these and stimuli gives us a total number of 118 stimuli divided into three blocks: block 1 – containing 39 stimuli, block 2 – 39, block 3 – 40. There is a pause for 5 minutes between each of these blocks. The goal of this session was to freely explore the face on the screen and evoke the same emotion as shown in the subject.

4.2.2 Second session

There was only 70 stimulus divided in two blocks: block 1 – containing 35 stimuli, block 2 – 35, with 5 minute break between. During this session the subject ought to observe the face on the screen. For each visage, he should understand and share the feelings that the face expresses. At the end of each stimuli he has to categorize the emotion of the stimuli (G – Happiness, S – Surprise, F – Frayeur, D – Disgust, N – Neutral) and evaluate the power of its expression (--, -, 0, +, ++). Subject has 3 seconds for each question.

5. Fixation data description

This chapter describes composition of recorded data of the eye gaze in certain areas of interest in the emotion expressing face.

5.1 Regions of interest

9 regions of interest (ROI) have been applied to each stimuli (Figure 5.1) image/video. The shape for the certain stimuli stays the same, for the videos the ROI object copies the movements of the face. As a 10th ROI is considered the outer space of these regions.

Each of these regions have their significance when expressing the emotions. For example, surprise – eyebrows elevate and eyes blink, disgust – upper lip grins, happiness – smile.

1. Left eye
2. Right eye
3. Left brow
4. Mouth
5. Chin
6. Nose
7. Right brow
8. Corrigateur
9. Front
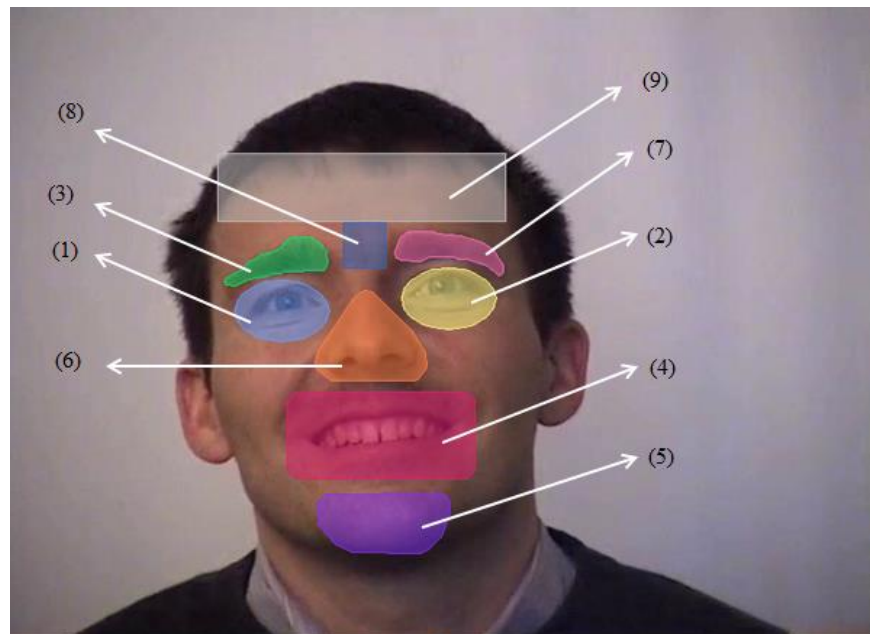
Figure 5.1: Regions of interest (source [54])

5.2 Data acquisition and organization

Data were acquired with eye tracker EyeLink with software SoftEye (.edf data format). With EDF2ASC program the .asc file was created and with use of Matbuilder (created by Gelu Ionescu) the *EventFix_Dynemo.mat* was created. Toolbox for the fixation for dynamic data was made by Nicole Christoff to adjust data and add the fixations into ROI. Data on fixations are sorted in structure by experiment and by sessions (EFE1/EFED1 and EFE2/EFED2).

There are 17 test subjects for dynamic data and 14 test subject for static data. Data structure obtained from static session does not contain fields: *Frame* and *NbFrame*. Example of structure shows Figure 5.2 and Table 5.1 explains the structure further for chosen experiment, subject and stimulation *i*.

Figure 5.2: Example of data structure for dynamic sessions.

Table 5.1: Structure of data – particular subject, particular stimuli

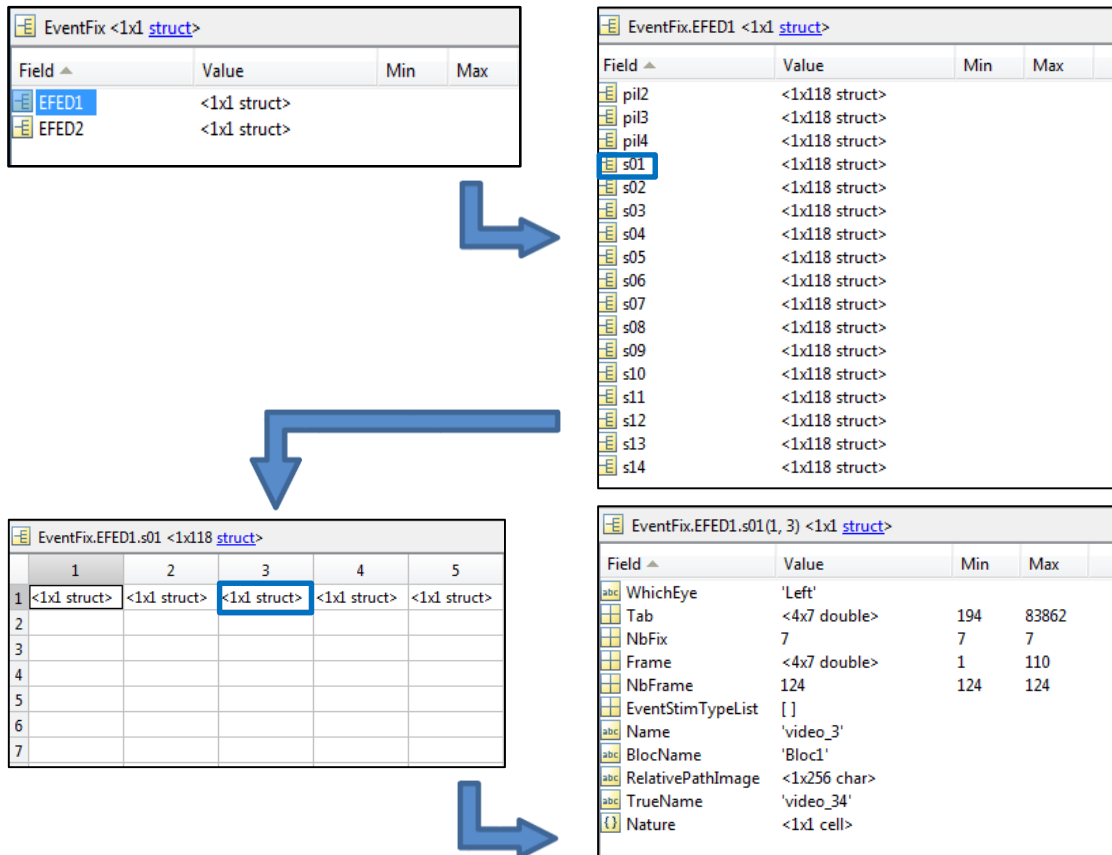| Name	Description	Type	Example
EventFix.Experiment.Subject(i).WhichEye	Observing eye	AN	'Right'
EventFix.Experiment.Subject(i).Tab	Table of fixations (4 x *NbFix*)	Mat	<4 x 10 double>
EventFix.Experiment.Subject(i).Tab(1,j)	Time of the start of the fixation *j*	N	40 66 89
EventFix.Experiment.Subject(i).Tab(2,j)	X position of fixation *j*	N	35 320 -9
EventFix.Experiment.Subject(i).Tab(3,j)	Y position of fixation *j*	N	40 66 89
EventFix.Experiment.Subject(i).Tab(4,j)	Duration of fixation *j*	N	60 555 378
EventFix.Experiment.Subject(i).NbFix	Number of fixation for the stimuli (without the first and last fixation)	N	10
EventFix.Experiment.Subject(i).Frame	Table of frames	Mat	<4 x 10 double>
EventFix.Experiment.Subject(i).Frame(1,j)	Number of frame where the fixation *j* starts	N	7 23 32
EventFix.Experiment.Subject(i).Frame(2,j)	Duration of fixation *j* in the first frame	N	18 13 8
EventFix.Experiment.Subject(i).Frame(3,j)	Number of frame where the fixation *j* ends	N	13 32 40
EventFix.Experiment.Subject(i).Frame(4,j)	Duration of fixation *j* in the last frame	N	31 1 24
EventFix.Experiment.Subject(i).NbFrame	Number of frames in the video	N	124
EventFix.Experiment.Subject(i).EventStimType List	List of *EventStim*	[ ]	[ ]
EventFix.Experiment.Subject(i).Name	Name of the stimuli in shown order to subject	AN/N	'Video_2'
EventFix.Experiment.Subject(i).BlocName	Name of the block in which the stimuli was shown	AN/N	'Bloc1'
EventFix.Experiment.Subject(i).RelativePathImage	Path of stimuli	AN	<1 x 256 char>
EventFix.Experiment.Subject(i).TrueName	True name of stimuli	AN/N	'video_58'
EventFix.Experiment.Subject(i).Nature	Information of nature of stimuli	AN	D (disgust)
EventFix.Experiment.Subject(i).ArousalAnswer	Response of subject for the 1st question	AN	'+'
EventFix.Experiment.Subject(i).EmotionAnswer	Response of subject for the 2nd question	AN	'D'
EventFix.Experiment.Subject(i).Roi	Table of ROIs for fixation	Struct	<1 x 10 cell>
EventFix.Experiment.Subject(i).Roi{1,n}	*n* is number of frames where fixation *j* occurs	Mat	<9 x n>
EventFix.Experiment.Subject(i).Roi{1,:}	Right eye	N	0 0 0

6. Analysis of fixations

This chapter provides a description of programs created to adjust data structure for easier access to information about fixations and to provide additional information, as well as to make graphic and numeric statistics on fixations. These outputs help to clarify the connections between gaze and emotions and to create a base ground for further EEG processing. All of these were written in a Matlab environment.

6.1 Data adjustments

Programs to adjust data on fixations had to be done before statistics itself. The previous intern Nicole Christoff working with these data sets was concerned mainly about the dynamic data (EFED1 and EFED2). Due to this, static data (EFE1 and EFE2) from eye tracker were not processed and connected to the regions of interest in the image. Since the Eye tracker information differ a little for the static and dynamic data, certain adjustments had to be done with these programs. For general conclusion about difference between static and dynamic sessions, the same information had to be provided. By closer observation of the data structures, addition of certain fields was essential.

6.1.1 Adding fixations for static data

Source for this work was m-file *ExeStep3AddRoi.m* that calls on certain functions located in the class file *AddRoi.m*. To distinguish both of these, final programs for static sessions are named: *ExeStep3AddRoiStatic.m* and *AddRoiStatic.m*.

      ExeStep3AddRoiStatic.m is the executive script of the class file ***AddRoiStatic.m.*** It initializes the data structure to work with, in this case *EventFix_Dynemo.mat,* removes the dynamic conditions, which leaves *EFE1* and *EFE2*. Source path for static masks has to be identified in this file. These had to be extracted from the video masks. Static stimuli is based on the apex of the video stimuli. This occurs at the time of 2.5 s (frame 62) and shows the most developed emotion. Finally, the new data structure with fixation in static is saved as *EventFix_Dynemo_Dest2.mat.* This script also calls the function *Process* situated in the class *AddRoiStatic.*

      The output of this program is structure with a new field inside the *EventFix* data structure named *Roi – 1 x NbFix –* where each contains a matrix – 13 x length of fixation. The rows identify the ROIs (1 - 9: ROIs, 10 - 13: out of roi). Example: if the first gaze appears on nose, then the matrix is filled with ones in the 6th row, the rest is zeros.

