CZECH TECHNICAL UNIVERSITY IN PRAGUE

Faculty of Electrical Engineering
Department of Circuit Theory

Classification of Physiological Correlates of Emotions

Klasifikace fyziologických korelátů emocí

Diploma Thesis

Study Programme: Biomedical Engineering and Informatics
Branch of study: Biomedical Engineering

Thesis advisor: Ing. Radoslav Bortel, Ph.D.

Bc. Petra Henychová

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Czech Technical University in Prague
Faculty of Electrical Engineering

Department of Circuit Theory

DIPLOMA THESIS ASSIGNMENT

Student: Bc. Petra H e n y c h o v á

Study programme: Biomedical Engineering and Informatics

Specialisation: Biomedical Engineering

Title of Diploma Thesis: Classification of Physiological Correlates of Emotions

Guidelines:

1. Assess the possibilities for the detection of the physiological correlates of emotions.
2. Choose from available physiological signals (EEG, ECG, GSR) those which allow classification of emotions of measured subjects.
3. Suggest a preprocessing algorithm of the selected physiological signals.
4. Design an algorithm for the classification of the physiological correlates of emotions in the selected physiological signals.
5. Implement the suggested algorithm in the MATLAB environment and verify this algorithm on real records of physiological signals.

Bibliography/Sources:

[1] Andreassi, L.: Psychophysiology: Human Behavior and Physiological Response. 4th Edition, Lawrence Erlabaum Associates, 2000.
[2] Duda, R.O.; Hart, P.E.; Stork, D.G.: Pattern Classification. 2nd Edition, Wiley, 2000.
[3] Sovka, P.; Uhlíř, J.: Číslicové zpracování signálů. Vydavatelství ČVUT, Praha, 2002.

Diploma Thesis Supervisor: Ing. Radoslav Bortel, Ph.D.

Valid until: the end of the summer semester of academic year 2014/2015

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Prague, January 10, 2014

České vysoké učení technické v Praze
Fakulta elektrotechnická

Katedra teorie obvodů

ZADÁNÍ DIPLOMOVÉ PRÁCE

Student: Bc. Petra H e n y c h o v á

Studijní program: Biomedicínské inženýrství a informatika (magisterský)

Obor: Biomedicínské inženýrství

Název tématu: Klasifikace fyziologických korelátů emocí

Pokyny pro vypracování:

1. Posuďte možnosti detekce fyziologických korelátů emocí.
2. Z dostupných fyziologických signálů (EEG, EKG, GSR) vyberte takové, které umožní klasifikaci emocí měřených subjektů.
3. Navrhněte algoritmus předzpracování vybraných fyziologických signálů.
4. Navrhněte algoritmus pro klasifikaci fyziologických korelátů emocí ve vybraných fyziologických signálech.
5. Výsledný algoritmus implementujte v prostředí MATLAB a ověřte na reálných záznamech fyziologických signálů.

Seznam odborné literatury:

[1] Andreassi, L.: Psychophysiology: Human Behavior and Physiological Response, 4th Edition, Lawrence Erlabaum Associates, 2000.
[2] Duda, R.O., Hart, P.E., Stork, D.G.: Pattern Classification, 2nd Edition, Wiley, 2000.
[3] Sovka, P. , Uhlíř, J.: Číslicové zpracování signálů, Vydavatelství ČVUT, Praha, 2002.

Vedoucí diplomové práce: Ing. Radoslav Bortel, Ph.D.

Platnost zadání: do konce letního semestru 2014/2015

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V Praze dne 10. 1. 2014

Annotation

The aim of this work is to design the algorithm for classification of the emotions based on the frontal brain asymmetry evoked by the short film clips. The algorithm is based on the differences in the frontal brain asymmetry evoked by the positive and negative stimuli. First, the pre-processing of EEG signal is described; the technical artefacts are eliminated and biological artefacts caused by movement and blinking are detected. Three different reference electrode approaches are used (forehead electrode, Cz electrode and Laplacian operator). Then, the power in the alpha band is computed. The power normalization is made using the power of the resting EEG or using the weighted average of the power of all film clips. The difference of the powers is computed for symmetric electrodes in the left and right frontal area. The algorithm is tested using a head model simulation and then applied on the real data obtained during presentation of short film clips from 10 reactive subjects. For statistical evaluation of the asymmetry Monte Carlo method was used. The frontal brain asymmetry was not found in response to the film clip stimuli. This is probably caused by the selection of subjects or stimuli which was not based upon any research.

Key words

Emotions, Frontal brain asymmetry, EEG, Physiological correlates of emotions.

Anotace

Cílem práce bylo navrhnout algoritmus klasifikující emoce, které vznikají v reakci na krátké filmy. Algoritmus vyhodnocuje změny frontální mozkové asymetrie, která se odlišně projevuje při pozitivních a negativních stimulech (filmech). V prvním kroku algoritmu je zařazeno předzpracování EEG signálu, technické artefakty jsou odstraněny, biologické artefakty způsobené pohybem a mrkáním jsou detekovány. Jsou využity tři odlišné způsoby reference (reference na čelní elektrodu, reference na Cz elektrodu a Laplaceův operátor). Následně je vypočítán výkon signálu v pásmu alfa mozkové aktivity. Výkon je normalizován pomocí váženého průměru všech filmů, nebo na klidové EEG. Rozdíl výkonů je vypočítán pro odpovídající elektrody v pravé a levé hemisféře. Algoritmus je testován pomocí simulačního modelu hlavy a následně použit na reálná data. Data byla získána od deseti jedinců, kteří během měření sledovali krátké filmy. Ke statistickému vyhodnocení asymetrie je použita metoda Monte Carlo. V reakci na krátké filmy nebyla nalezena frontální mozková asymetrie. To může být způsobeno výběrem subjektů nebo filmů, který nebyl podpořen dalšími výzkumy.

Klíčová slova

Emoce, frontální mozková asymetrie, EEG, fyziologické koreláty emocí.

Acknowledgments

I would like to thank to my supervisor Ing. Radoslav Bortel, Ph.D. for his guidance, valuable advice in field of signal processing and stylistics. I am grateful for the time he provided and for his positive attitude.

I am thankful to my parents for their support. Special thanks belong to my boyfriend for his encouragement and advice.

Prohlášení autora práce

Prohlašuji, že jsem předloženou práci vypracovala samostatně a že jsem uvedla veškeré použité informační zdroje v souladu s Metodickým pokynem o dodržování etických principů při přípravě vysokoškolských závěrečných prací.

V Praze dne 12. 5. 2014 ……..…….….

Podpis autora práce

Contents

List of Abbreviations

BEM	Boundary element method
EEG	Electroencephalography
EMG	Electromyography
GSR	Galvanic skin response
PET	Positron emission tomography

1 INTRODUCTION

Motivation

This work is motivated by the need of the objective estimation of emotional stimuli. Common way how to evaluate opinion and interest in the different evocative stimuli such as film clips is filling a questionnaire. However, this suffers from several disadvantages. Incorrect or untrue information could be provided or subjects may have trouble expressing themselves correctly. Therefore, there is a need or a more precise way of emotional responses evaluation that avoids wrong interpretation and provides objective rating. An efficient way how to achieve the objective evaluation is to measure physiological responses to the stimuli and evaluate those using objective methods. Therefore, this thesis concentrates on the problem of finding and evaluating physiological correlates of emotions.

Aim of this Work

This thesis has the following objectives which lead to the creation of the system classifying emotions.

- Choose appropriate physiological signal for the classification of emotions and suggest an algorithm of its pre-processing.
- Design an algorithm for the classification.
- Implement the algorithm and verify it on real records.

State of the Art

This chapter summarizes the state of the art in the field of emotions classification. The review is divided into several parts. The first part deals with the frontal EEG asymmetry in general, followed by the connections between emotions and the asymmetry, which is described in different cases – depressed people, emotions during sleep, infants and emotional responses to the film clips. Methodological issues connected with evaluation of the frontal EEG asymmetry are reviewed. Galvanic skin response as the tool for assessing arousal is described.

1.1. EEG Asymmetry

Preliminary research of cortical asymmetry [1] confirmed the hypothesis that the right hemisphere has a special role in emotions by asking subjects four types of questions. The lateral eye movements were scored and they differed significantly in complex cognitive and affective questions. It was proposed that more precise localisation of the source of the emotions should be made by other means of measurement (such as the EEG).

Bilateral EEG filtered to 8 – 13 Hz band (so called alpha band [2]) was used to demonstrate task dependent cerebral asymmetry. Right hemisphere activation during musical and spatial tasks and left hemisphere activation during numerical and verbal tasks were showed by several papers (e.g. [3]). Work [4] studied sex differences in patterns of EEG asymmetry. It showed that during tasks designed to unilateral activation of the cerebral hemispheres, females had greater cortical asymmetries than males. Work [5] investigated EEG asymmetry filtered for 8 – 13 Hz activity during musical and non-musical self-generation tasks. Greater relative right hemisphere activation was shown in non-musically trained subject while whistling the melody of a song. Study [6] showed that the frontal brain asymmetry is related to certain immune responses.

While the older studies mentioned above were focused on the asymmetries in the occipital or parietal parts of the brain. The newer studies mentioned in the following text are focused on a frontal asymmetry occurred in the alpha band of EEG activity.

Anterior brain electrical asymmetries in the alpha band in response to reward and punishment were found in [7]. According to study [8] the frontal brain asymmetry in the alpha2 band (10.5 – 12 Hz) occurred in response to a verbal memory task which were neutral, positive and negative (reward and punishment). Work [9] examined a frontal brain asymmetry comparing the resting and fear-induced state made by fearful film clip. The resting-state brain asymmetry was not significant but the group with high anxiety level showed greater EEG asymmetry. Another study [10] compared frontal asymmetry before and after stress induction. The level of alpha activity in the right hemisphere was greater after the stress stimuli. Investigators in [11] found asymmetries in alpha activity which was correlated with neurophysiological tasks.

In conclusion, cerebral asymmetry in the whole brain was examined in works focused on the response to different tasks, e. g. musical, numerical or verbal. Also, the frontal brain asymmetry was found in response to the reward and punishment, verbal memory task, anxiety or stress. The studies showed that in reaction to certain tasks asymmetries in brain occur.

1.2. Emotions and Asymmetry

Several works showed that the processing of emotions in a brain is also asymmetrical. The processing of positive vs. negative emotions was investigated in many studies that can be divided into several branches.

- normal populations (e.g. [12], [13], [14], [15], [16], [17], [18], [19], [20], [21])
- brain-damaged populations (e.g. [23], [24], [25], [26], [27])
- psychiatric populations (e.g. [28], [29], [30], [31])

All studies mentioned in the list above show that the frontal parts of the right hemisphere are more activated in response to the processing of negative affect but the frontal parts of the left hemisphere are more activated in response to the processing of positive affect. Some of the more interesting studies are mentioned and discussed in the following text.

Work [12] verified the hypothesis that the hemispheres are specialized differently for positive and negative emotions. Subjects were asked to push a button on the right or the left side according to the side of the picture (the images with happy or sad faces were projected on the right or the left side of their visual field randomly).A reaction time of right vs left visual field was studied, and it was faster when the expression was happy compared to the sad pictures.

The regulation of emotions was studied in respect to eye-blink startle by [13]. The attenuated startle magnitude after negative stimuli occurred in subjects with greater anterior activation on the left side of the EEG.

In study [14] it was examined how the resting frontal brain activity affects responses to positive and negative stimuli. It was showed that if the frontal asymmetry is stable during a certain time period (two measurements were made 3 weeks apart), a greater left (right) activation occurred in response to positive and negative film clips, respectively. The subject who had the stable frontal asymmetry during a time period of several weeks and whose rest brain activity was relatively grater on the left side reported higher reactivity in response to the positive clips and vice versa.

Study [21] assesses asymmetries in facial expression during happiness and sadness. The 3D imaging method (physiognomic range finder ‘Fiore’ manufactured by NEC, Japan) was used to investigate facial movements. The study supported conclusions in paper [17], which claimed the response to emotions in brain to be differed in the both hemispheres.

Work [22] noticed that greater left frontal cortical activity is associated with approach motivation, which can be positive (enthusiasm) or negative (anger). Their study is based on another work [32], where they claimed that the anterior asymmetry varies as a function of motivational direction rather than affective valence.

Studies focused on connections of the frontal brain asymmetry and emotions showed that the frontal activation in the left and right hemisphere varies as the response to the negative and positive stimuli.

1.2.1. Depressed People

Some investigations concentrated on depressed subjects. Their relative right frontal activation was greater compared with subjects who did not suffer from depression [18], [33]. Greater activation of right hemisphere agrees with other hypotheses that the left and right frontal regions specialize for particular positive and negative effects. The study [34] based on the previous findings confirmed the left frontal hypo activation in currently and previously depressed subjects. Another study of depressed subjects [35] showed that the subjects with current or previous incidence of depression had greater frontal brain asymmetry. The EEG asymmetry was compared between depressed and normal subjects in other experiment [36]. It was showed that the frontal EEG asymmetry is a risk marker for depressive disorder. In this study the subjects were asked to make four different facial expressions connected to withdrawal (afraid and sad) and approach (angry and happy). Lower relative left frontal activity was displayed in lifetime depressed individuals compared with normal ones.

1.2.2. Sleep

Despite most of the research has been comparing the alpha activity in frontal region at subjects who were awake, a few works concentrated on sleeping subjects. The central region of the brain activity was measured ([37], [38], [39]), but no asymmetry was found in these works. Study [40] showed that the level of frontal brain activation asymmetry in wakefulness could predict the emotional content of dreams. Work [41] showed connections between alpha asymmetry in frontal region during wakefulness and sleep. If the asymmetry during wakefulness and sleep is stable, it could be caused by emotional activity during dreaming.

1.2.3. Infants

Brain activity of ten-month-old infants was recorded from the frontal regions of the scalp. In paper [42] two studies were presented and infants showed greater activation of the left frontal than of the right frontal area in response to the happy facial expression.

Work [43] made another experiment with different stimuli: a stranger-approach, mother-approach, and maternal separation experience. Changes in EEG asymmetry in frontal

lobes also reflected changes in facial behaviour. This idea was supported by an experiment where the response to taste (sucrose solution and citric acid solution) was measured on new-born infants [44]. The relative left-sided activation was greater for the sucrose solution in frontal and parietal regions in the 6 – 12 Hz band. Paper [45] is focused on the response to maternal separation with the similar results. Children who cried showed greater right frontal activation.

1.2.4. Emotions and Film Records

In paper [46] the investigators let subjects watch short film clips and found that if facial expression is not considered and the analysis is made from the whole film clip period, no reliable differences in frontal EEG asymmetry is produced in ether the alpha or beta bands. The film clips were selected carefully and precisely to elicit both self-report and facial signs of positive and negative emotion. The selection of the stimuli was supported by paper [47], where the facial expressions were examined during watching the selected film clips. Silent clips were used because of the hypothesis that auditory patterns could affect the activation of certain parts of the hemispheres. They compared results of EEG asymmetry in the whole film clip period and in parts with certain facial expression and concluded that only appearance of facial expressions ensures significant asymmetry.

On the other hand, work [48] confirmed frontal EEG asymmetry which occurred during watching the emotional film clips. The activation was regional, especially for the stimuli selected to elicit happy or disgust emotions. The subjects were selected according to the rate of the reaction to the film clip stimuli and using Multidimensional Personality Questionnaire.

Study [49] presented outcomes of the experiment made at healthy students. They saw two film clips (one sad and one happy) and were asked to think about sad and happy events of their lives after clips. The frontal EEG asymmetry in alpha band was confirmed especially during the sad emotions because time to “regenerate” the brain from the sad to happy emotion was not long enough and it could have affected the results.

In the three studies mentioned above [46], [48], [49] where the frontal EEG asymmetry was showed in response to the film clips, selected subjects were all right-handed,

it the first case only women, in the second and third case students from the same schools. In study [46] the frontal brain asymmetry was shown just in the time intervals with facial expression. Work [48] found frontal asymmetry in subjects who were selected for high positive and negative affectivity and the stimuli had high evocative nature. Work [49] presented higher frontal brain asymmetry in the first stimuli (negative), than in the second stimuli (positive).

Positron emission tomography (PET) was used for the localization of the brain regions responsible for response to different stimuli. One part of paper [50] investigated regions reacting to the film clip stimuli. The investigators stated that film-generated emotion was associated with significantly greater increases in activity bilaterally in the occipitotemporoparietal cortex; lateral cerebellum, hypothalamus, and a region that includes the anterior temporal cortex, amygdala, and hippocampal formation, suggesting that there regions participate in the emotional response to certain exteroceptive sensory stimuli. Another study [51] localized responses to the happiness, sadness and disgust by PET as well. These emotions are associated with increased activity in the thalamus and medial prefrontal cortex, and also with activation of anterior and posterior temporal structures in case of induction by film clip. The same findings were provided by work [52] based also on PET but with different stimuli (the set of pictures).

In contrast with the abovementioned works, there were also some cases where the frontal asymmetry was not found. In work [46] the frontal brain asymmetry was not found, when the power in the alpha band was computed during the whole film clip period. Also, paper [49] showed no significant results for the positive stimuli, which followed the negative one. This indicates that the frontal asymmetry is not always a robust indicator of the emotional valence, and unless the experiment is set up correctly, no differences in frontal power can be detected.

1.3. Methodological Issues

Methodology previously used for the correct evaluation of the frontal asymmetry and reactivity of the subjects is discussed in this section.

1.3.1. EEG Signal

Paper [53] summarizes methodology for assessment of the frontal asymmetry. Three main aspects were discussed: metrics of asymmetry, artifacts and reference electrode location. Each part will be presented in detail in following text.

Metrics of Asymmetry

For the examination of the EEG asymmetry, the power in various frequency bands is computed (most often in the alpha band, in some studies the power in the beta band was computed). An asymmetry index is calculated from symmetric locations on right and left side of the head. The index is computed as the right-hemisphere power divided by the power of the left hemisphere [49], [53]

$$index1 = \frac{P_{right}}{P_{left}}, \tag{1}$$

where P_{right} and P_{left} is the power in the right and symmetric left lead, respectively.

Other possible approach is to compute [42], [53]

$$index2 = \frac{P_{right} - P_{left}}{P_{right} + P_{left}}. \tag{2}$$

Artifact Elimination

For the correct estimation of the power in the alpha band of the EEG signal, it is necessary to handle the problem with several types of artifacts that affect EEG recordings.

Physiological artifacts which should be removed from the signal include primarily blinking and muscular artifacts.

Blinking is easily observable in the frontal EEG leads and can be simply eliminated by simple thresholding [57]. The principle of the elimination is described in detail in Section 2.3.1.

Muscular artifacts should be treated as well. The frequency content of EMG activity is broad and interferes with the frequency content of the EEG activity. Especially facial expressions, which may be asymmetrical [21], can bias measures of EEG asymmetry [53]. To detect the artifacts, the power of the EEG signal is measured in higher frequencies which do not contain any neurogenic activity. Parts with higher power which match the EMG activity are removed from the recordings. The principle of the elimination is described in greater detail in Section 2.3.1.

Eye movements could also be considered as possible source of artifact which can affect the EEG. However, the slow eye movements influence the power of low frequencies and do not influence the power of the alpha band which is examined in case of frontal EEG asymmetry connected with the emotional response [55].

Reference Electrode Location

An appropriately chosen reference is essential for the measurement of the frontal EEG asymmetry. Work [56] reported that the commonly used linked earlobe reference decreased the magnitude of task-dependent asymmetry and therefore it is not suitable for the purpose of the asymmetry evaluation. The other possibility which seems to be more appropriate is to use the Cz electrode (placed on the cranial vertex) as the reference. Also, the reference-free solution can be used – the scalp surface Laplacian operator. The use of the surface Laplacian is described in detail in Section 2.3.2.

Other Considerations

Other methodological requirements which should be incorporated into research of human emotions are [46]:

- *Emotion must be actually elicited* – some other evidence that confirm that the investigated emotion was produced should exist.
- *Adequate procedures must be used to verify the presence of the intended emotion* – every subject reacts differently to the stimuli, which were meant to have certain reaction. It means that the stimuli picked to elicit one emotion can evoke more emotions and affect the results.
- *Epochs of different discrete emotions must be separable* – the period of time with the examined emotion should be extracted from the whole measurement using other independent method. For example analysis of the facial behaviour recording can be used.
- *Behavioural and physiological measures of emotion must be appropriately synchronized* – for the extraction of suitable parts of record according to pervious point.
- *At least two emotions and a baseline condition must be compared* – every emotion should be compared with the baseline measurement, because asymmetry of two emotions can differ from each other but not from the baseline condition.
- *The data must be of sufficient duration for each emotion under study* – at least 10 seconds long record should be made to obtain a stable estimate of spectral power.

1.3.2. Galvanic Skin Response

The galvanic skin response (GSR) is a method of measuring the electrical conductance of skin which differs depending on various physiological processes ongoing in the human body. This indicator is used for the assessment of the arousal of a subject.

The GSR increases if the sympathetic branch of the autonomic nervous system is aroused. The arousal could be caused by emotional response, but the sympathetic branch of the autonomic nervous system can also be activated during the physical movement. To assess

the arousal caused by the emotional response, the increase of GSR caused by the movement should be suppressed.

Also the overlap of GSR changes caused both by movement and emotion appears. The movement could cause the huge increase of the GSR, but the increase caused by the emotional arousal is usually lower. Then, techniques suppressing the increasing and decreasing trend, respectively, caused by the movement are applied to emphasize the peaks caused by the emotional arousal. An example of this technique is using the first derivate, which emphasises the fast changes [57].

Structure of the Thesis

The second chapter (Methods) describes the conditions of measurement, the algorithm for pre-processing of physiological signals and the algorithm of classification of physiological correlates of emotions.

The third chapter (Results) summarizes results obtained with implemented algorithm.

The fourth chapter (Discussion) analyses the results and proposes possible adjustment that could improve quality of future experiment.

The last chapter is summary of the work.

2 METHODS

This chapter describes the methodology used for the classification of the physiological correlates of emotions. First the selection of the appropriate signal and measurement is discussed. Secondly, the pre-processing of EEG signal is explained; this includes artifact detection, filtering and exclusion of electrodes with bad signal contact. Next, the reference electrode choice, the computation of the power in the alpha band and the power normalization is described. Also, the pre-processing of the GSR and its use for the selection of aroused subjects is characterized. Finally, the description of the algorithm testing is included.