6.1.2 Additional fields in data structures

Two programs (***AddFieldsStatic.m*** and ***AddFieldsDynamic.m***) have been coded in the Matlab environment to add another information into the *EventFix* structure. The idea stays the same but the way to work with each static and dynamic differs a little. The program

for static works with *EventFix_Dynemo_Dest2.mat* and the program to adjust dynamic data works with *EventFix_Dynemo_Dest.mat*.

For both sessions and every trial, a new field *FixInVid* is created. An empty matrix is initialized with size of 13 rows (ROIs + out of ROIs) and 5000 columns (duration of video stimuli). For the dynamic sessions *Frame* field is used to compute the duration of each fixation, as well as the start of the fixation in the means of the video. *Roi* field serves for the purpose of getting the location of fixation (ROI). Position in the matrix that is given by the location and start of fixation is filled with ones until the end of the fixation. This process is repeated as many as there is *NbFix* times. On contrary, *Tab* field is used to get the duration of particular fixation in the static data structure, and since there is no time stamps needed, fixations are always separated by one 0. If the data about ROIs is missing, then *FixInVid* is empty.

Two changes have been done to the second session data set. *ArousalAnswer* field has been fixed and new numeric scale <-2, 2> replaced the previous one ('—', '-', 0, '+', '++'). Furthermore, nature of the trial (*Nature*) and the answer to the recognition of the emotion (*EmotionAnswer*) is compared to create *AnswerStatus* field. This gains either 0 (not matching) or 1 (right answer). In the end the data structures are saved as *EvenFixStatic.mat* and *EventFixDynamic.mat*.

6.2 Statistics

Five separate functions have been coded in order to help understand the common pattern during the visual observation of the stimuli. These are connected by Matlab GUI for more user friendly interface and fast and easy setup of preferences for analyzing the fixations (Figure 6.1).

6.2.1 User Interface

Figure 6.1 shows a user interface **HistoEmoGUI.m**. Left part of the window consists of input information that is required for running the execution buttons. A button *Choose data folder* calls on a dialog window to choose a path to a directory where *EventFixDynamic.mat* and *EventFixStatic.mat* data structures are. A pop-up list labeled as *Choose experiment* requires to select either one of static (EFE1 and EFE2) sessions or dynamic (EFED1 and EFED2) sessions. Another pop-up list *Choose emotion* is used to select the emotion (All, Neutral, Disgust, Surprise, Happiness, and Fear). There are two edit windows: *Minimum fixation duration* and *Maximum fixation duration*. Two of these are of huge importance and were added after further observation of the length of emotion to get rid of the extremely long and short fixations. The setup of these two is limited by knowledge of physiological duration of fixation and is to be set in milliseconds.
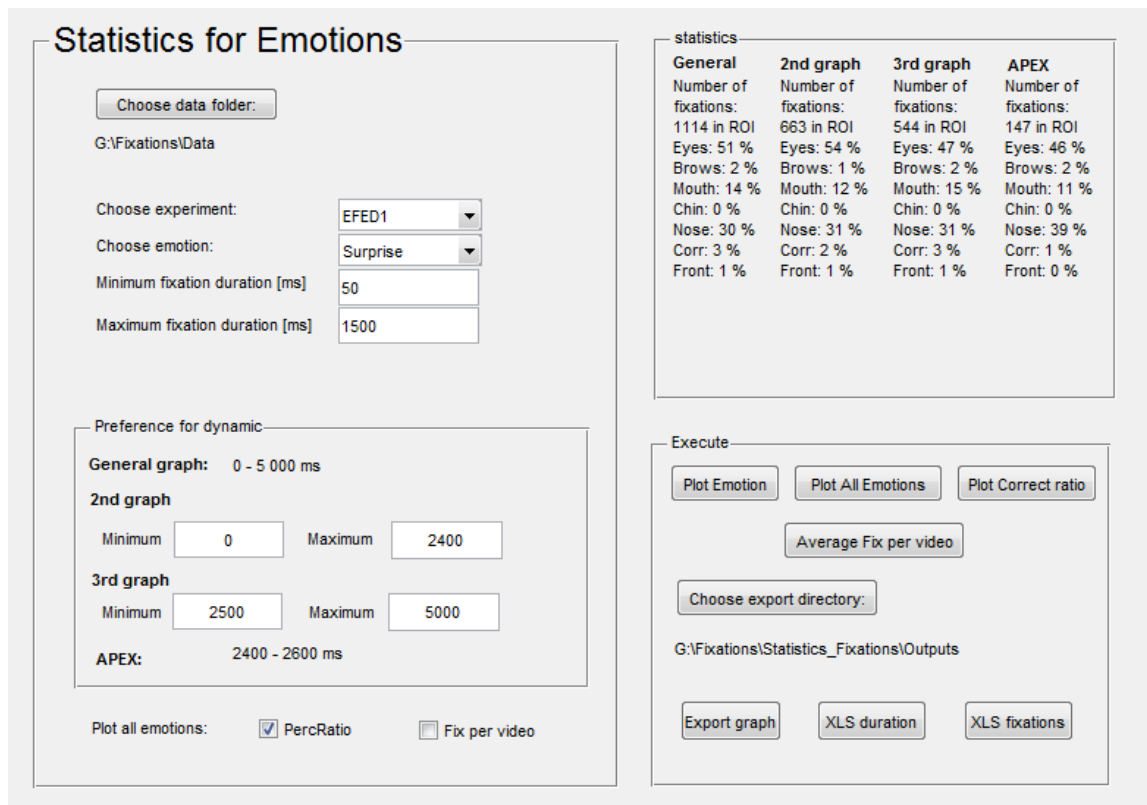
Figure 6.1: Executive interface for statistics on fixations.

There is a separate panel *Preference for dynamic.* This one is used only for analysis of dynamic sessions. The length of the video stimuli is 5 s. The idea is to see whether there is a difference in fixations (number and length) between certain time intervals of the video stimuli. The **General graph** informs that the statistics will be done for the whole video, the **2nd** and **3rd graph** allow to choose the minimum and maximum (interval) time stamp of the video to make the statistics. Finally, an **APEX** (an explicit time when the emotion is evolved the most) is automatically set in the middle of the video. The *statistics* panel is tightly connected to this panel. Each column's label corresponds with the label in this panel and shows numeric statistics on fixations. At the bottom left, there are check boxes with the options for *Plot all emotions* (*PercRatio* and *Fix per video*). Difference between these two is in plotting the distribution of number of fixation. As the label indicates, first one is to plot the percentage, the other one plots the number of fixations per video. Only one of these has to be ticked off to proceed in plotting the graphs.

An execute panel consists of eight buttons in total. One button to choose an export directory, one button to save the particular graph in this directory as *'graph(efed)_(emotion)_(limitdwn)_(limitup)ms.bmp'*, four executive buttons for graphic and numeric outputs (*Plot Emotions*, *Plot all Emotions*, *Plot Correct ratio*, *Average Fix per video*) and two to export *.xls* files on the data (*XLS fixations*, *XLS durations*). These call on a particular functions that are described along with the essential input and example of the output.

6.2.2 Functions

Plot emotion

This button calls on a ***HistoEmotions.m*** function. There are seven inputs required to execute this function. All of these are connected with the GUI. Table 6.1 describes the inputs. This function works for both static and dynamic data, but *mini* and *maxi* inputs that are meant especially for videos, for static sessions they are automatically fixed on 0 and 5000.

Table 6.1: Inputs for HistoEmotions.m

Input	Description	Example
path	Path to the directory with EventFix data	'G:\Fixations\Data'
emotion	Particular emotion for statistics	Neutral
mini	Start of the interval in ms (only for video)	1000
maxi	End of the interval in ms (only for video)	2800
efed	Experiment	'EFE1'
limitdwn	Minimum duration of fixation in ms	50
limitup	Maximum duration of fixation in ms	1500

Due to the setup of the path to the data structure and choice of the experiment, the proper *EventFix* is loaded. Then the program itself runs through every subject and every trial and searches whether the field *Nature* contains the same emotion as the input. If the match is found then a matrix (13 x 5000) from *FixInVid* field is loaded. At this point a cut is made for the chosen interval in the video. Since the choice of the time stamp might be cutting a fixation itself apart, which would for sure lead to the wrong idea of the length of that particular fixation, there is a condition to check for the real start of the fixation that is cut and the whole length of it is considered. The interest for statistics is laid on the ROIs and that is the reason why only first nine rows are considered to be looked over for the fixations in the matrix. If the fixation is found, a comparison to the *limitdwn* and *limitup* is done. If all of the conditions are satisfied, the fixation is accounted along with its duration. In the end, the right and left eye are considered as one ROI as well as the eyebrows, leaving us with only 7 ROIs.

There are three outputs to this function (Table 6.2). The *statistics* is connected to the *statistics* panel to show the information about the fixations (total number of fixations and percentage of fixations in each ROI). By pushing ***plot emotion*** button, a pop-up window with graphic indication of statistics for fixations and average duration of one fixation in each ROI for the chosen emotion appears (Figure 6.2). If the dynamic experiment is chosen, the function runs four times in order to count with all of the possible intervals set in the *Preference for dynamic* panel of the interface.

Table 6.2: Outputs for HistoEmotions.m

Output	Description
statistics	Indicator for total number of fixations and percentage in each ROI
VidInd	Index of the trial for particular emotion on the position (i, k), i for a subject, k for index
NbFx	Sum of the fixations on the (i, k), i for a subject, k for index
Graph	Graphical output to show distribution of number of fixations in each ROI and average duration of 1 fixation for chosen emotion.
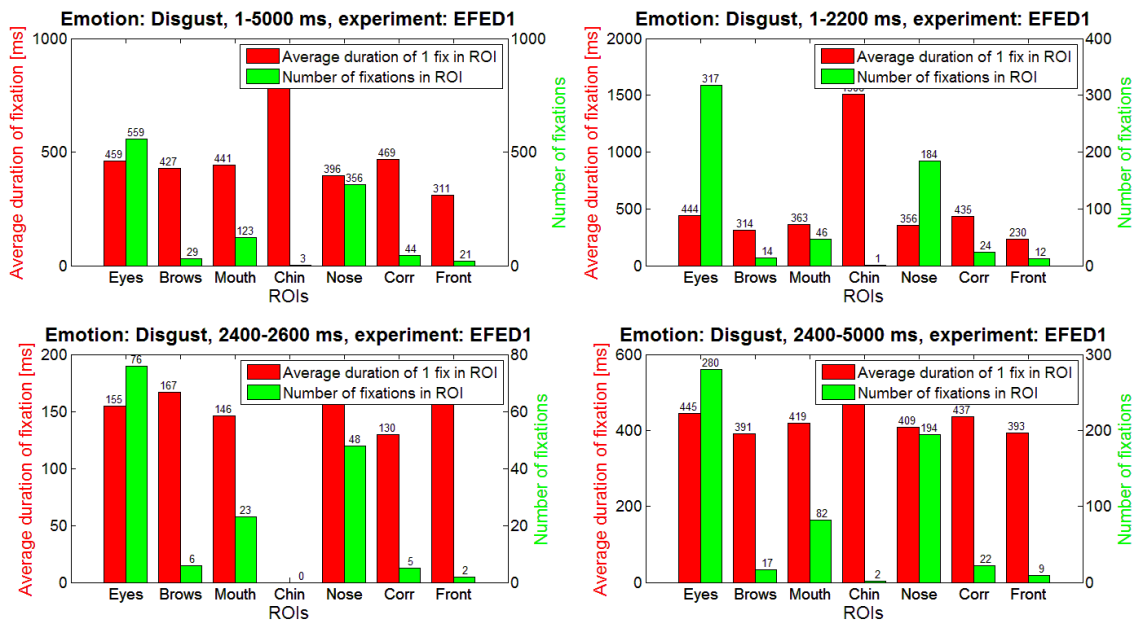
Figure 6.2: Graph for distribution of fixation in ROIs for Disgust.