2.1. Selection of the Appropriate Signal

According to the summarized literature, there are two signals that seem to be a good choice for the classification of emotions. These are EEG and GSR. The EEG is relatively easy to measure (at least in comparison with other modalities of brain measurement) and it can reflect valence of the stimuli, which is usually detected as the frontal asymmetry in the alpha band. The GSR is also very easy to measure, and is a very good indicator of arousal. Therefore, the EEG and GSR were chosen for further processing in this thesis.

2.2. Measurement

For this work EEG and GSR datasets measured within another project were used. This section describes the procedures with which these data were measured.

Thirty-one subjects were recruited, 15 male and 16 female, both right- and left-handed. 27 subjects were between 19 and 29 years of age. 4 subjects were older (31 – 37 years old).

ECG, GSR and EEG were measured. All signals were recorded using Ag-AgCl electrodes with the conductive gel. The sampling frequency was 1024 Hz.

The ECG was recorded using the I. and II. Einthoven lead. GSR electrodes were placed on the second and the third finger of the left and right hand. The EEG was recorded by 111 electrodes. The high density EEG cap (Fig. 1) was used. 6 extra electrodes were used to

improve the forehead coverage. The reference electrode was placed on the forehead. The schematic diagram of the EEG electrode arrangement is in Fig. 1.

The process of putting the EEG cap end electrodes on took about an hour. The cap was placed on the head and it was fixed. The positioning of measuring electrodes followed. The longest procedure was putting the electrodes on. Each electrode was placed separately using a conductive gel.

During measurement the subjects were sitting in a chair with a head rest, so that their neck muscles could be relaxed. They were asked not to move during the measurement. The room where the measurements took place was acoustically isolated and equipped with a monitor and an audio reproduction system.

(a) (b)

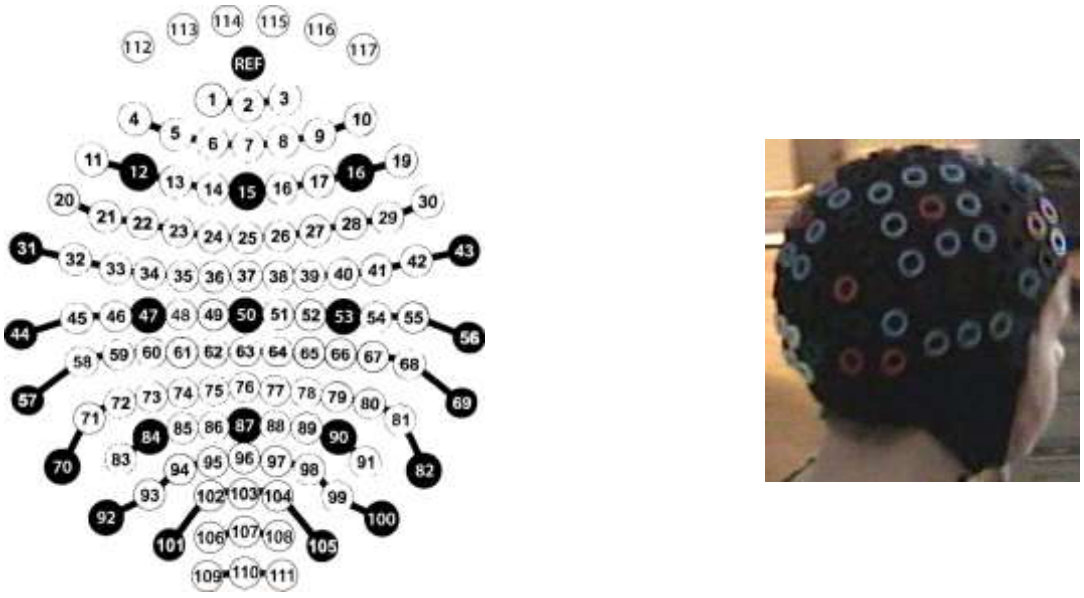


Fig. 1 (a) EEG electrode arrangement and (b) EEG cap.

The measurement used the following procedure (Fig. 2). Two records of resting EEG were measured, one with open eyes and one with eyes closed. Next, the presentation of the videos followed. Last, the second interval of resting EEG was recorded.

Fig. 2 Scheme of the measurement.

The stimuli consisted of short film clips (about 2 minutes long) which were supposed to evoke emotions (positive, negative or neural). The positive clips were either amusing or affectionate; the negative clips showed violence or elicited disgust. Between videos, 30 seconds pauses with noise were placed.

Videos were presented in two different orders for the first 18 subjects and the rest. The videos were divided into 4 groups, reference videos – positive, negative and neutral; and one group with commercials. During the measurement subjects saw 29 film clips, which consisted of 13 commercials, 5 positive, 5 negative and 6 neutral film clips.

2.3. Pre-processing of Physiological Signals

This chapter describes the methods used for pre-processing of physiological signals. This includes the elimination of power noise interference, suppression of muscular and blinking artifact, recognition of electrodes with bad signal contact and GSR pre-processing.

In the following text the EEG signal will be denoted as

$$\boldsymbol{x}[n] = \left[x_1[n],\ x_2[n],\ \dots\ , x_L[n]\right]^T, \text{where } n = 1 \dots N, \tag{3}$$

where $x_i[n]$ is a signal measured by lead i, L is the number of leads and N is the number of samples.

2.3.1. Pre-processing of EEG

Power noise interference was reduced using the notch filter, which eliminates the power at the frequency of 50 Hz. The bandwidth of the filter was 2.5 Hz. The higher harmonies were also reduced.

In the next step, the muscular artifacts were detected in the EEG signal,

The detection of the muscular artifacts used the fact that frequency content of muscular activity which occurs in the EEG signal is higher than the frequency content of brain activity. For the extraction of the muscular activity a high-pass filter (Chebyshev type I) with the cutoff frequency of 50 Hz was used,

$$\boldsymbol{x}_{HP}[n] = HP\{\boldsymbol{x}_{\boldsymbol{l}}[n]\}\,, \tag{4}$$

where $\boldsymbol{x}_{HP}$ is the filtered signal and HP is the high-pass filter.

The signal power was estimated and smoothed using a 300 point moving average FIR filter on the signal squared

$$\tilde{\boldsymbol{p}}[n] = LP\{|\boldsymbol{x}_{\boldsymbol{HP}}[n]|^2\}, \tag{5}$$

where $\tilde{\boldsymbol{p}}[n]$ is the power estimate and LP is the moving average filter (low-pass filter).

A threshold for the detection was computed as 3 times the 90% quantile of the signal power estimate

$$T = 3q_{0.9}, \tag{6}$$

where T is threshold and $q_{0.9}$ is 90% quantile of the estimate of the signal power.

In order to avoid generation of technical artifacts in the subsequent filtering, the artifacts were not eliminated right away. Instead, the positions of the detected muscular artifacts were merely stored and the artefacts were removed later. The block diagram of the detection of the muscular artifacts is in Fig. 3.

In the next step, the detection of blinking was performed. The process of the detection is similar to the process of detection of the muscular artifacts with two differences. The first difference is in the first filtering because the frequency content of blinking is the highest in the frequencies between 4 and 10 Hz. Therefore, the band pass filter (Chebyshev type I) with the cutoff frequencies between 4 and 10 Hz was used. The second difference is in the threshold computation. The threshold for the detection of blinking was computed as 5 times the median of the signal power estimate. For the detection of the blinking, the frontal electrodes were used because the artifacts are the most significant there. As well as the muscular artifacts, artifacts caused by blinking were not eliminated right away. The positions of detected blinking were stored for the further use.

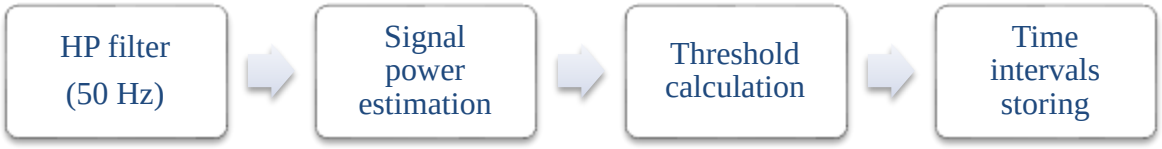


Fig. 3 Detection of the muscular artifacts.

Next, the electrodes with bad signal contact were excluded. The electrodes with bad contact did not measure brain activity but only power noise interference. For detecting the bad electrodes, the power of the signal was measured at 48 – 52 Hz and at 0 – 48 Hz and 52 – 100 Hz separately. If the power in 48 – 52 Hz was higher than the power in the remaining bands, the electrode contact was considered to be bad and the electrode was excluded.

The EEG signal was filtered to the alpha band using the 4th order Chebyshev Type I band pass filter with the passband 8 – 13 Hz.

In the last step, the removal of the muscular artifacts and the artifacts caused by blinking was performed. For the removal, the stored positions of the artifacts were used. Note, that if the artifacts were removed before filtering to the alpha band, this may create discontinuities, which may introduce increased power in the frequency band of interest, and affect the signal power estimates. The formation of the possible discontinuities is shown in

Fig. 4, where the red part in the first picture is the detected artifact and after the elimination of the artifact right away, the step and discontinuity would appear.

The block diagram in Fig. 5 shows procedure of the pre-processing of the EEG.

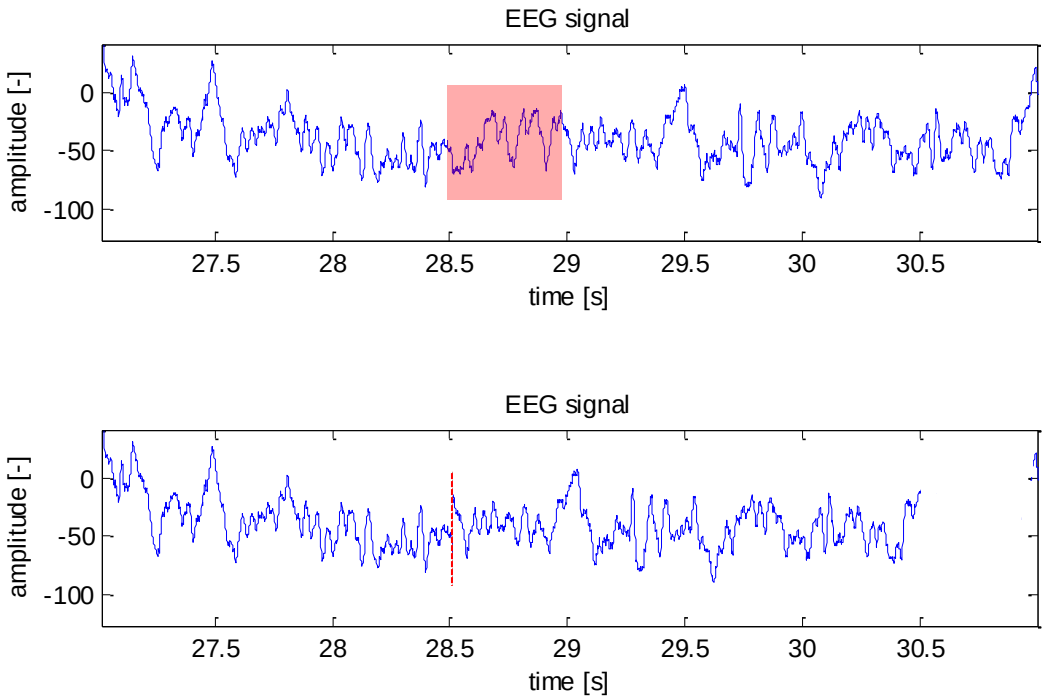


Fig. 4 A discontinuity formed by direct elimination of detected artifact prior to band pass filtering to alpha band.