Plot All Emotions & XLS fixations

Both of these buttons call on ***AllEmotions.m*** function. There are nine inputs required to execute it (Table 6.3). It is based on the same idea as the previous function but more detailed. Difference between the two buttons (*Plot All Emotions* and *XLS fixations*) is in the input *export*. For the first button it is set to a value of 0, for the latter it is set to 1. The value then decides which part of the function will be executed.

Fix per video and *PercRatio* check boxes are linked to the check input. If the first one is ticked off, the *check* is set to value of 1, if the other one is ticked off, it is set to 0. The program runs just like the previous one but for all of the emotions. This leads to creating a structure named *all* with fields *N, F, D, S,* and *G*. Each of those contains a set of number of fixations in concerning ROIs. Then for the graphical output, either a number of fixations per video is computed simply by dividing the total number of fixations in

ROI by the number of stimuli, which differs per emotion, or a percentage is computed and considered as y axis (**Chyba! Nenalezen zdroj odkazů.**).

Table 6.3: Inputs for the AllEmotions.m

Input	Description	Example
path	Path to the directory with EventFix data	'G:\Fixations\Data'
way	Path to the directory to save the .xls file	'G:\Fixations\Output'
mini	Start of the interval in ms (only for video)	1000
maxi	End of the interval in ms (only for video)	2800
efed	Experiment	'EFE1'
limitdwn	Minimum duration of fixation in ms	50
limitup	Maximum duration of fixation in ms	1500
export	Logical value to execute .xls export (1)	0
check	Logical value to choose the y axis of the graph	1

By executing the button *XLS fixations*, three .xls files are created. There are three structures initialized (*s, v, t*) in order to save proper data. As the function runs through each emotion it saves information about the number of fixations in each stimuli for each subject, as well as the index of the stimuli and the real name of the stimuli. These are saved to the directory that is set in the GUI as the export path under a name *Experiment_Output_limitdwn_limitupms.xls*.
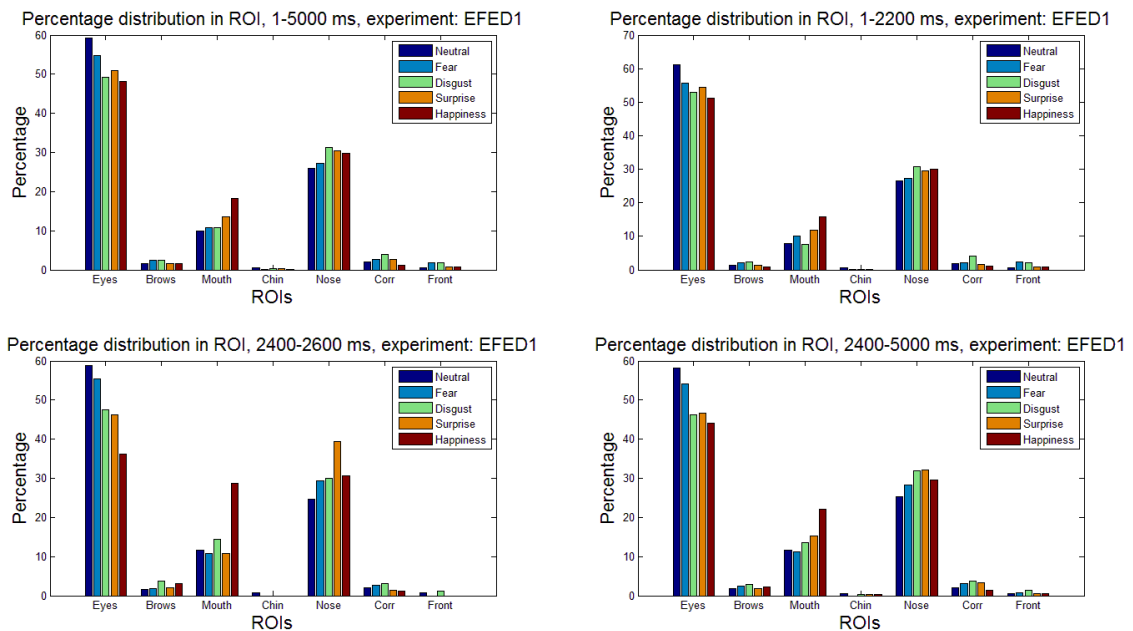
Figure 6.3: Percentage distribution in ROI for all emotions.

Table 6.4: Outputs of AllEmotions.m

Output	Description
Graph	Distribution of fixations in ROIs between emotions
Number of fixations	.xls with a sheet per emotion, first column indicating a subject, others number of fixations in each stimuli.
Video index	.xls with a sheet per emotion, first column indicating a subject, others index of particular stimuli
True Name of video	.xls with a sheet per emotion, first column indicating a subject, others true name of particular stimuli

Plot Correct ratio

The Plot Correct ratio button executes correctratio.m function. There are only two inputs required: path and efed (Table 6.5). This function compares two fields: real nature of the stimuli (*Nature*) with the actual answers to the recognition of the nature of the stimuli (*AnswerStatus*). The right answers for each emotion are added and then divided by total number of the videos with that particular emotion.

Table 6.5: Inputs for the correctratio.m

Input	Description	Example
path	Path to the directory with EventFix data	'G:\Fixations\Data'
efed	Experiment	'EFE2'
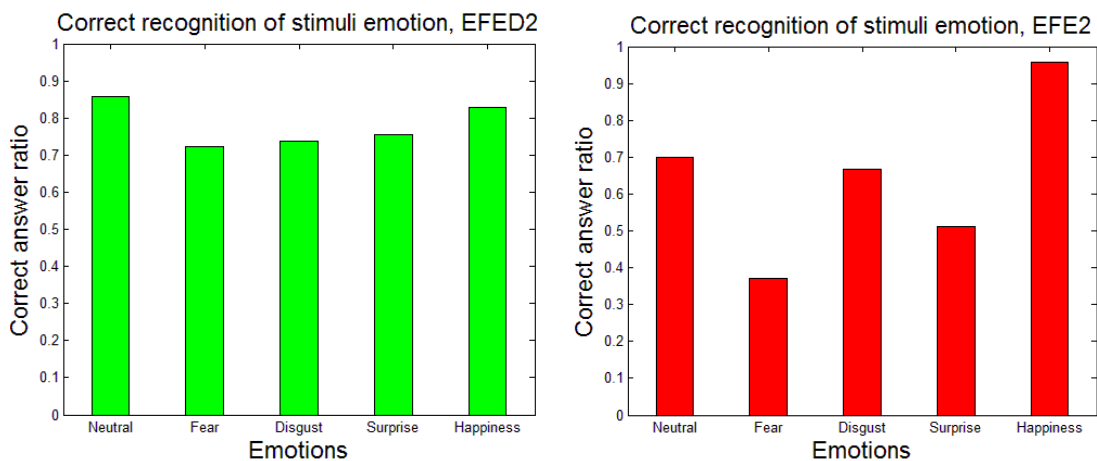
Figure 6.4: Correct recognition ratio for EFE2 and EFED2.

If *efed* is set to any of the first session a warning window pops up to inform that this function runs only either for EFE2 or EFED2. The outputs are shown in Figure 6.4.

Average Fix per video

The *Average Fix per video* button executes *FixInVid.m* function that runs on the very same principal as the previous functions. The difference is that it counts the number of fixations for the stimuli with the same name (*TrueName*) for each emotion, no matter the subject. The final output (Figure 6.5) shows the average number of fixations per stimuli for each emotion in a given experiment.

Table 6.6: Inputs for the FixInVid.m

Input	Description	Example
path	Path to the directory with EventFix data	'G:\Fixations\Data'
mini	Start of the interval in ms (only for video)	1000
maxi	End of the interval in ms (only for video)	2800
efed	Experiment	'EFE1'
limitdwn	Minimum duration of fixation in ms	50
limitup	Maximum duration of fixation in ms	1500
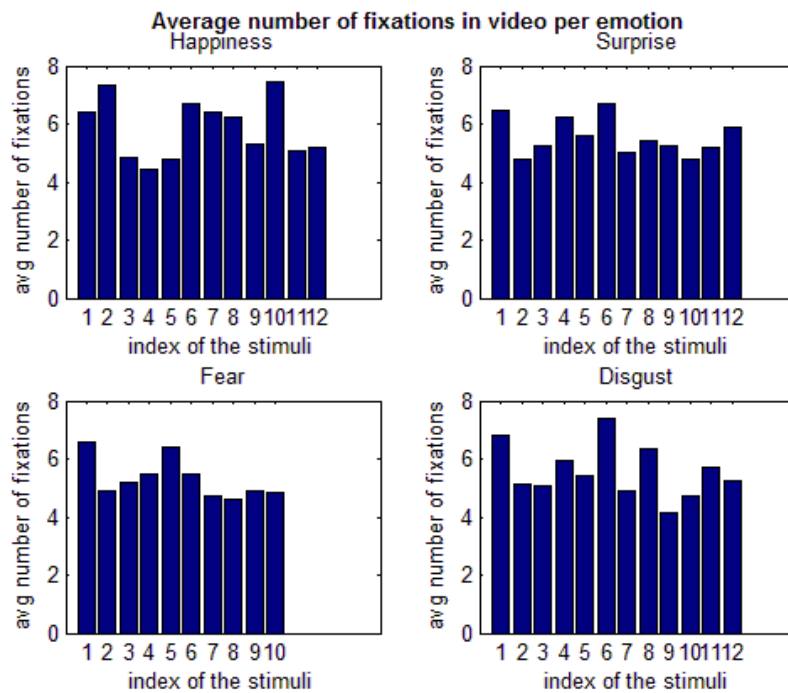
Figure 6.5: Average number of fixations of length 50 – 1800 ms in video per emotion for EFED1.

XLS durations

The *XLS durations* button calls on **XLSexportDuration.m** function. The output .xls file serves as the input for other functions to show the distribution of the length of the fixations. The structure of each sheet is strictly given, as follows: first column gives the

information about the subject (one row per subject), each cell is filled with the duration of fixation. Length of rows differs by the number of fixations.

Table 6.7: Inputs for the XLSexportDuration.m

| Input	Description	Example
path	Path to the directory with EventFix data	'G:\Fixations\Data'
way	Path to the directory to save the .xls file	'G:\Fixations\Output'
efed	Experiment	'EFE1'
limitdwn	Minimum duration of fixation in ms	50
limitup	Maximum duration of fixation in ms	1500

For this study, the setup is to sort the durations by emotions and ROIs (example: D1 – disgust on eyes, S3 – surprise on mouth, etc.). The resulting file is saved to the given export directory and the name is *Experiment_durations_limitdwn_limitupms.xls*. These *.xls* files are used to create histograms for the duration of the fixations.
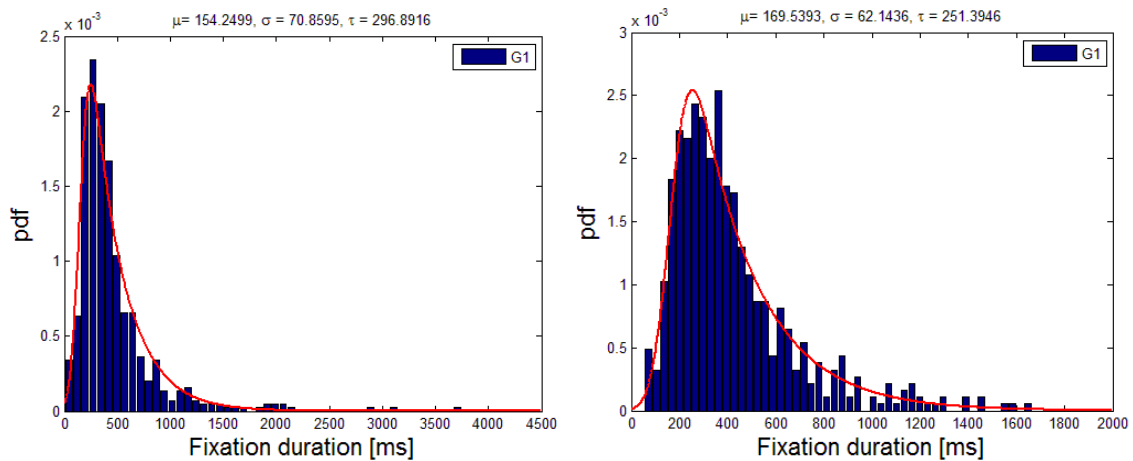
Figure 6.6: Histograms of distribution for fixations on eyes in happiness (EFED1).