Fig. 5 Pre-processing of the EEG.

2.3.2. *Reference Electrode Choice*

Three different references were used and compared: using the forehead reference electrode, using the Cz reference electrode and reference-free method, scalp surface Laplacian.

The first option using the forehead reference electrode with which the measurement was performed.

The second option was the recalculation of the reference to the Cz electrode (lead fifty in our measurement, see Fig. 1 a)

$$\boldsymbol{x_{Cz}}[n] = \boldsymbol{x}[n] - x_{50}[n]\,, \tag{7}$$

where $\boldsymbol{x_{Cz}}[n]$ is the recalculated signal and $x_{50}[n]$ is the EEG signal in the lead 50 (Cz electrode).

The first and second options of reference are shown in Fig. 6.

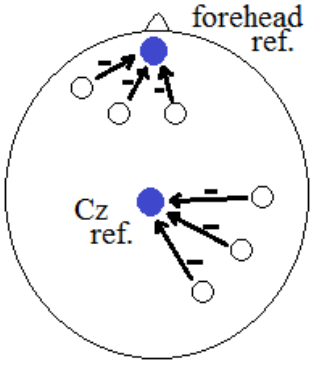


Fig. 6 Forehead and Cz electrode reference.

The last option used in this study was the scalp surface Laplacian. The surface Laplacian L of voltage Φ recorded on a plane surface with coordinates (x, y) is defined by the [59]

$$L = \frac{\partial^2 \Phi}{\partial x^2} + \frac{\partial^2 \Phi}{\partial y^2} \tag{8}$$

The Laplacian mapping is able to enhance the high spatial frequency components of cortical electrical activity, which are smeared and distorted over the scalp when volume conducting through the low-conductivity skull [60]. Each channel represents the difference between an electrode and a weighted average of the surrounding electrodes. This is a reference-free method [60].

Linked earlobe reference is a common used reference, but is not utilized for purposes of assessing the frontal brain asymmetry, because it decreases the magnitude of task-dependent asymmetry [56].

2.3.3. Computation of the Power of the Alpha Activity

Based on the suggestion in [53], the average power of alpha activity was computed for each stimulus and each electrode as

$$\tilde{\boldsymbol{p}}_{avg} = \sum_{n=1}^{N} \tilde{\boldsymbol{p}}\,[n]\,, \text{ where } n = 1 \ldots N, \tag{9}$$

where $\tilde{\boldsymbol{p}}_{avg}$ is the average power estimate computed from the whole time period of the film clip and N is the number of samples in the film clip.

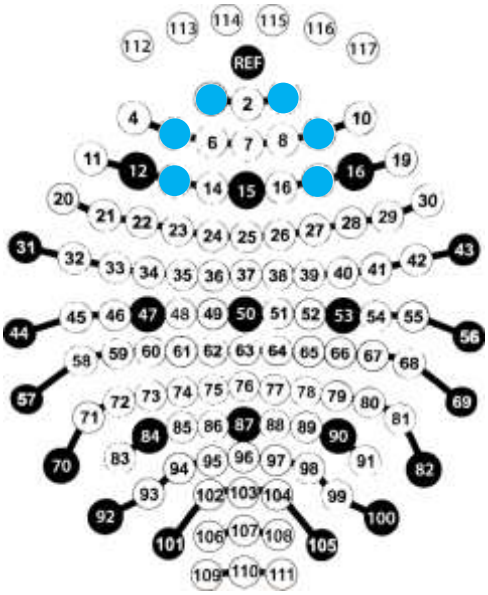


Fig. 7 The symmetrical leads selected for the power comparison.

The power was compared in the right and left frontal area in the symmetrical leads. From each area three leads were selected (Fig. 7). The difference was computed in these 3 combinations of the leads. More than one combination was selected because the response to the same stimulus could be localized differently for different subjects and also the electrode cap placement may vary.

The power computed in the symmetrical leads was compared separately for each stimulus.

2.3.4. Normalization

It was necessary to normalize the EEG signals in order to eliminate resting asymmetries and differences in levels of amplitudes in brain activity. Two different approaches were used.

In the first approach, the power of the resting EEG in the alpha band was computed. For this purpose an interval of resting EEG was used. The resting EEG record was checked for artifacts, filtered to the alpha band, and the artifacts were eliminated. Then the average power for each lead was computed. The average power estimate of each lead of signal during whole time period of every film clip was divided by the average power of the resting EEG

$$\tilde{\boldsymbol{p}}_{norm1}[l] = \frac{\tilde{\boldsymbol{p}}_{\mathrm{avg}}[l]}{\tilde{\boldsymbol{p}}_{\mathrm{rest}}[l]}, \text{ where } l = 1 \dots L, \tag{10}$$

where $\tilde{\boldsymbol{p}}_{norm}[l]$ is the normalized power estimate in the lead l and $\tilde{\boldsymbol{p}}_{\mathrm{rest}}[l]$ is the average power estimate in the lead l computed from the time period of the resting EEG.

The second approach of the signal normalization was to compute a weighted average of powers computed through all the film clips used for the comparison. The weighted factor was the length of the film clips

$$\tilde{\boldsymbol{p}}_{weighted} = \frac{1}{\sum_{i=1}^{S} F_i} \sum_{i=1}^{S} \mathrm{F_i}\, \tilde{\boldsymbol{p}}_{\mathrm{avg}}[i], \tag{11}$$

where $\tilde{\boldsymbol{p}}_{weighted}$ is the weighted average estimate of the power, F_i is length of the film clip i, $\tilde{\boldsymbol{p}}_{\mathrm{avg}}[i]$ is the average power estimate computed from the whole time period of the clip i and S is the number of the selected film clips.

After computing the $\tilde{\boldsymbol{p}}_{weighted}$, the normalized power estimate of each film clip was computed as

$$\tilde{\boldsymbol{p}}_{norm2}[l] = \frac{\tilde{\boldsymbol{p}}_{avg}[l]}{\tilde{\boldsymbol{p}}_{weighted}} . \quad (12)$$

Last, the normalized power estimate was recalculated into the logarithmic scale

$$\tilde{\boldsymbol{p}}_{log}[l] = 10log(\tilde{\boldsymbol{p}}_{norm}[l]) \quad (13)$$

where $\tilde{\boldsymbol{p}}_{log}[l]$ is the normalized power estimate in the lead *l*.

The block diagram in Fig. 8 summarizes the algorithm.

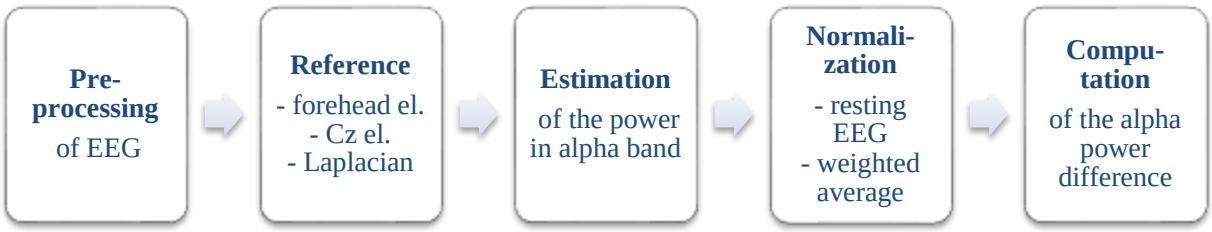


Fig. 8 Algorithm for classification of physiological correlates.

2.3.5. Pre-processing of GSR

As it was mentioned in the Introduction, the GSR increases when a subject is aroused emotionally or by the movement. The component of the GSR caused by the emotional arousal is important for the evaluation of the reactivity, but the component caused by the movement should be eliminated. The process of suppressing the movement component and evaluating the emotional reactivity to the film clips is described.

The measurement took about an hour and subjects were asked to limit their movements during watching the film clips to eliminate artifacts. During the projection of the

film clips the subjects paid attention to the clips and moved slightly. But during the pauses when the noise was screened, they started fidgeting and the GSR increased as the response to their movement.

The GSR was assessed during the whole time period of the film clips. To suppress the increase in GSR made by the movement, the first derivate (differential) was used. Using the differential emphasized the peaks originated by the arousal caused by the reactive response to the film clips.

The GSR was evaluated visually. If peaks were high enough, the film clip connected to it was picked for further evaluation.

Each film clip and each subject were assessed using the GSR and only the film clips with certain level of reaction were used for the evaluation of the algorithm. The subjects who did not manifest any arousal, as evaluated by the GSR, were excluded from further evaluation. This was done to increase the chance of frontal asymmetry detection.

2.4. Algorithm Testing

In order to test the functionality of the implemented algorithm, the simulation of the EEG signal which was designed in works [61] and [62] was used.

The simulation used a three layer realistic head model computed using the boundary element method (BEM) based on the symmetric approach. The three boundaries represented skin and the inner and outer surface of a skull. The simulation consisted of 45 frontal brain sources and totally 150 brain sources randomly placed into the brain volume [61]. The sources signal were represented by pseudorandom numbers with the standard normal distribution filtered using a low-pass filter in order to simulate the brain activity which occurs in frequencies from 0 to approximately 30 Hz [2]. The surface potential was computed from the sources in the positions of the electrodes.

The outcome of the simulation were signals from 111 leads representing 2 minutes long recording with the sampling frequency of 1024 Hz. The resulting signal had similar character as the brain activity.

The frontal asymmetry in the model was tested. To simulate the asymmetry, the magnitude of the respective frontal sources was increased to various levels. Two cases were designed, higher activity in the left frontal lobe (response to the positive stimuli) and higher activity in the right frontal lobe (response to the negative stimuli). The designed algorithm was applied to the simulation data.

2.5. Classification of the Film Clips

For the classification of the film clips and for the verification of the statistical significance, following steps were used.

First, the power difference in the symmetrical leads was estimated

$$\tilde{r} = \tilde{\boldsymbol{p}}_{log}[l_1] - \tilde{\boldsymbol{p}}_{log}[l_2] \ , \tag{14}$$

where $\tilde{r}$ is the power difference estimate, l_1 and l_2 are symmetrical leads.

The power difference estimate $\tilde{r}$ is statistically significant in case that its value is higher than a threshold T. The threshold T is defined as a value, which is exceeded by $\tilde{r}$ with the probability $\propto$ assuming that the true frontal asymmetry is zero

$$p[\tilde{r} > T | r = 0] = \propto . \tag{15}$$

Thus T is the $\propto$-quantile of the distribution of $\tilde{r}$ provided that true $r = 0$, where r is the true value of the power difference.

To determine the threshold T, Monte Carlo simulation was used [63]. The measurement was simulated using the head model described in Section 2.4. The brain sources were set so that there was no frontal asymmetry. 1600 simulated signals were computed and processed with methods described in Section 2.3, resulting in 1600 power differences estimates $\tilde{r}$. These estimates were then used to estimate the $\propto$-quantiles, and the respective threshold T. The quantiles were estimated using the following procedure.

- The values of $\tilde{r}$ were arranged in the ascending order, forming a vector $\tilde{r}_s$.
- The quantile is obtained as the k-th value in the vector $\tilde{r}_s$, where

$$k = \left[V \frac{q}{100} \right], \tag{16}$$

where V is the number of the values in the vector $\tilde{r}_s$, q is the value of the quantile in the percent and [.] denotes the integer part of its argument.

Regarding the choice of the significance level, a single test could be performed at a chosen level $\propto = 10$ %; however, with the number of test rather high, this could lead to

a high number of false positive detections. Therefore, Bonferroni correction was used and the significance level was decreased using the formula

$$\propto' = \frac{\propto}{k}, \tag{17}$$

where $\propto$ is the original significance level, $\propto'$ is the corrected significance level and k is the number of independent tests [64].

In this study, $\propto$ was chosen as 10%. In the measurement 10 subjects and 3 electrode combinations were selected, 30 independent tests were used; therefore, the significance level was corrected to 0.3 %.

Consequently, the 0.3% and 99.7% quantiles were used as the threshold for the testing of the hypotheses, that the power in the right hemisphere is higher in response to the positive stimuli and the power in the left hemisphere is higher in response to the negative stimuli, respectively. It is decided, whether the computed asymmetry is caused by the physiological processes or if it is a random event.

The algorithm was tested on the real records from 10 subjects. Records from 31 subjects were available, but only reactive subject were selected according to the arousal evaluated using the galvanic skin response.

2.6. Implementation in MATLAB Environment

The whole algorithm was implemented in the MATLAB environment, including the pre-processing of the EEG signal and GSR, reference electrode choice, normalization and testing the algorithm using the simulation.

The inputs of the algorithm are measured data, selected symmetrical combinations of electrodes which were examined, position of tags which identify start and end of each film clip. The output is the table of power differences in symmetrical combinations for selected film clips.

3 RESULTS

In this chapter results are presented. First, illustrative results of power noise elimination, detection of muscular artifact and blinking, using the scalp surface Laplacian are described. Then, tables summarizing testing and assessment of algorithm for frontal asymmetry classification are included.

3.1. Pre-processing of EEG

The following section presents the results and the illustrative waveforms obtained in the individual steps of the EEG pre-processing.

3.1.1. Reduction of Power Noise Interference

The result of reduction of the power noise interference is visualised in Fig. 9. The green line denotes the signal with power noise and the blue line denotes the signal without power noise. The lines are visualised with the offset for better clarity.

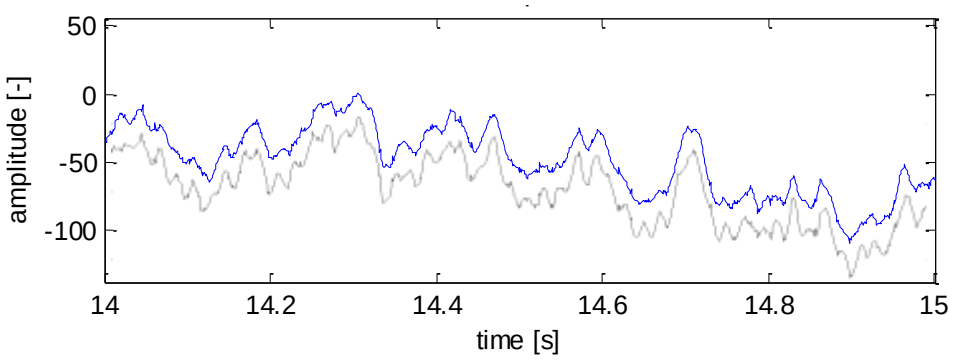


Fig. 9 One second long record of the signals with and without the power noise interference.

The first possibility of the visualisation in the time domain is complemented with the visualisation in the frequency domain using the spectrogram.

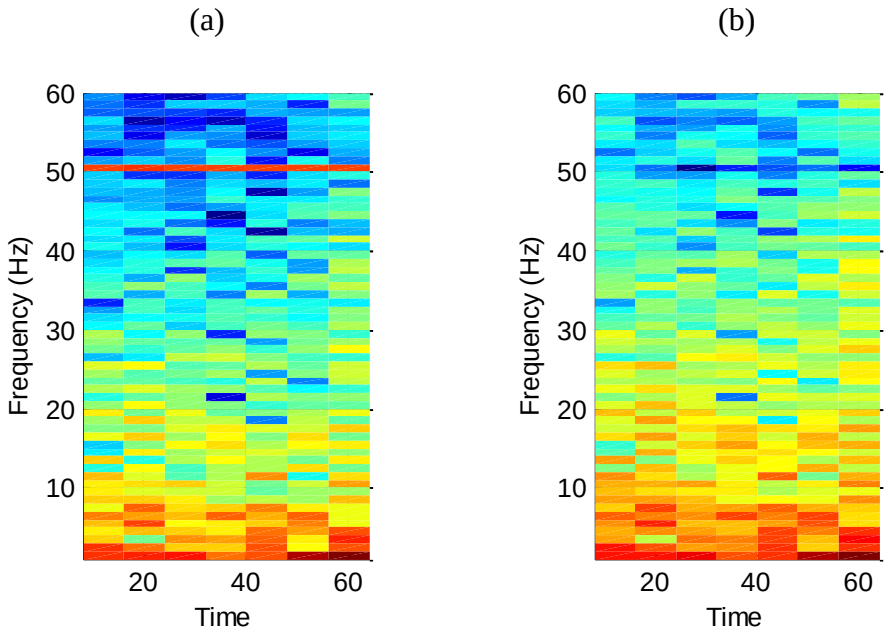


Fig. 10 Spectrogram of the signal (a) with (b) without the power noise interference.

Spectrograms of the signals in Fig. 9 are shown in Fig. 10. In the spectrogram of the signal with the power noise interference, the high amplitude of 50 Hz frequency is easily recognisable. After filtering the amplitude of 50 Hz is low, the power noise was removed successfully.

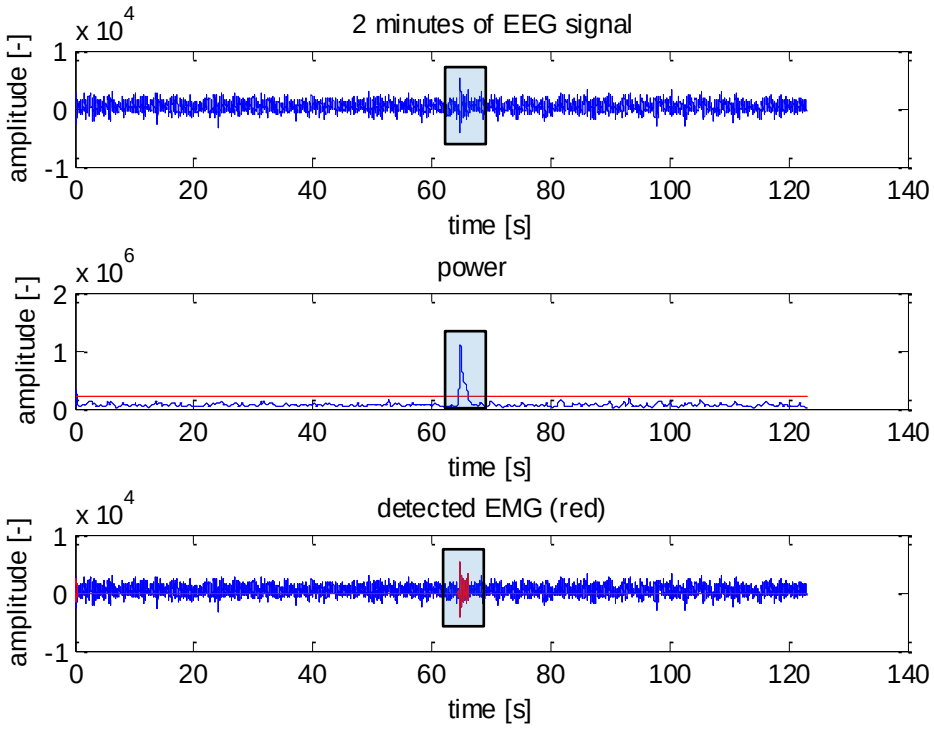
3.1.2. Detection of Biological Artifacts

The process of the detection of the muscular artifacts is illustrated in Fig. 11. It shows a signal from one electrode of one selected subject. The record was obtained during one whole film clip which lasted for 2 minutes.

The process of the detection of the blinking is in Fig. 12. Similarly, it shows a signal from one selected subject, one whole clip, which lasted for 2 minutes, and one selected lead.

The inspection of the detection was performed on the real data from two randomly selected subjects. Specifically, the detection of biological artifacts was inspected. For the examination, the records from 8 film clips (each film clip was approximately 2 minutes long) were selected and the signals from all EEG leads were inspected. A careful inspection confirmed the correct functionality of the designed algorithm.

(a)



(b)