Resulting histograms with the Gaussian fit distribution are shown in Figure 6.6. The symbol µ then stands for the mean value, σ for standard deviation and τ for skewness. The histogram on the left is the source of the idea to cut the extremely long and short fixations. The histogram on the right then shows the change in the distribution without the faulty fixations.

6.3 Statistics conclusion

As the graphs show there are not many significant differences within the fixations and the emotions. Three ROIs show the biggest importance – Eyes, nose, and mouth. The interesting fact is nose ROI. It is considered as a neutral region of interest in case of emotion, but the experiment show that it is fixated on during dynamic as well as static stimulation. The assumption is that the nose is the center of the stimuli so that eyes fixate there to gather as much information as possible (not only emotional, but facial features, movements, etc.).

For the video stimuli it might be interesting to study the preapex phase and afterapex phase of the video. The reason for this is that preapex is considered as a neutral emotion because of the state of evolving of the certain emotion. The afterapex is considered the opposite. This basically implies that there should be difference between these two. As the picture for all emotions shows the percentage of distribution in each ROI, happiness shows a significant change in gazed ROI – a growth of fixation on mouth on apex.

Interesting results shows the ratio for recognition of the emotion. As the graphs (Figure 6.4) show, the static stimuli do not show good ratio of correct answer overall but there is very good ratio for happiness even for static stimuli. The worst emotion to recognize is fear with only 40 % recognition. For the dynamic stimuli the ratio for every emotion is around 80 %. This leads to the conclusion that the dynamic stimuli are in fact easily recognizable.

The histograms for distribution of the duration of fixation revealed mistakes in acquisition and for further study the extremely long (≥ 1800 ms) and short (≤ 50 ms) fixations were removed from the study.

As for the number of fixation in ROI. My presumption was that it would be more obvious to recognize the emotions by the gaze in the regions of interested but it seems that there are very similar patterns of exploration of the face. In my opinion this is due to fact that the face is not an "average" model to observe just the emotion but the faces features and other distracting moves affect these results.

7. ERP extraction

Given EEG raw data format in *.*vhdr*, *.*eeg* and *.*vrmk*. The EEG data used for this work is already synchronized with eye tracking data (*.*asc* format) with a software GazeEEG synchro to create data sets in asc.eeg, asc.vhdr and asc.vrmk formats. These data sets consists both EEG data and eye tracker data along with markers concerning eye movements, blinks and fixations. Data set consists of total 71 channels, nominally, 64 EEG channels, 2 Mastoid channels, 2 EOG channels concerning vertical and horizontal eye movements, 2 channels concerning eye saccading and blink channel.

The structure of data processing is illustrated in Figure 7.1. Certain steps are described in details further.
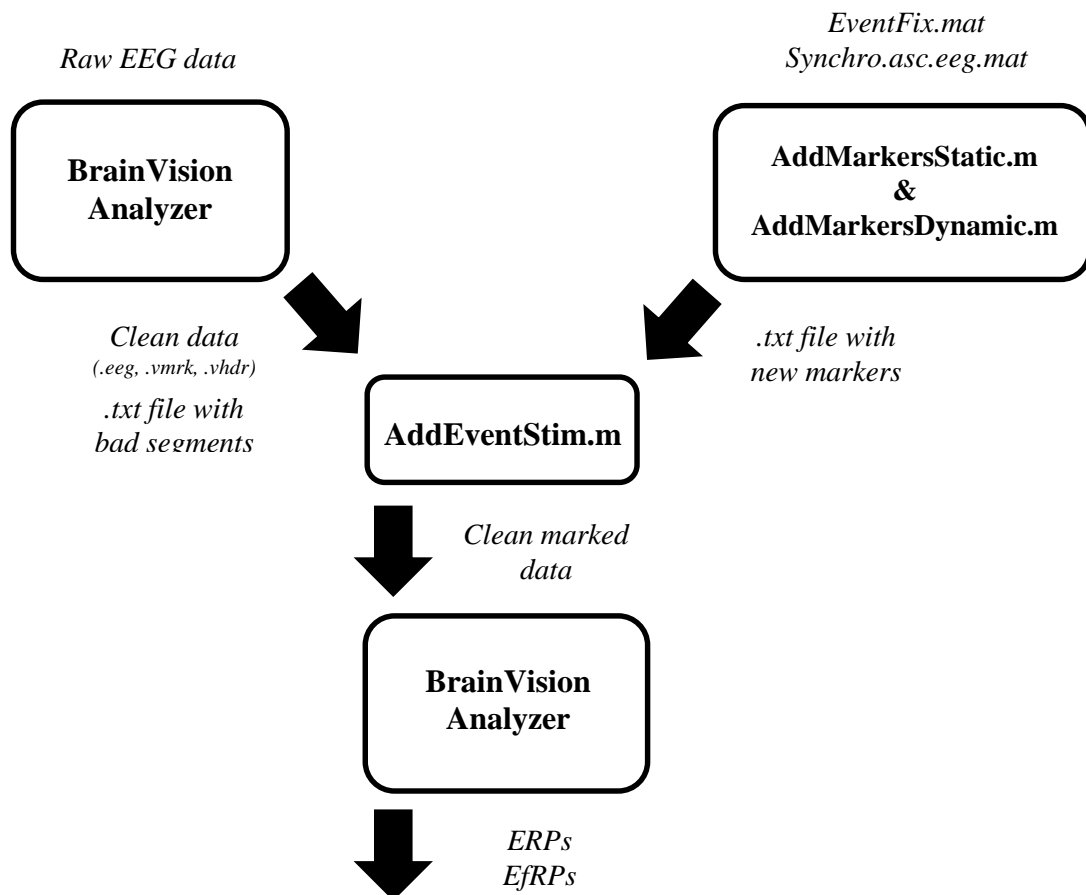

Figure 7.1: Schematic overview of ERP extraction

7.1 Signal preprocessing

All the data sets were uploaded to BrainVision Analyzer 2.1 and these certain pre-processing steps were made:

Filter → Segmentation → Artifact rejection → Ocular correction → Baseline correction

- **High-pass IIR filter** at 0.1 Hz for removal of slow drift (sweating, slow body movements, etc.).
- **Low-pass IIR filter** set up to 70 Hz to remove high frequency content. The IIR filters are implemented as phase shift-free Butterworth filters.
- **Notch filter** at 50 Hz to eliminate interference from the electricity network. The notch filter has a bandwidth of 5 Hz which is symmetrical around the set notch frequency.
- **Segmentation,** the marker time locked on the onset of video/image is labeled S 30. The segments are cut in intervals 500 ms before the onset and 5000 ms after.
- **Artifact Rejection** to manually mark non-stereotypical artifacts such as bursts of EMG activity, rare non-EEG glitches across all channels, whole-body startle reactions and other artifacts.
- **Independent Component Analysis Ocular Correction (ICA)** in semiautomatic mode in order to overcome losing trials contaminated by EOG artifacts and have control over component selection.
- **Baseline Correction** of the segments. Mean subtraction on the interval <-200, 0> ms.

7.2 Advanced preprocessing methods

ICA is stochastic mathematical method to separate pure signals at stationary positions (here EEG electrodes) from signals propagated through all detectors. The key of separating this signal mixture is in so called unmixing matrix. The data matrix formed as channels x samples multiplied with unmixing matrix preserves as transformation into activations. Activations are also formed as matrix where rows represent component and column represent samples (Figure 7.2). The activation component is basically linear sum of weighted channel activations. Even the number of independent components is unknown its restricted by the number of electrodes, since its only possible to decompose N electrodes into linearly weighted sum of N components. The unmixing proces can be afterwards done in a reversed manner so that activation matrix is multiplied with inverse unmixing matrix. Rows of inverse unmixing matrix contain relative weights and polarities of of the back-projections from each component to each electrode. ICA is aiming for finding unmixing matrix so that it has maximal indpendence across all components. The search for maximally independent unmixing matrix is basically searching for global

maximum in landscape of potential unmixing matrices. It procedes as stepwise optimization process with stochastic gradient ascent limited by number of steps, but stops as soon as global maximum is found even when the step number limitation is not reached. [56], [57]
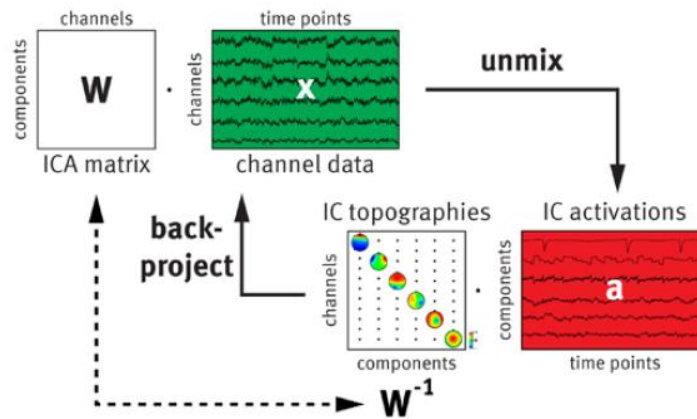
Figure 7.2: Schematic flowchart of ICA unmixing and back-projecting (source [57])

ICA implies maximum independence of two variables so that distributions or probability density functions of these two random variables are completely unrelated. While the independency is not stated only as lack of correlation, but involves all moments of distribution (not possible in real life), it was stated that the computation based on fourth moment, known as kurtosis, is sufficient. Kurtosis is one of measure of non-Gaussianity of distribution. This leads to constraint that ICA can succesfully unmix only non-Gaussian signals. Therefore it fits into box of EEG analysis whose signals has super-Gaussian distribution. [57]

Ocular components have characteristic patterns in both their time courses as well as their topographies which can be used as selection criteria. The algorithm implemented in BrainVision Analyzer 2.1 is a specialized version of the ICA transformation which identified and pre-selects components with time-courses that are potentially associated with eye movements and blinks. [57]

The steps of ICA transformations used for this experiments in BrainVision Analyzer interface are:

1. Blink marker placement: We have the blink channel and markers from eye tracker, the S1020 marker is used to recognize start of the blink. In other cases the software offers two algorithms to detect blinks (Mean Slope algorithm of Gratton et al. (1983) and the Value Trigger algorithm).
2. ICA decomposition: all EEG channels are fed into ICA, previously marked bad segments are neglected by ICA. Set to compute ICA matrix from all electrodes.

3. Identification of "ocular" components: time intervals limited by blink markers are used to indentify components of VEOG activity. All data is used to indentify components related to HEOG.

4. Removal of "ocular" components: Components selected for rejection are marked in red. The interactive view is opened (Figure 7.3) to changes and fine-tuning. Blue intervals mark the blink period. The table in the upper right corner lists the criterion score of all components for VEOG and HEOG activity and enables to remove or retain the components. Green components will be kept, red removed. Below table there is topographic mapping view of the component currently selected.