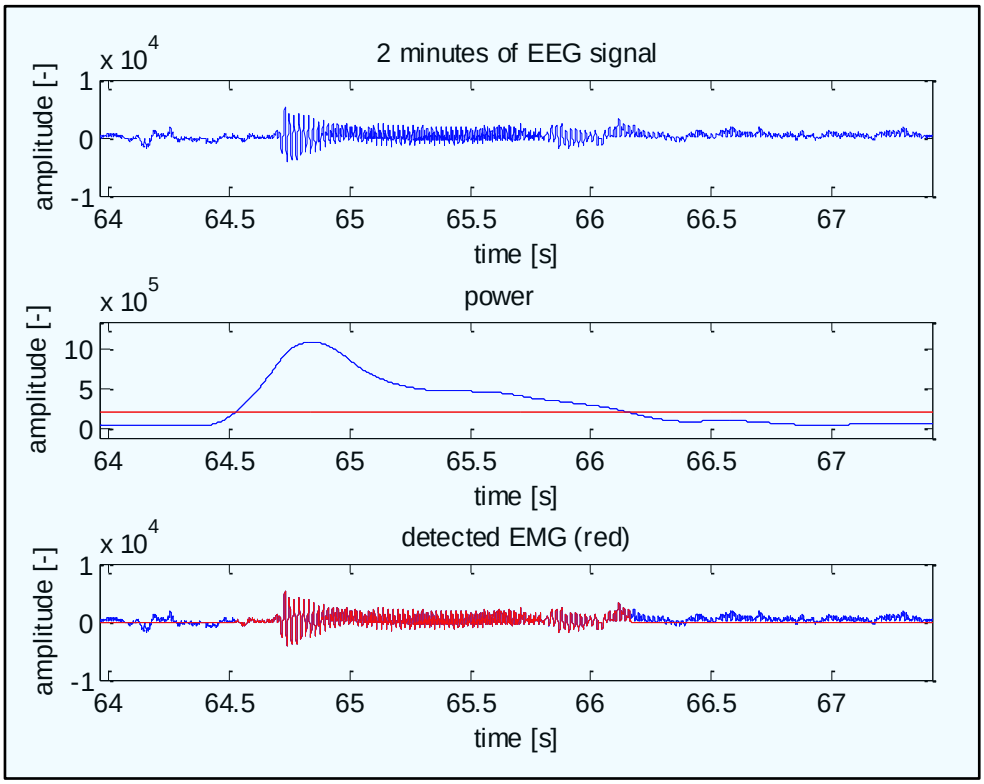
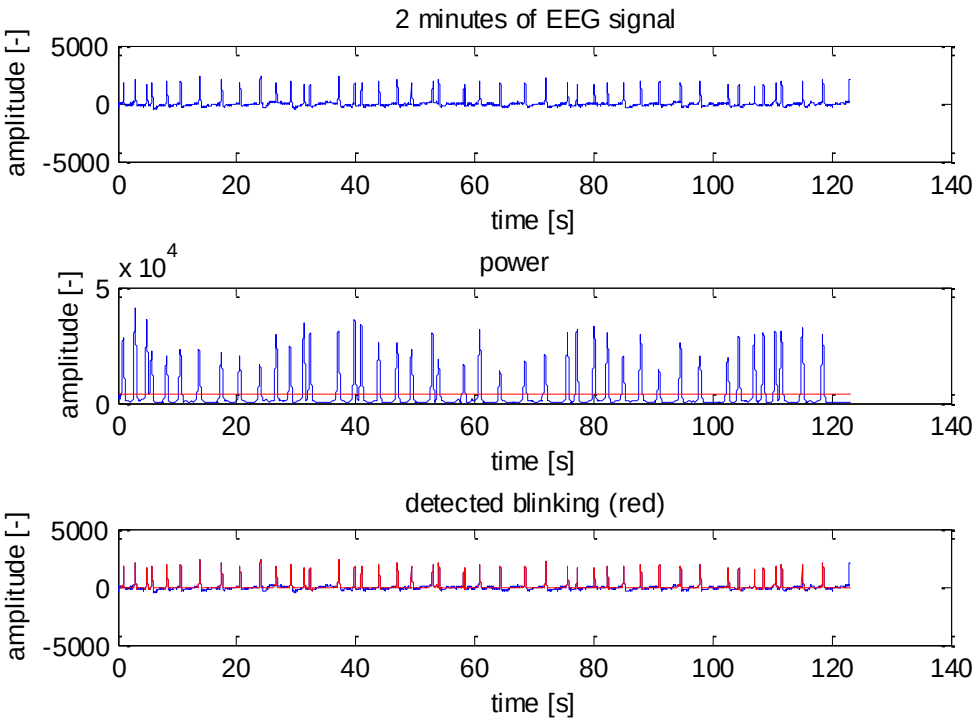


Fig. 11 (a) Process of detection of EMG (b) with detail of a signal artifact.

(a)



(b)

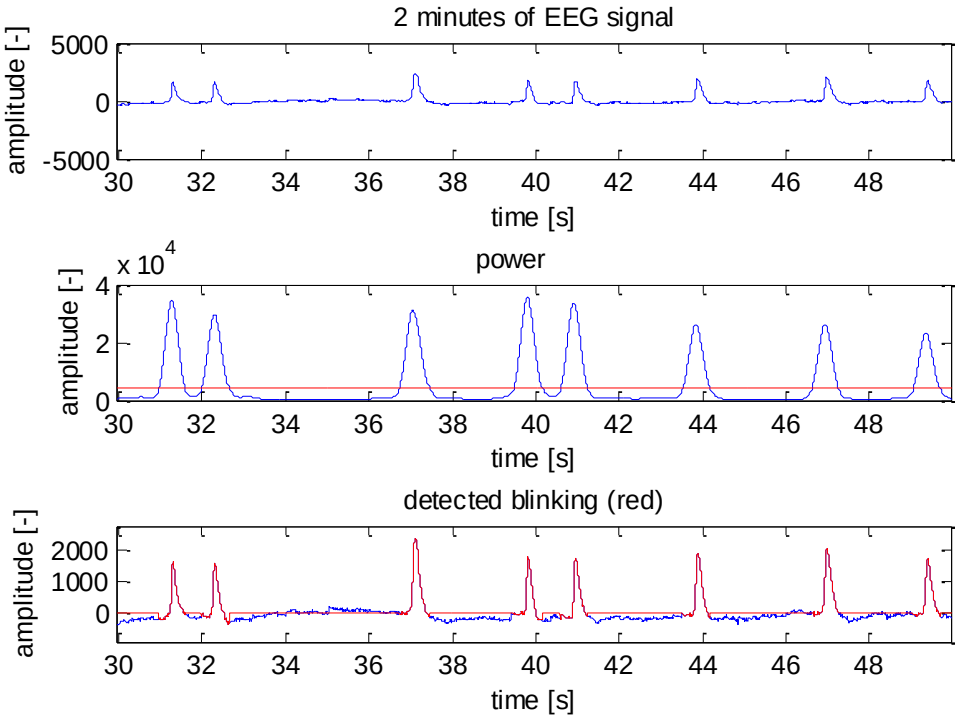
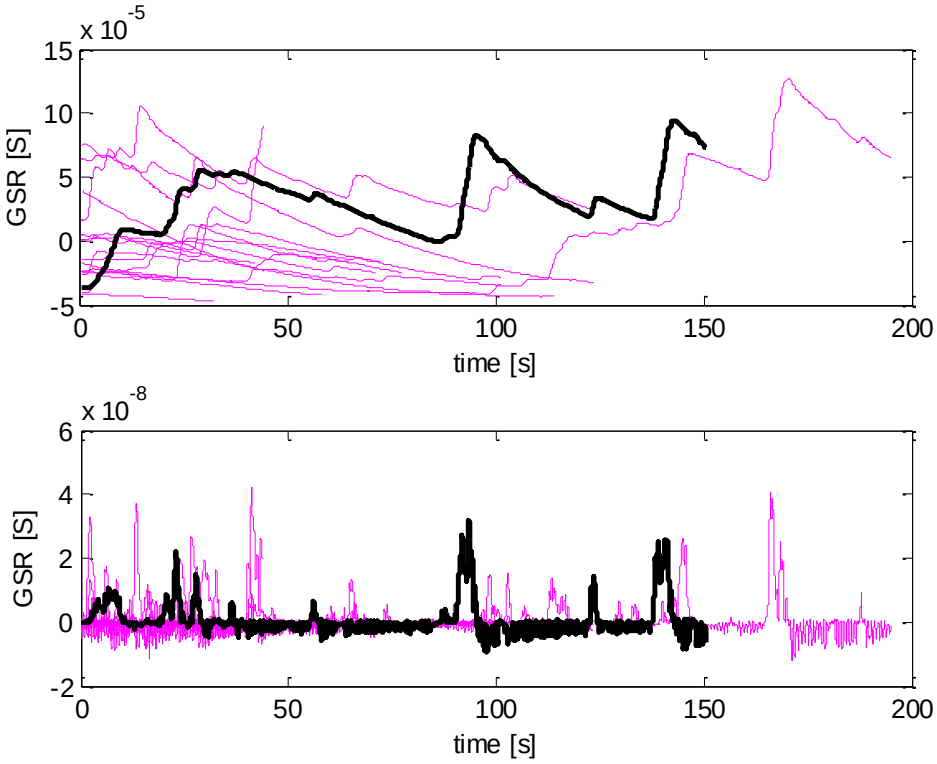


Fig. 12 (a) Process of detection of blinking (b) with detail.

(a)



(b)

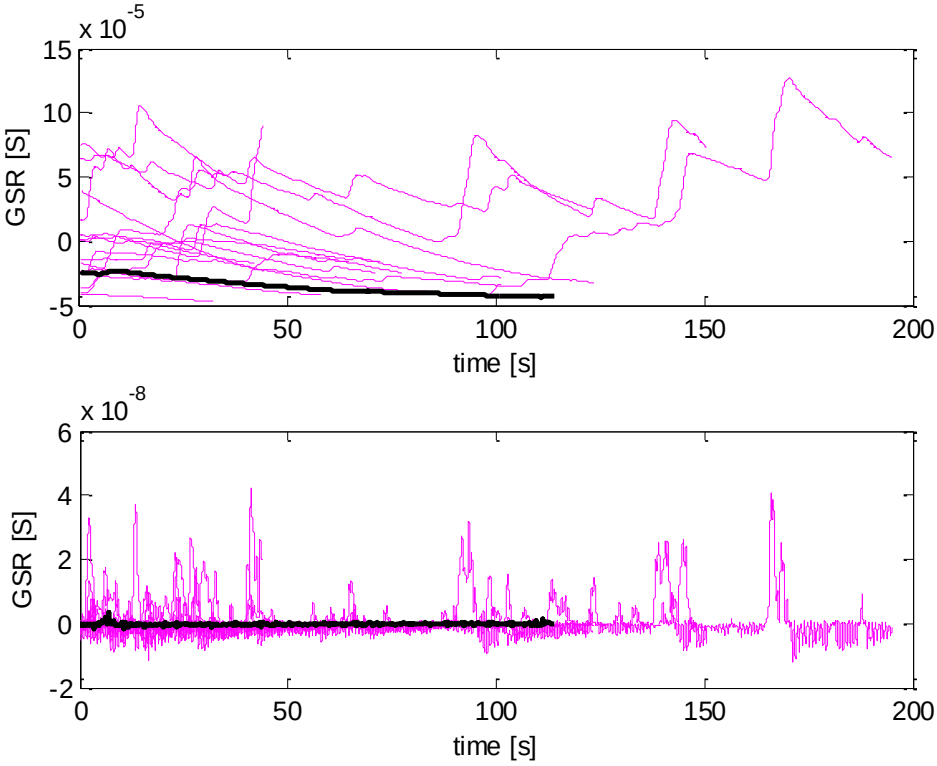


Fig. 13 (a) reactive response to the film clip (b) no response to the film clip.

3.2. Evaluation of Reactivity

In Fig. 13 the GSR from all selected film clips is visualized in one graph and the response to the specific clip is highlighted. Fig. 13 shows the difference between reactive and unreactive responses to the clip. If the subject is aroused by the film clip, the GSR is increased. The second picture in Fig. 13 is the differential of the GSR. There are noticeable peaks created as the reactive response. In contrast, third and fourth picture in Fig. 13 shows how the response to the film clip looks with no arousal. The amplitude of the GSR decreases during the film clip and no noticeable changes in the amplitude appears.

The film clips with the reactive response were selected from the available records to increase the chance of frontal asymmetry detection. Only film clips which were positive or negative in general were used. Sometimes the reactive response occurred in case of neutral clip.

3.3. Reference Electrode Choice

The usage of the scalp surface Laplacian is visualized. The comparison of the potential referred to the forehead electrode and after the use of the Laplacian over the whole scalp is in Fig. 14. The difference between these two choices of reference is in spatial resolution. When the Laplacian is used, the activity under each electrode is accentuated. The spatial resolution is better.