Figure 7.3: Interactive view of ICA with components

The option to show original data with the correction is also available, example of the view is shown in Figure 7.4. The signal in red is the original data, black ones are data after correction. All these interactive features enable to properly check for the ocular artifacts and check the outcome of the method.
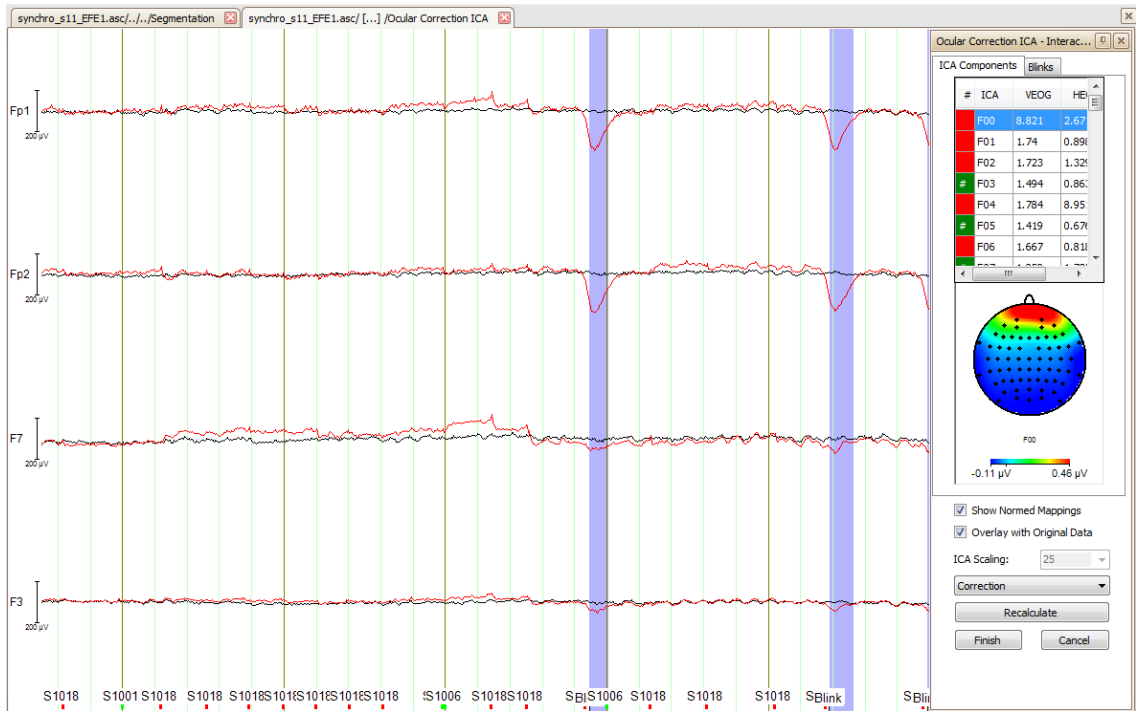
Figure 7.4: Interactive ICA view showing correction with Original Data – blink
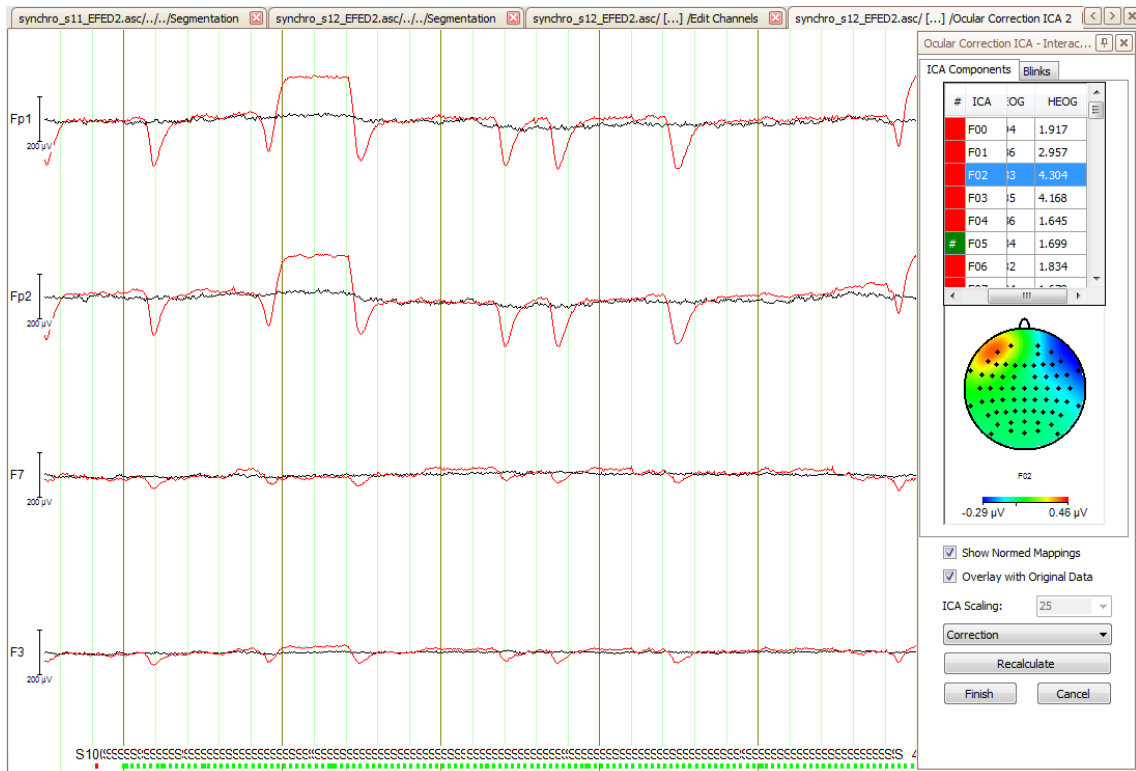

Figure 7.5: Interactive ICA view showing correction with Original Data – both vertical and horizontal eye movements

7.3 ERP and EfRP extraction

The clean EEG data need to be connected with the data from Eye tracker in order to add new triggers for the subtraction of evoked potentials.

7.3.1 Markers

EEG data set consists of EEG file, header file and marker. The latter includes markers concerning triggers (0, 256) and information from eye tracker labeling certain events such as image display, blinks, eye saccades and fixations (≥ 1000).

As for the image/video onset labeled by marker S 30 and actual display labeled S 1001 (image) and S 1004 (video), we studied whether this delay is not remarkable and cannot affect further extraction of evoked potentials. Time difference between these two markers was tested for each onset and the delay for the whole data set for EFE1 (1888 trials) oscillates between -1 and 2 ms. This will not affect data for our purpose and therefore marker S 30 is used as the onset marker for segmentation and ERP extraction.

In a purpose of extracting certain evoked potentials concerning corresponding stimuli, creation of new markers was required. All of the possibilities to classify the events were considered leading to three main ones: time of fixation, emotion and localization (Figure 7.6). Whole range of dictionary is shown in Table 7.1. With use of this table it is possible to mark fixations combining all the conditions.

Table 7.1: Dictionary of new markers

2		X		X		X	
		Time		**Emotion**		**Localization**	
	Static	0	Any	0	Neutral	0	Any
		3	Fix	1	Fear	1	Eyes
	Dynamic	1	Preapex	2	Disgust	2	Eyebrows
		2	Afterapex	3	Surprise	3	Mouth
		3	All	4	Happiness	4	Chin
				5	Any	5	Nose
				6	Distracteur	6	Corr
						7	Front

Two programs to create a .txt file with new markers were created along with purpose to add markers in a data structure for both static (***AddMarkersStatic.m***) and dynamic (***AddMarkersDynamic.m***) experiments. Both of these require certain files to be executed: *synchro_(subject)_(experiment).asc.eeg.mat* (*EegAcq* data structure) and *EventFixStatic.mat* or *EventFixDynamic.mat* (*EventFix* data structure).

EegAcq structure contains all synchronized information from eyetracker, EEG data and events. To find a corresponding timestamps for onsets of image/video *EegAcq.Events.Triggers* corresponding with marker S 30 is used. *EventFix* structure is then used to search for additional information. Information about emotion is given by

field *Nature*, information about location is in the field *Roi* and finally the information about timestamp is in a *Tab* (*n*, 1), where *n* indexes the fixation.
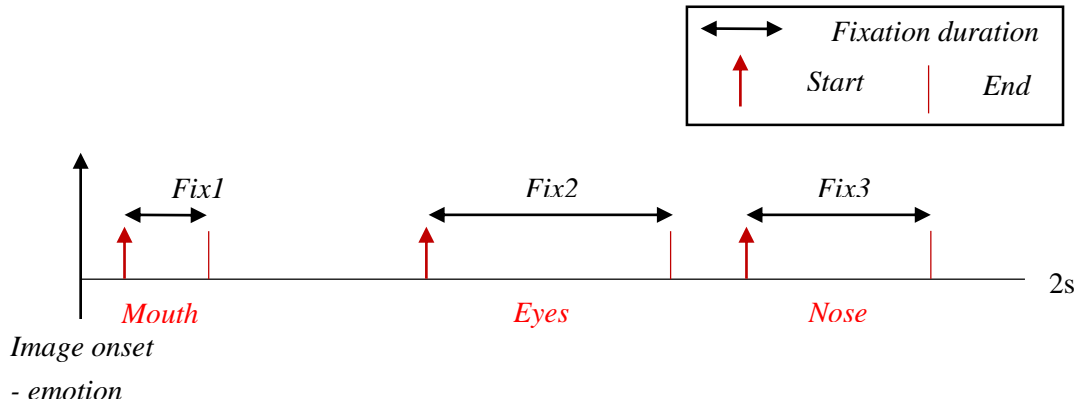

Figure 7.6: Schematic view on considered conditions for static session

Another conditions were applied concerning previous study of fixations. Only fixations with the length in an interval from 50 to 1800 ms are considered. Also fixations out of the regions of interest are left out. For the data from dynamic session, condition to decide whether the fixation appeared before or after apex of video stimuli is added. For this purpose, apex is set to a point of Onset + 2200 ms.

Example of filling the Tab field is shown in Figure 7.7. First, third and fifth fixations appear outside of regions of interest, second fixation is too long. That is why these are filled with zeros. By decoding the fourth fixation with the help of the Table 7.1, it is fixation in a video of neutral emotion, on nose appearing after apex. Eight numbers are combinations of all of the possible markers for these conditions.

EventFix.EFED1.s13(1, 21).Tab <12x5 double>

	1	2	3	4	5
1	366960	367350	370062	370793	371375
2	414	443.8000	443	421.8000	498.7000
3	296.6000	315.5000	357.5000	324	311.4000
4	381	2697	709	557	320
5	0	0	0	2350	0
6	0	0	0	2300	0
7	0	0	0	2355	0
8	0	0	0	2305	0
9	0	0	0	2250	0
10	0	0	0	2200	0
11	0	0	0	2255	0
12	0	0	0	2205	0
13					

Figure 7.7: Example of added markers in Tab field.

The final output is a text file *synchro_(experiment)_(subject)_fix.txt* (Figure 7.8) that is exported by the function ***SaveCellToFile.m*** and updated data structure *EvenFix* by new field *Onset* and *Tab* field contains the markers for each fixation.

```
40     Happy               54316
350    fix                 54754
340    fixHappy            54754
351    fixEyes             54754
341    fixHappyEyes        54754
150    Preapex             54754
140    PreapexHappy        54754
151    PreapexEyes         54754
141    PreapexHappyEyes    54754
```

Figure 7.8: Example of .txt file structure (synchro_EFED1_s05_fix.txt)

As it is illustrated in a Figure 7.1, beside the clean data exported from BrainVision Analyzer and text file with new markers to execute *AddEventStim,* a *clean.txt* file with numbers concerning segments which has been considered as bad was created for all of experiments. Furthermore, raw data is required as a reference data to create new clean and marked data set. Finally an eventstim_fix directory is created with new **.vmrk*, **.vhdr*, **.dat* files alongside with a dictionary created for each experiment with the meanings and number of occurred events (Figure 7.9).

```
1017    flowFixationRight        1425
1018    flowSaccadeLeft          491
1019    flowSaccadeRight         1432
1020    flowBlinkLeft            30
1021    flowBlinkRight           24
2000    Neutral                  24
2010    Fear                     10
2020    Disgust                  12
2030    Surprise                 11
2040    Happy                    12
2060    Distracteur              48
2100    PreapexNeutral           72
2101    PreapexNeutralEyes       46
2103    PreapexNeutralMouth      8
2105    PreapexNeutralNose       18
```

Figure 7.9: Example of .txt dictionary (synchro_EFED1_s05_fix-synchro_s05_EFED1.asc_clean.dat.event.txt)

7.3.2   ERPs

Data set with new markers was uploaded to BrainVision Analyzer for particular study of evoked potentials. Firstly, a study on visual stimuli concerning emotions and static and dynamic stimuli, was conducted. The goal was to reproduce the experiment of Trautmann et col. (2013). [49]

New segmentation → Baseline correction → Average → Grand average

Recently created onset marker concerning emotion is used for the segmentation. Nominally, 2000 is for neutral, 2010 is for fear, 2020 is for disgust, 2030 for surprise, 2040 is for happiness. For each subject and each experiment, EEG data was segmented on these markers on the interval <-200, 1000> ms. Baseline correction was done on the interval

<-200, 0> ms. These segments had to be averaged for each subject and then a grand average was counted over all for static and dynamic session separately.

Midline electrodes (Fz, Cz, Pz, Oz, POz) were selected for representation of ERPs. For better resolution only latter three are shown in this overview. Figure 7.10 and Figure 7.11 show the response to the onset of the stimuli (picture/video). The green vertical line corresponds to time window of 200 ms, positive values are below the dotted baseline, negative are above. There are at least two major ERP waves to be identified: N170 and EPN. On the Pz electrode a LPP can be observed.
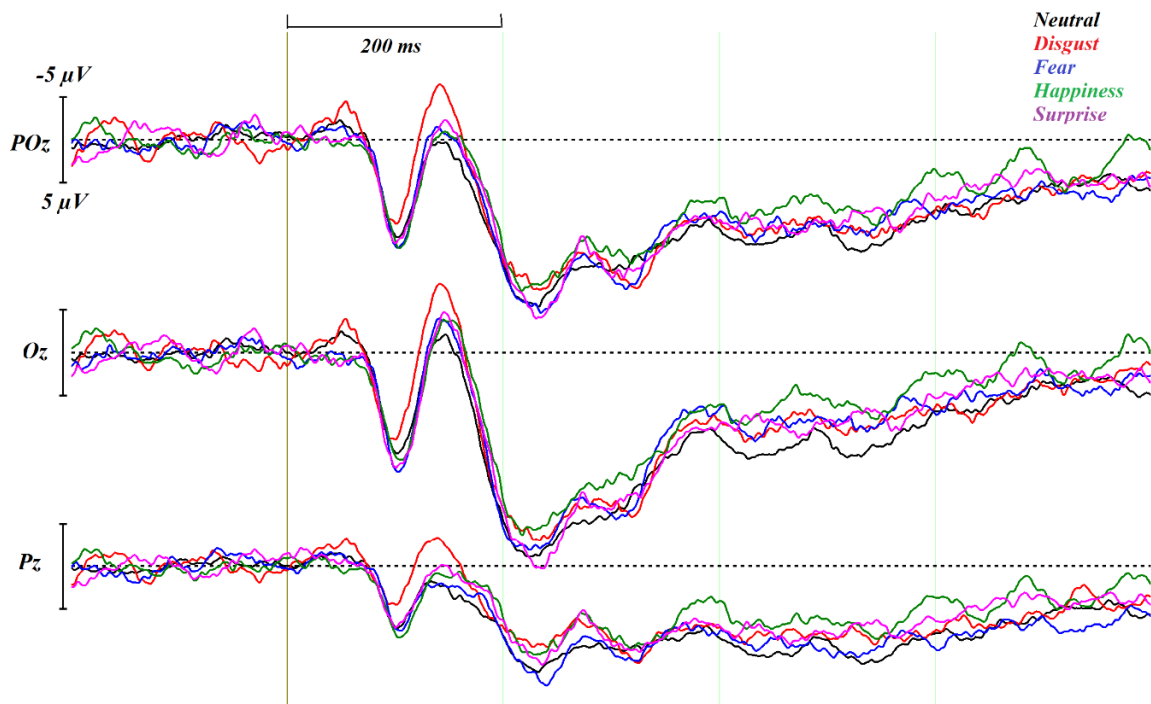

Figure 7.10: ERPs for EFE1 – static

As for the study of the emotion, the onset of the video is not very adequate due to the evolution of the emotion. The apex of the video is interesting part, but as the possibilities were studied, there is not a correct onset on the emotions that could be used as the common trigger. Topographic plots were done (for inspection of neurophysiologist) for all of the emotions with use of all of the electrodes to see whether there is a pattern in localization and the strength of the ERP (Figure 7.12). The scale had to be empirically set to <-4, 11> µV for the comparison due to the limitation of the software to normalize the different data sets.
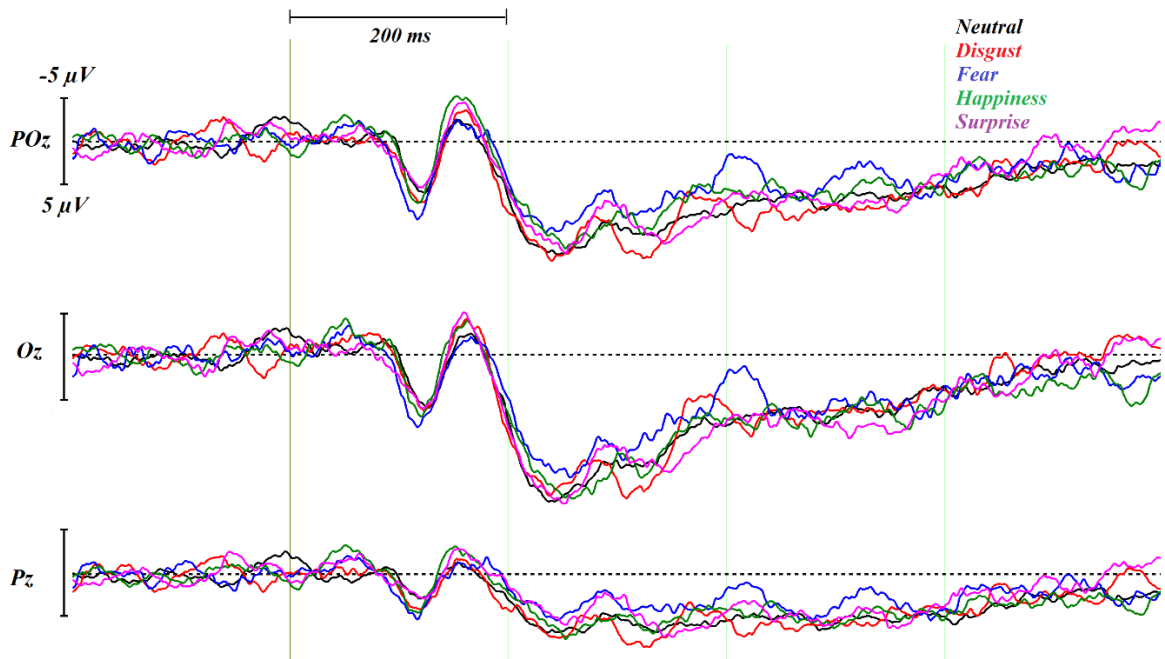
Figure 7.11: ERPs EFED1 - dynamic

The ERPs for each emotion for the static sessions are displayed for further comparison with the ERPs of the neutral emotion. The difference overlay was done as well as the topographic plot of the difference between these. Example for the disgust ERP (EFE1) is shown in the Figure 7.13.
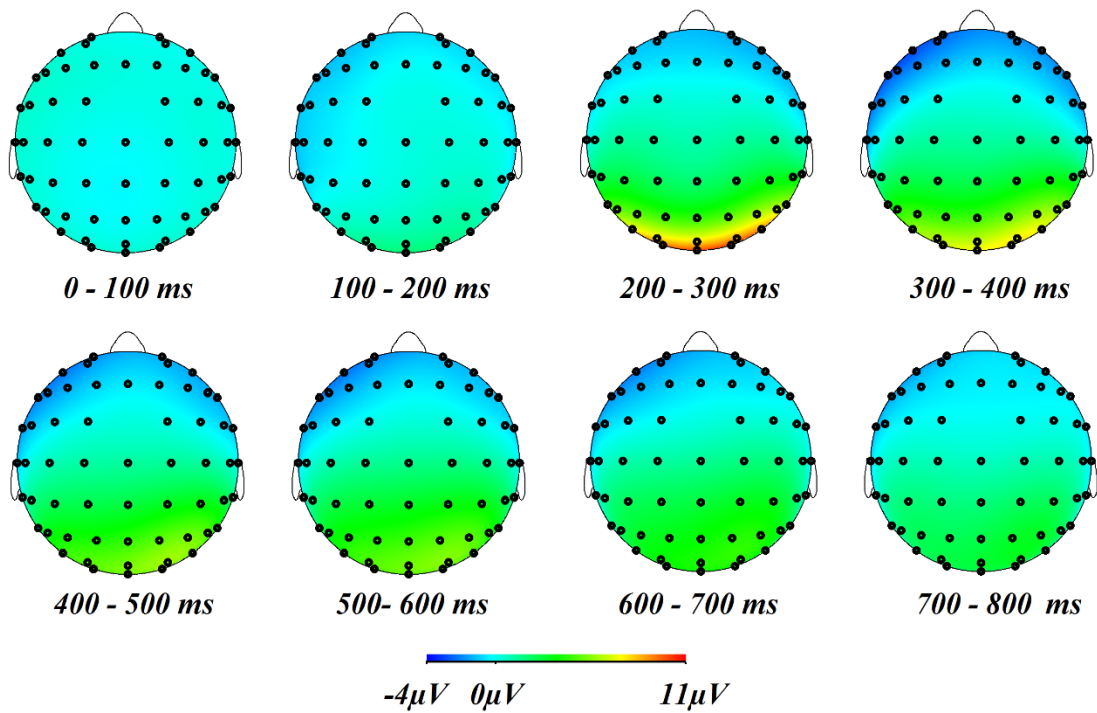

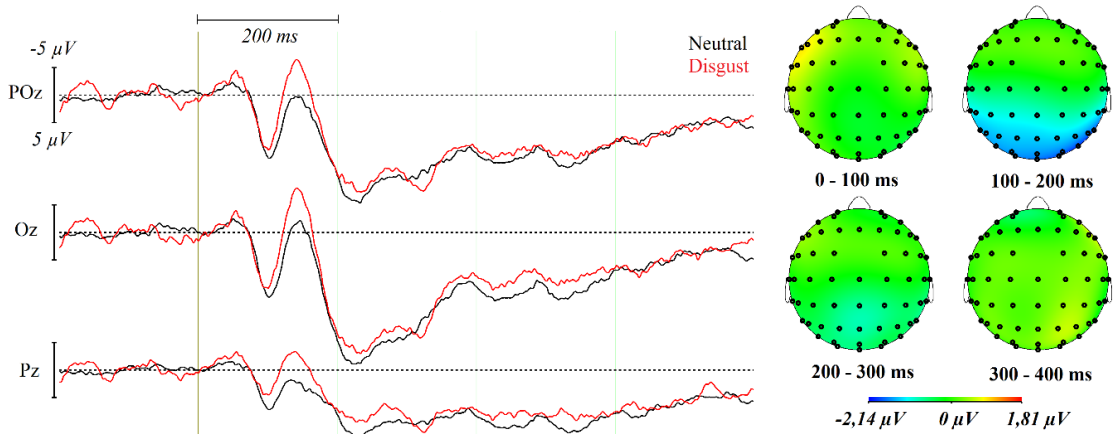**Figure 7.12: Topograph for ERP – disgust EFE1**

Figure 7.13: Difference in disgust and neutral emotion on midline electrodes and topograph.