(a) (b)

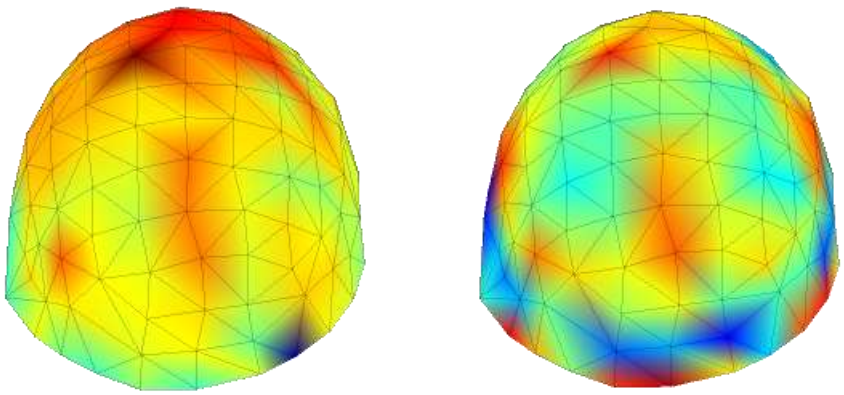


Fig. 14 Comparison of two different references (a) forehead electrode (b) surface Laplacian.

3.4. *Testing and Validation of the Algorithm*

This section presents the results of the algorithm applied on the simulated data. In Table 1, Table 2 and Table 3 the power differences of 3 selected electrodes combinations are shown. Each table represents one type of reference; two types of normalization are covered in each table. Green numbers represents the positive values and red numbers represents the negative values.

The set of simulation data which represented the positive film clips had the opposite asymmetry than the dataset of simulation represented the negative film clips.

Table 1 Power differences estimated from simulation data – forehead electrode reference.

	Resting EEG			**Weighted average**		
	Difference [dB]			**Difference [dB]**		
Film clip	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**
Positive 1	-3.703	-11.491	-10.453	-6.066	-8.828	-8.060
Positive 2	-3.693	-11.339	-10.258	-6.056	-8.676	-7.865
Positive 3	-3.659	-11.341	-10.297	-6.022	-8.678	-7.904
Positive 4	-3.725	-11.469	-10.398	-6.088	-8.806	-8.005
Negative 1	8.441	6.101	5.581	6.078	8.764	7.974
Negative 2	8.427	6.073	5.532	6.064	8.736	7.926
Negative 3	8.419	6.074	5.568	6.056	8.737	7.961
Negative 4	8.399	6.087	5.581	6.036	8.750	7.974

Table 2 Power differences estimated from simulation data – Cz electrode reference.

	Resting EEG			**Weighted average**		
	Difference [dB]			**Difference [dB]**		
Film clip	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**
Positive 1	-3.905	-11.947	-11.125	-6.439	-9.520	-8.899
Positive 2	-3.722	-11.421	-10.491	-6.256	-8.994	-8.265
Positive 3	-3.671	-11.347	-10.392	-6.205	-8.920	-8.166
Positive 4	-3.824	-11.712	-10.858	-6.359	-9.285	-8.633
Negative 1	8.866	6.769	6.284	6.332	9.196	8.510
Negative 2	8.849	6.735	6.213	6.315	9.161	8.439
Negative 3	8.866	6.783	6.319	6.332	9.210	8.545
Negative 4	8.816	6.724	6.245	6.281	9.151	8.471

Table 3 Power differences estimated from simulation data – surface Laplacian reference.

	Resting EEG			Weighted average		
	Difference [dB]			Difference [dB]		
Film clip	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**
Positive 1	-3.652	-10.369	-9.900	-0.962	-8.824	-8.097
Positive 2	-3.655	-10.262	-9.668	-0.965	-8.716	-7.865
Positive 3	-3.660	-10.240	-9.646	-0.970	-8.695	-7.844
Positive 4	-3.544	-10.292	-9.744	-0.855	-8.746	-7.942
Negative 1	1.779	7.225	6.150	0.911	8.770	7.953
Negative 2	1.701	7.200	6.075	0.989	8.746	7.878
Negative 3	1.730	7.180	6.149	0.959	8.726	7.952
Negative 4	1.797	7.194	6.163	0.892	8.739	7.965

Combinations of all used references and normalization were assessed. In each case the power difference of "positive film clips" has the opposite polarity than the power difference of "negative film clips".

Therefore, the results of the simulation proved the correctness of the implemented algorithm.

3.5. Significance Level Estimation

This section shows results of the significance levels estimation of all used types of references and normalization using the simulation. First, the distributions of differences in 1600 samples in the simulated data are visualised in Fig. 15. Next, the 0.3% quantile and the 99.7% quantile computed from the distributions are summarized in Table 4.

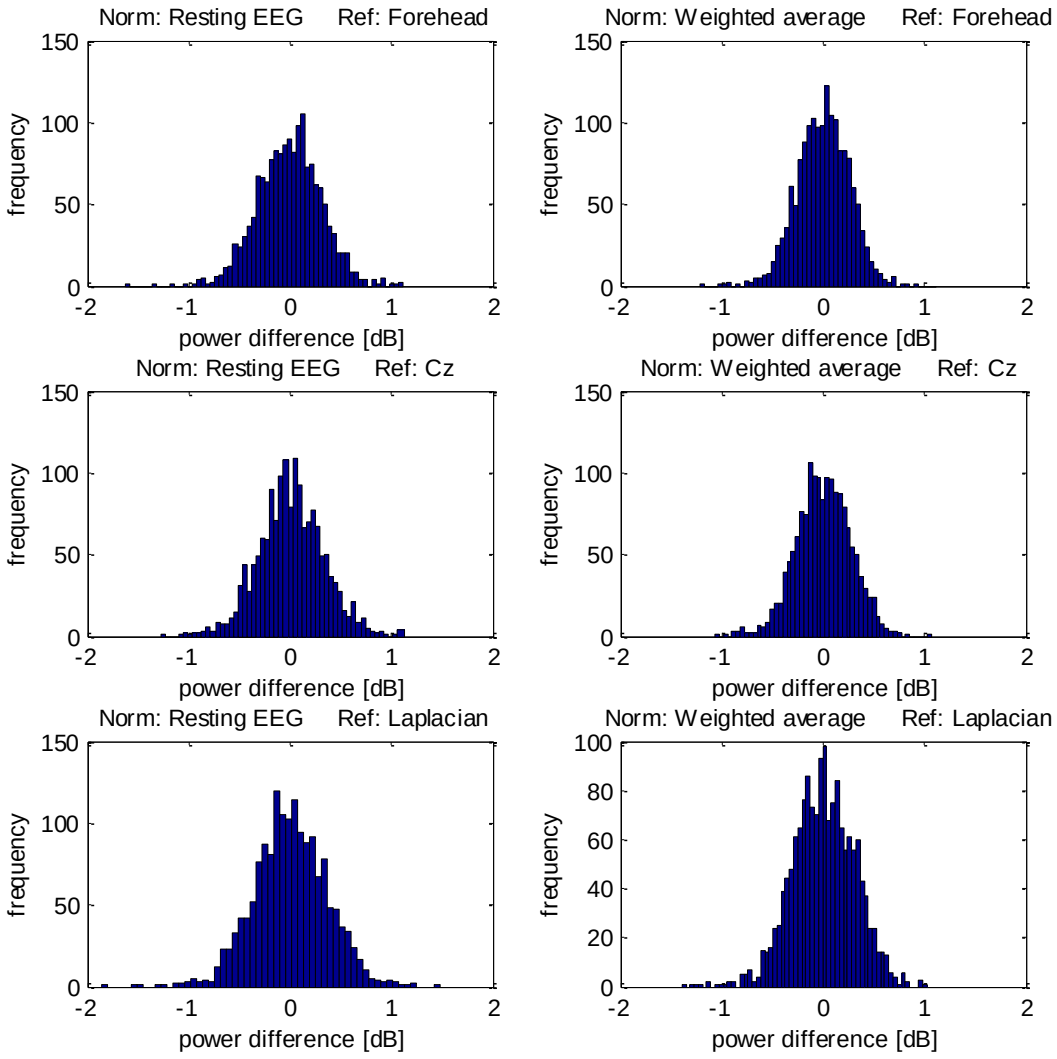


Fig. 15 Histograms of distribution of power differences in combinations of normalization and references in simulation sample. *Norm* denotes the type of the normalization, *Resting EEG* denotes the normalization to the power of the resting EEG and *Weighted average* denotes the normalization using the weighted average of all film clips. *Ref* denotes the type of the reference. *Forehead* denotes the forehead electrode reference, *Cz* denotes the Cz electrode reference and *Laplacian* denotes the surface Laplacian reference.

Table 4 Significance levels for combinations of normalizations and references.

	Resting EEG		**Weighted average**	
	0.3% quantile	**99.7% quantile**	**0.3% quantile**	**99.7% quantile**
Forehead	-0.929	0.922	-0.897	0.704
Cz	-0.967	1.009	-0.862	0.721
Surface Laplacian	-1.228	1.094	-1.136	0.824

3.6. Application of the Algorithm on the Real Data

This chapter presents the results of the algorithm applied on the real data. The general description of selected reactive subjects is in Table 5. It includes gender, age and handedness.

Table 5 Description of selected subjects.

Subject	Gender	Age	Handedness
1	male	20	left
2	male	19	left
3	male	26	right
4	male	24	right
5	female	21	right
6	female	21	right
7	female	20	right
8	male	21	right
9	male	21	right
10	female	20	right

The significance levels (thresholds) from Table 4 were used for the assessment of the statistical significance of the power differences in the real data for 10 selected subjects. The complete results of the power differences for 10 selected subjects are in tables from Table 6 to Table 35. The tables summarize the power differences computed for the combination of 2 described normalizations and 3 choices of reference electrode. Three combinations of the symmetrical electrodes were selected to cover the average power of the frontal lobes.

In the table, the red and green numbers represent statistically significant results according to the estimated significance levels. Red numbers are below the 0.3% quantile and green numbers are above the 99.7% quantile. *Resting EEG* denotes normalization to the power of the resting EEG in the alpha band. *Weighted* denotes normalization using the weighted average of all film clips.

Results of one subject are summarized in 3 tables. Each table represents one reference. The first table summarizes the results of the forehead electrode reference, the second table summarizes the results for the Cz electrode reference and the last table summarizes the scalp surface Laplacian reference.

Results for subject 1 (20 years old left-handed male)

Table 6 Power differences estimated from real data - subject 1 – forehead electrode reference.

	Resting EEG			Weighted		
	Difference [dB]			Difference [dB]		
Film clip	**El. 1 and 3**	**El. El. 5 and 9**	**El. El. 13 and 17**	**El. 1 and 3**	**El. El. 5 and 9**	**El. El. 13 and 17**
Positive 1	**-1.365**	-0.758	**-1.194**	-0.033	-0.210	0.115
Positive 2	**-1.509**	-0.493	**-1.762**	-0.464	0.055	-0.454
Positive 3	-0.869	-0.356	**-1.130**	0.176	0.192	0.179
Positive 4	**-1.233**	-0.679	**-1.508**	-0.188	-0.131	-0.199
Negative 1	**-0.938**	-0.722	**-1.231**	0.107	-0.174	0.078
Negative 2	**-1.397**	-0.440	**-1.192**	-0.352	0.109	0.117
Negative 3	-0.671	-0.005	-0.803	0.373	0.543	0.506
Negative 4	-0.799	-0.561	**-1.505**	0.246	-0.013	-0.196

Table 7 Power differences estimated from real data - subject 1 – Cz electrode reference.