7.3.3 EfRP

A brain response on the onset of the fixation in certain area for static session was studied (Figure 7.14) and each of the ROI has been compared to the EfRPs from the videos – preapex and afterapex (Figure 7.15). To obtain these, first, EEG data set with new markers had to be uploaded to BrainVision software by its I/O interface. Then, for each subject a new segmentation was done to cut out the response on each ROI. The segments were cut on the onset on interval <-200, 400> ms, but mean subtraction to get the baseline was counted on the interval <-200, -100> ms. The reason for this is the appearance of the spike response for eye saccade right before the fixation – onset for EfRPs.
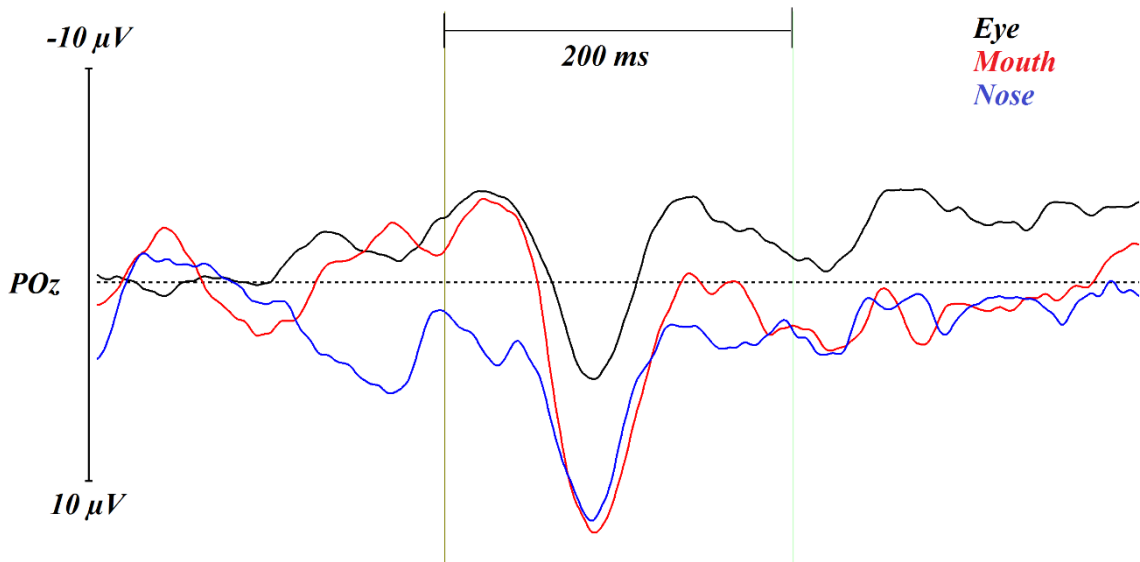
Figure 7.14: EfRP for static on eyes, mouth and nose EFE1

Three main ROIs were chosen for this: Nose, representing the neutral area in the face, mouth and eyes representing the area affecting the emotions most. Namely by

markers S 2351 (eyes), S 2353 (mouth), S 2355 (nose), has been used for static segmentation and S 2151, S 2153, S 2155 for the dynamic before apex and S 2251, S 2253, S 2255 for the dynamic after apex.

Topographs for all of the conditions above have been plotted plus comparison to the neutral ROI – nose, has been done as follows: each ROI – nose at a certain time stamp. For example: difference between eye and nose EfRPs on after apex. All of the outputs are in the appendix of the work.

Figure 7.15: EfRPs on eyes for static (black), dynamic before apex (red), after apex (blue) EFE2

Discussion and conclusion

This diploma thesis discusses the issue of joint analysis of eye tracking and electroencephalography. This approach is described as a research method to study an emotional response to a static and dynamic visual stimuli. A certain data processing steps had to be done to see the possible outcomes.
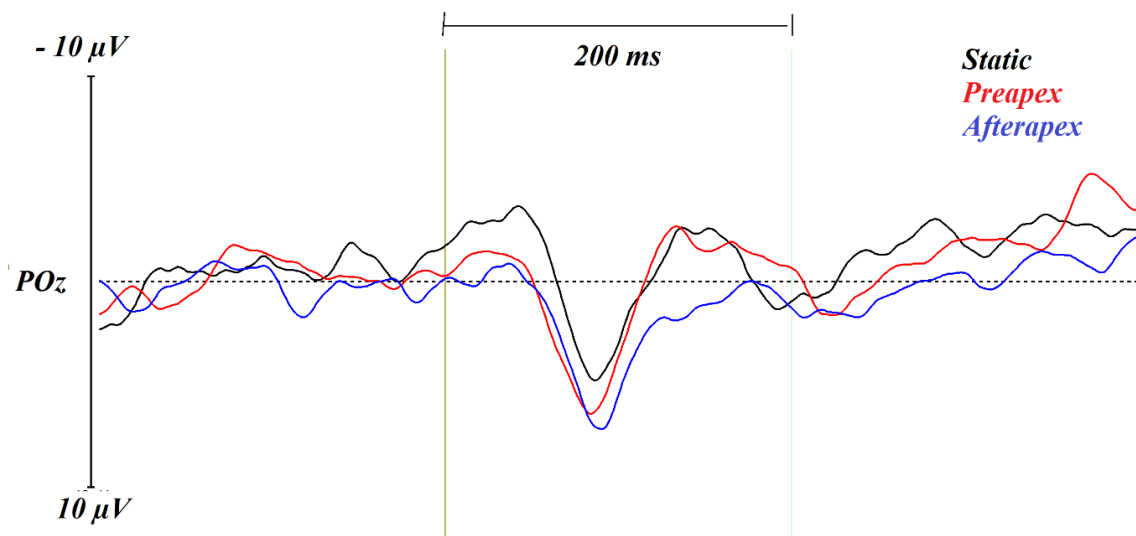
This work is divided into two main sections. First one provides background information for both techniques, EEG and eye tracking. The other one consists of description of this new experimental method, the experimental setup and protocol. Recorded data are described for better understanding of further processing and software development.

The coded programs and scripts (in a Matlab) for fixations enable to study the amount, duration and location of fixations in emotional facial expression. These help to provide ideas on the distribution of fixation in the face and a certain difference between emotions. They provide both graphic and numeric statistics. These programs have been described in details in chapter 6.2. A partial conclusion on fixations is described in chapter 6.3.

EEG data had to be preprocessed first, new markers had to be created and synchronized with the fixations in advance to ERP and EfRP processing itself. These steps have been done in BrainVision Analyzer and are described in chapter 7.

First idea to compare the ERPs for static and dynamic sessions was to extract ERPs on the onset of the image for the static and extract ERPs on the apex of the video for the dynamic. Similar experiment was realized by Trautmann et col. and by Recio. [49], [58] Obtained results were not showing any particular pattern in response as expected. After further observation, the conclusion that this was due to the fact that the video is ongoing and it is not possible to visually detect the trigger as it is in fact the apex. The resulting ERP on the apex was very random curve due to the overlay of responses at different times. Perhaps a more global method to extract ERPs for dynamic stimuli would provide better results because of the continuous stimulation. This is also a reason why the comparison between static and dynamic stimulation could not be done for the ERPs. In fact, it can be stated that the emotion is differentiated almost always during the observation of dynamic face. On the opposite hand a picture showing emotion does not provide enough information for the emotion to be defined. This statement is supported mostly by correct ratio graphs (Figure 6.4).

Interesting thing to do might be including the correct answers to emotion recognition from the statistics on fixations into ERPs and see whether the ERP for the emotion would change in some way, since for the static stimuli the recognition was

around 70 %. In fact, this approach was not included for this study, but since this information is already included it may be interesting to observe the results in further study.

Figure 7.14 shows EfRPs in different ROIs. After 200 ms, these responses become very curvy. This is a result of averaging a standard length of EEG signal. By cutting out 600 ms (200ms before the onset, 400 ms after) long signal, appearance of more than one response is possible but always at a different onset time. Perhaps segmenting the intervals due to their actual length would be more practical. Sadly, this could not be done in the BrainVision Analyzer interface due to its limitations.

Because of many possibilities to be considered and studied, this experiment is far from the end. With this work, EEG data are labeled with variety of markers that enables to study fixations in certain areas, fixations in visual stimuli expressing certain emotion or both of these conditions at the same time. This research is still ongoing and will be continued with new analysis at the Gipsa-lab laboratory from September 2015.

Bibliography

[1.] SALADIN, K. *Human Anatomy*. New York: McGraw-Hill, 2008. ISBN 978-0-07-294368-9.

[2.] Brain Anatomy. *Functional Area of the Brain* [online]. 2014 [cit. 2014-12-22]. Available from: http://brainanatomy.tk/tag/functional-area-of-the-brain

[3.] SIULY. *Analysis and Classification of EEG Signals*. Toowomba: 2012. Dissertation. University of Southern Queensland [cit. 2012-12-22]. Available from: https://eprints.usq.edu.au/23460/1/Siuly_2012_whole.pdf

[4.] Brain Basics: Know Your Brain. *National Institute of Neurological Disorders and Stroke* [online]. 2014 [cit. 2014-12-22]. Available from: http://www.ninds.nih.gov/disorders/brain_basics/know_your_brain.htm

[5.] GALLANT, T. Neuron Structure [online]. [cit. 2014-12-22]. Available from: http://kvhs.nbed.nb.ca/gallant/biology/neuron_structure.html

[6.] Neurons, Brain, Chemistry, and Neurotransmission. In: *NIH Office of Science Education/SEPA* [online]. [cit. 2014-12-22]. Available from: http://science.education.nih.gov/supplements/nih2/addiction/guide/pdfs/lesson2.pdf

[7.] EEG Electroencephalography. *StimulatingStuff* [online]. 2014 [cit. 2014-12-22]. Available from: http://neurologiclabs.com/home/about-ionm/eeg/

[8.] DUBOIS, M. L. *Action Potential: Biophysical And Cellular Context, Initiation, Phases, And Propagation*. New York: Nova Science, 2010. ISBN 9781616688332.

[9.] HADDAD, W. M. Q. HUI a J. M. BAILEY. Human Brain Networks: Spiking Neuron Models, Multistability, Synchronization, Thermodynamics, …. *Entropy*. 2014, no. 16, pp. 3939-4003.

[10.] SORNMO, L. a P. LAGUNA. *Bioelectrical Signal Processing in Cardiac and Neurological Applications*. Amsterdam: Elsevier Academic Press, 2005. ISBN 9780124375529.

[11.] NIEDERMEYER, E. *Electroencephalography: Basic Principles, Clinical Applications, and Related Fields.* [online]. Philadephia, PA, USA: LWW, 2004 [cit. 2014-11-15]. Available from: http://www.ebrary.com

[12.] DAVIDSON, R. J. D. C. JACKSON a C. L. LARSON. Human electroencephalography. In: CACIOPPO, J. T. G. G. BERNSTON a L. G. TASSINARY. *Handbook of Psychophysiology*. 2nd. New York, NY: Cambridge University Press, 2000, pp. 27-52 [cit. 2014-12-23].

[13.] SANEI, S. a J. A. CHAMBERS. *EEG Signal Processing* [online]. Chichester, England: John Wiley & Sons Ltd. 2007 [cit. 2014-11-12]. 13 978-0-470-02581-9. Available from: http://classes.engineering.wustl.edu/ese497/images/2/20/EEG_Book.pdf

[14.] Sleepwarrior. *Brain Waves & Brainwave entertainment* [online]. 2008 [cit. 2014-12-22]. Available from: http://www.sleepwarrior.com/wp-content/uploads/valovi-450x440.gif

[15.] en.wikipedia.org. *Electroencephalography* [online]. 2014 [cit. 2014-12-10]. Available from: http://en.wikipedia.org/wiki/Electroencephalography

[16.] GERLA, V. *Automated Analysis of Long-Term EEG Signals*. Prague: 2012. Doctoral Thesis. The Czech Technical University in Prague, Department of Cybernetics [cit. 2014-01-01]. Available from: http://bio.felk.cvut.cz/psglab/disertace/disertace-2012-02-29.pdf

[17.] BROSE. Topography. *Neuro Therapy Tacoma* [online]. 2015 [cit. 2014-12-28]. Available from: http://www.neurotherapytacoma.com/topography.php

[18.] BAILLET, S. J. C. MOSHER a R. M. LEAHY. Electromagnetic Brain Mapping [online]. 2001, pp. 14-21 [cit. 2014-12-09]. Available from: http://cogimage.dsi.cnrs.fr/hmtc/references/files/BailletMosherLeahy_IEEESPMAG_No.pdf

[19.] MALMIVUO, J. a R. PLONSEY. *Bioelectromagnetism - Principles and applications of bioelectric and biomagnetic fields* [online]. New York: Oxford University Press, 1995 [cit. 2014-11-15]. ISBN 978-0195058239. Available from: http://www.bem.fi/book/28/28.htm

[20.] XIZHENG, Z. Y. LING a W. WEIXIONG. Wavelet Time-frequency Analysis of Electro-encephalogram (EEG) Processing. *International Journal of Advanced Computer Science and Applications* [online]. New York: 2010, **1** (5). ISSN 2156-5570.

[21.] REY, H. G. M. AHMADI a Q. R. QUIROGA. Single trial analysis of field potentials in perception, learning and memory. *Current Opinion in Neurobiology* [online]. 2015, pp. 148-155 [cit. 2015-05-13]. ISSN 0959-4388. Available from: http://www.sciencedirect.com/science/article/pii/S0959438814002098

[22.] PURVES, D. et al. *Neuroscience* [online]. Sunderland: Sinauer Associates, 2001 [cit. 2014-12-12]. Available from: http://www.ncbi.nlm.nih.gov/books/NBK10991/

[23.] STERN, R. M. W. J. RAY a K. S. QUIGLEY. *Psychophysiological Recording* [online]. Cary, NC, USA: Oxford University Press, 2000 [cit. 2014-12-18]. Available from: http://www.ebrary.com/

[24.] PHUOS, H. T. et al. When viewing natural scenes, do abnormal colors impact on spatial or temporal parameters of eye .... *Journal of Vision*. 2012, **12** (2).

[25.] PANNASCH, S. J. SCHULZ a B. M. VELICHKOVSKY. On the control of visual fixation durations in free viewing of complex images. *Attention, Perception, & Psychophysics* [online]. 2011, **73** (4), 1120-1132 [cit. 2015-02-08]. Available from: http://link.springer.com/content/pdf/10.3758%2Fs13414-011-0090-1.pdf

[26.] DUCHOWSKI, A. *Eye Tracking Methodology: Theory and Practise* [online]. London (GBR): Springer, 2007 [cit. 2015-04-03]. Available from: http://www.ebrary.com

[27.] GLENSTRUP, A. J. a T. ENGELL-NIELSEN. Techniques Based on Reflected Light. *Department of Computer Science* [online].[cit. 2015-04-03]. Available from: http://www.diku.dk/~panic/eyegaze/node9.html

[28.] RICHARDSON, D. C. a M. J. SPIVEY. Eye Tracking: Characteristics And Methods, chap. 99. In: *Encyclopedia of Biomaterials and Biomedical Engineering*. 2. Informa Healthcare, 2008, pp. 1028-32.

[29.] ARDEN, G. B. a J. R. HECKENLIVELY. *Principles and Practice of Clinical Electrophysiology of Vision*. Cambridge, Mass: MIT Press, 2006. ISBN 9780262083461.

[30.] MERINO, M. et al. A Method of EOG Signal Processing to Detect the Direction of Eye Movements. In: *Sensor Device Technologies and Applications (SENSORDEVICES), 2010 First International Conference on* [online]. Venice: IEEE, 2010, pp. 100-05 [cit. 2014-10-15]. ISBN 978-1-4244-7474-5. Available from: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5632116&isnumber=5632098

[31.] Physiology Practical. *Electrooculography (EOG) with the Biopac recording system* [online]. 2013 [cit. 2014-15-11]. Available from: http://elte.prompt.hu/sites/default/files/tananyagok/physiology_practical/ch09s06.html

[32.] LANDA, L. et al. Event-related Potentials and Their Applications. *Acitvitas Nervosa Superior: Journal for Neurocognitive Research* [online]. 2014, **56** (1-2), 17-23 [cit. 2015-04-02]. Available from: http://www.activitas.org/index.php/nervosa/article/viewFile/171/193

[33.] TONG, S. a N. V. THANKOR. *Quantitative EEG Analysis Methods and Clinical Applications.* [online]. Norwood, MA, USA: Artech House, 2009 [cit. 2014-12-22]. Available from: http://www.ebrary.com/

[34.] QUIROGA, Q. R. et al. What can We Learn from Single-Trial Event-Related Potentials? *Chaos and Complexity Letters*. Nova Science Publishers, Inc. 2007, **2** (2/3), 345-63. ISSN 1555-3995.

[35.] BRANDEIS, D. a D. LEHMANN. Event-Related Potentials of the Brain and Cognitive Processes: Aproaches and Applications. Great Britain: Pergamon Press Ltd. 1986, **24** (1), 151-68.

[36.] HAJCAK, G. a A. MACNAMARA. Event-Related Potentials, Emotion, and Emotion Regulation: An Integrative Review. *Developmental Neuropsychology*. Taylor & Francis Group, LLC, 2010, no. 2, pp. 129-55. ISSN 8756-5641.

[37.] SUR, S. a V. K. SINHA. Event-related potential: An overview. *Industrial Psychiatry Journal*. Medknow Publications, 2009, **18** (1), 70-73.

[38.] JOYCE, C. et al. Tracking eye fixations with electroocular and electroencephalographic recordings. *Psychophysiology*. 2002, **39** (05), 607-18. ISSN 0048-5772.

[39.] BANERJEE, A. et al. Detecting eye movement direction from stimulated Electro-oculogram by intelligent algorithms. Coimbatore: IEEE, 2012, pp. 1-6.

[40.] KAMIENKOWSKI, J. E. et al. Fixation-related potentials in visual search: A combined EEG and eye tracking study. *Journal of vision* [online]. 2012, no. 12(7), pp. 1-20 [cit. 2014-11-22]. Available from: http://www.journalofvision.org/content/12/7/4

[41.] HAAG, A. et al. Emotion Recognition Using Bio-Sensors: First Steps towards and Automatic System. In: *Affective Dialogue Systems*, sv. MMMLXVIII. Springer Berlin Heidelberg, 2004, pp. 36-48. ISBN 978-3-540-24842-2.

[42.] EKMAN, P. Basic emotions. In: DALGLEISH, T. a M. POWER. *Handbook of cognition and emotion*. Sussex, U.K.: John Wiley & Sons, Ltd. 1999, pp. 45-60.

[43.] PLUTCHIK, R. *The Emotions: Facts, Theories and a New Model*. New York: Random House, 1962.

[44.] SMITH, E. et al. Electrocortical responses to NIMSTIM facial expressions of emotion. *International Journal of Psychophysiology*. 2013, no. 1, pp. 17-25.

[45.] ADOLPHS, R. Recognizing emotion from facial expressions: psychological and neurological mechanisms. 2002, pp. 21-62.

[46.] CREEL, D. J. Webvision: The Organization of the Retina and Visual System. In: *Visually Evoked Potentials* [online]. 2014 [cit. 2014-November-28]. Available from: http://webvision.med.utah.edu/book/electrophysiology/visually-evoked-potentials/

[47.] BRADLEY, M. M. a P. J. LANG. The International Affective Picture System (IAPS) in the study of emotion and attention. In: COAN, J. A. a J. J. B. ALLEN. *Handbook of Emotion Elicitation and Assessment*. Oxford University Press, 2007, pp. 22-46.

[48.] CALVO, G. M. L. NUMMENMAA a J. HYONA. Emotional and neutral scenes in competition: Orienting, efficiency, and identification. *Quarterly journal of experimental psychology*. Psychology Press, 2007, **60** (12), 1585-93.

[49.] TRAUTMANN-LENGSFELD, S. A. et al. The Perception of Dynamic and Static Facial Expressions of Happiness and Disgust Investigated by …. *PLoS ONE* [online]. 2013, **8** (6) [cit. 2015-02-04]. Available from: 10.1371/ journal.pone.0066997

[50.] BATTY, M. a M. J. TAYLOR. Early Processing of the six basic facial emotional expressions. 2003, pp. 613-20.

[51.] RECIO, G. *Perception of Dynamic Facial Expressions*. Berlin: 2013. Dissertation. Humboldt-Universität, Mathematisch-Naturwisseschafttlichen Fakultät II [cit. 2014-01-02]. Available from: http://edoc.hu-berlin.de/dissertationen/recio-guillermo-2013-03-07/PDF/recio.pdf

[52.] GOLD, J. M. et al. The Efficiency of Dynamic and Static Facial Expression Recognition. *Journal of Vision* [online]. 2013, **13** (5), 1-12 [cit. 2015-02-14]. Available from: http://www.journalofvision.org/content/13/5/23

[53.] LABAR, K. S. et al. Dynamic Perception of Facial Affect and Identity in the Human Brain. *Cerebral Cortex* [online]. 2003, **13** (10), 1023-33 [cit. 26-03-2015]. Available from: http://cercor.oxfordjournals.org/content/13/10/ 1023.full.pdf+html

[54.] CHRISTOFF, N. *Développement d'un logiciel d'analyse des fixations oculaires pour l'étude conjointe des signaux* …. Sofia: 2014. Projet de fin d'études. Universite Technique de Sofia, Filiere francophone de Génie Electrique et Informatique.

[55.] MEILLON, B. et al. Dynemo: A Corpus of Dynamic and Spontaneous Emotional Facial Expressions. In: *Dynemo* [online]. 2010 [cit. 2015-05-20]. Available from: http://membres-lig.imag.fr/adam/documents/LREC_Dynemo_MMC.pdf

[56.] DELORME, A. T. SEJNOWSKI a S. MAKEIG. Enhanced detection of artifacts in EEG data using higher-order statistics and independent component …. *NeuroImage* [online]. 2007, no. 34, pp. 1443-49 [cit. 2015-06-15].

[57.] PLANK, M. Independent Component Analysis - demystified! In: *Brain Products* [online]. 2014 [cit. 2015-May-20]. Available from: http:// pressrelease.brainproducts.com/independent-component-analysis-demystified/

[58.] RECIO, G. W. SOMMER a A. SCHACHT. Electrophysiological correlates of perceiving and evaluating static and dynamic facial emotional …. *Brain Research*. 2011, pp. 66-75.

[59.] POPELKA, S. A. BRYCHTOVA a J. BRUS. Advanced Map Optimalization Based on Eye-Tracking. In: *Cartography - A Tool for Spatial Analysis* [online]. 2012 [cit. 2014-12-20]. Available from: http://www.intechopen.com/books/cartography-a-tool-for-spatial-analysis/advanced-map-optimalization-based-on-eye-tracking

[60.] American Association for Pediatric Ophthalmology and Strabismus. *Conditions: Anatomy of the Eye* [online]. 2013 [cit. 2014-12-02]. Available from: http://www.aapos.org/client_data/files/2011/_196_anatomy1.jpg

[61.] OSTERHOUT, L. ERP Tutorial. *Cognitive Neuroscience of Language Lab* [online]. [cit. 2014-01-01]. Available from: http://faculty.washington.edu/losterho/erp_tutorial.htm

List of Abbreviations

AP	Action Potential
BP	Bereitschaftspotential
CNS	Central Nervous System
CNV	Contingent Negative Variation
DFT	Discrete Fourier Transfrom
DVA	Dynamic Visual Acuity
ECG	Electrcardiography
ECoG	Electrocorticography
EEG	Electroencephalography
EFE	Emotional facial expression
EFED	Emotional facial expression (dynamic)
EfRP	Event fixation Related Potential
EMG	Electromyography
EOG	Electrooculography
EPN	Early Positive Wave
ERP	Event-Related Potential
fMRI	Functional magnetic resonance imaging
FT	Fourier Transform
HEOG	Horizontal Electrooculograph
IAPS	The International Affective Picture System
ICA	Independent Component Analysis
LPP	Late Positive Potential
MMN	Mismatch Negativity
PCA	Principal Component Analysis
PSD	Power Spectral Density

PSP   Postsynaptic Potential

VEOG   Vertical Electrooculograph

List of appendix

A CD content

A.1 Diploma thesis

A.2   Matlab programs for fixations

A.3 Programs to add markers for EEG

A.4 Exported pictures from BrainVision Analyzer