	Resting EEG Cz			Weighted		
	Difference [dB]			Difference [dB]		
Film clip	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**
Positive 1	-0.595	-0.787	-0.826	-0.027	-0.033	-0.180
Positive 2	-0.590	-0.604	-0.591	-0.022	0.150	0.055
Positive 3	-0.549	-0.803	-0.635	0.019	-0.049	0.011
Positive 4	-0.460	-0.612	-0.443	0.108	0.142	0.202
Negative 1	-0.400	-0.726	-0.223	0.168	0.028	0.423
Negative 2	-0.640	-0.703	-0.816	-0.073	0.051	-0.170
Negative 3	-0.878	**-1.464**	**-1.227**	-0.311	-0.710	-0.581
Negative 4	-0.577	-0.644	-0.607	-0.010	0.110	0.038

Table 8 Power differences estimated from real data - subject 1 – surface Laplacian reference.

	Resting EEG			Weighted		
	Difference [dB]			Difference [dB]		
Film clip	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**
Positive 1	-1.140	**-2.578**	**-2.060**	-0.049	-0.038	0.149
Positive 2	-1.114	**-1.972**	**-2.781**	-0.022	0.568	-0.572
Positive 3	-1.037	**-2.380**	**-2.184**	0.054	0.160	0.025
Positive 4	-1.095	**-2.514**	**-2.526**	-0.003	0.026	-0.317
Negative 1	**-1.505**	**-3.205**	**-1.747**	-0.413	-0.665	0.462
Negative 2	-0.837	**-2.265**	**-1.570**	0.254	0.275	0.639
Negative 3	-0.643	**-2.453**	**-2.020**	0.448	0.087	0.189
Negative 4	-1.198	**-2.613**	**-2.610**	-0.107	-0.072	-0.401

Results for subject 2 (19 years old left-handed male)

Table 9 Power differences estimated from real data - subject 2 – forehead electrode reference.

	Resting EEG			Weighted		
	Difference [dB]			Difference [dB]		
Film clip	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**
Positive 1	**-1.416**	**-2.363**	**-1.547**	**0.816**	0.045	0.220
Positive 2	**-3.812**	**-3.441**	**-2.978**	**-1.579**	**-1.034**	**-1.211**
Positive 3	**-1.572**	**-1.489**	**-1.053**	0.660	**0.919**	**0.714**
Negative 1	**-2.471**	**-2.584**	**-2.017**	-0.239	-0.176	-0.250
Negative 2	**-2.406**	**-2.590**	**-1.883**	-0.173	-0.182	-0.116
Negative 3	**-2.828**	**-2.201**	**-1.619**	-0.595	0.207	0.148

Table 10 Power differences estimated from real data - subject 2 – Cz electrode reference.

	Resting EEG			Weighted		
	Difference [dB]			Difference [dB]		
Film clip	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**
Positive 1	-0.390	-0.633	-0.634	0.163	-0.014	-0.143
Positive 2	-0.610	-0.153	0.540	-0.056	0.466	**1.031**
Positive 3	-0.294	-0.209	0.328	0.260	0.409	**0.819**
Negative 1	-0.727	-0.667	-0.909	-0.173	-0.048	-0.418
Negative 2	-0.666	-0.856	-0.721	-0.112	-0.237	-0.230
Negative 3	-0.685	-0.800	-0.809	-0.131	-0.181	-0.319

Table 11 Power differences estimated from real data - subject 2 – surface Laplacian reference.

	Resting EEG			Weighted		
	Difference [dB]			Difference [dB]		
Film clip	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**
Positive 1	0.362	**-3.421**	**-3.336**	0.275	-0.135	-0.286
Positive 2	-0.688	**-3.980**	**-3.333**	-0.776	-0.694	-0.283
Positive 3	0.728	**-2.303**	**-1.788**	0.641	**0.983**	**1.262**
Negative 1	-0.153	**-3.290**	**-3.264**	-0.240	-0.004	-0.214
Negative 2	-0.028	**-3.390**	**-3.252**	-0.115	-0.103	-0.202
Negative 3	-0.091	**-3.362**	**-2.967**	-0.178	-0.076	0.083

Results for subject 3 (26 years old right-handed male)

Table 12 Power differences estimated from real data - subject 3 – forehead electrode reference.

	Resting EEG			Weighted		
	Difference [dB]			Difference [dB]		
Film clip	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**
Positive 1	**2.507**	**1.403**	0.243	0.481	**-0.992**	0.149
Positive 2	**4.015**	**1.659**	-0.067	**1.990**	-0.736	-0.160
Positive 3	**1.055**	**4.468**	0.027	**-0.970**	**2.072**	-0.066
Negative 1	**1.628**	**1.336**	-0.148	-0.397	**-1.059**	-0.241
Negative 2	**2.695**	**1.983**	0.357	0.670	-0.412	0.264
Negative 3	**1.141**	**2.352**	0.237	-0.885	-0.044	0.144

Table 13 Power differences estimated from real data - subject 3 – Cz electrode reference.

	Resting EEG			Weighted		
	Difference [dB]			Difference [dB]		
Film clip	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**
Positive 1	-0.446	**-1.546**	**-1.279**	-0.044	**-0.944**	-0.087
Positive 2	-0.007	-0.825	**-1.106**	0.396	-0.224	0.087
Positive 3	-0.444	1.030	-0.849	-0.042	**1.632**	0.343
Negative 1	-0.643	**-1.498**	**-1.552**	-0.241	**-0.896**	-0.359
Negative 2	-0.370	**-1.244**	**-1.395**	0.032	-0.642	-0.203
Negative 3	-0.499	-0.643	**-1.240**	-0.096	-0.041	-0.048

Table 14 Power differences estimated from real data - subject 3 – surface Laplacian reference.

	Resting EEG			Weighted		
	Difference [dB]			Difference [dB]		
Film clip	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**
Positive 1	0.436	**1.578**	**-3.848**	-0.033	-0.807	-0.252
Positive 2	-0.176	**2.091**	**-3.641**	-0.646	-0.294	-0.045
Positive 3	0.703	**4.219**	**-3.222**	0.234	**1.834**	0.374
Negative 1	0.556	**1.423**	**-3.700**	0.087	-0.962	-0.103
Negative 2	0.404	**1.712**	**-3.726**	-0.066	-0.674	-0.130
Negative 3	0.726	**2.163**	**-3.660**	0.257	-0.222	-0.063

Results for subject 4 (24 years old right-handed male)

Table 15 Power differences estimated from real data - subject 4 – forehead electrode reference.

	Resting EEG			Weighted		
	Difference [dB]			Difference [dB]		
Film clip	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**
Positive 1	**1.785**	-0.799	-0.386	0.388	-0.131	0.018
Positive 2	**1.163**	-0.677	-0.343	-0.234	-0.009	0.062
Positive 3	**1.302**	-0.741	-0.436	-0.096	-0.074	-0.032
Negative 1	**2.044**	-0.047	-0.143	0.647	0.620	0.261
Negative 2	**1.171**	**-1.150**	-0.611	-0.226	-0.483	-0.206
Negative 3	**1.201**	-0.522	-0.410	-0.197	0.145	-0.005

Table 16 Power differences estimated from real data - subject 4 – Cz electrode reference.

	Resting EEG			Weighted		
	Difference [dB]			Difference [dB]		
Film clip	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**
Positive 1	**-1.215**	-0.908	**-1.681**	-0.191	-0.260	-0.489
Positive 2	**-1.104**	**-0.985**	**-1.627**	-0.080	-0.338	-0.435
Positive 3	**-0.970**	-0.697	**-1.192**	0.054	-0.050	0.000
Negative 1	-0.942	-0.724	**-1.185**	0.082	-0.076	0.007
Negative 2	-0.945	-0.366	-0.843	0.079	0.281	0.349
Negative 3	**-0.990**	-0.407	-0.881	0.034	0.241	0.312

Table 17 Power differences estimated from real data - subject 4 – surface Laplacian reference.

	Resting EEG			Weighted		
	Difference [dB]			Difference [dB]		
Film clip	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**
Positive 1	**-3.050**	**-1.508**	**-3.031**	-0.158	-0.264	-0.206
Positive 2	**-2.870**	**-1.622**	**-2.885**	0.023	-0.378	-0.059
Positive 3	**-2.860**	**-1.318**	**-2.851**	0.033	-0.074	-0.026
Negative 1	**-3.162**	-0.822	**-2.586**	-0.269	0.422	0.239
Negative 2	**-3.012**	**-1.324**	**-2.958**	-0.120	-0.080	-0.133
Negative 3	**-2.697**	-0.987	**-2.677**	0.195	0.257	0.149

Results for subject 5 (21 years old right-handed female)

Table 18 Power differences estimated from real data - subject 5 – forehead electrode reference.

	Resting EEG			Weighted		
	Difference [dB]			Difference [dB]		
Film clip	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**
Positive 1	0.757	**-1.012**	**1.177**	0.237	0.065	-0.108
Positive 2	0.595	**-0.984**	**1.392**	0.075	0.093	0.107
Positive 3	0.465	**-0.989**	**1.413**	-0.055	0.089	0.128
Positive 4	0.343	**-1.085**	**1.104**	-0.177	-0.007	-0.181
Negative 1	**1.707**	-0.324	**2.629**	**1.187**	**0.753**	**1.344**
Negative 2	0.151	**-1.410**	0.808	-0.369	-0.332	-0.477
Negative 3	0.494	**-0.967**	**1.160**	-0.026	0.111	-0.125
Negative 4	0.393	**-1.261**	**1.374**	-0.127	-0.184	0.090

Table 19 Power differences estimated from real data - subject 5 – Cz electrode reference.

	Resting EEG			Weighted		
	Difference [dB]			Difference [dB]		
Film clip	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**
Positive 1	-0.673	-0.120	-0.464	-0.119	-0.262	-0.372
Positive 2	-0.463	0.161	-0.055	0.091	0.019	0.036
Positive 3	-0.327	0.570	0.162	0.227	0.428	0.253
Positive 4	-0.545	0.268	0.137	0.009	0.126	0.228
Negative 1	-0.458	-0.058	-0.195	0.096	-0.200	-0.104
Negative 2	-0.870	-0.244	-0.467	-0.316	-0.386	-0.375
Negative 3	-0.282	0.452	0.191	0.272	0.310	0.282
Negative 4	-0.545	0.251	-0.014	0.008	0.109	0.078

Table 20 Power differences estimated from real data - subject 5 – surface Laplacian reference.

	Resting EEG			Weighted		
	Difference [dB]			Difference [dB]		
Film clip	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**
Positive 1	0.052	**-1.556**	-1.071	0.372	0.247	-0.352
Positive 2	-0.175	**-2.155**	-0.733	0.145	-0.352	-0.014
Positive 3	-0.710	**-1.632**	-0.580	-0.389	0.171	0.139
Positive 4	-0.581	**-1.597**	-0.603	-0.260	0.206	0.116
Negative 1	0.077	**-1.494**	0.519	0.397	0.309	**1.238**
Negative 2	-0.350	**-1.840**	**-1.977**	-0.030	-0.037	**-1.257**
Negative 3	-0.309	**-1.665**	-0.793	0.012	0.138	-0.074
Negative 4	-0.423	**-2.055**	-0.176	-0.102	-0.252	0.543

Results for subject 6 (21 years old right-handed female)

Table 21 Power differences estimated from real data - subject 6 – forehead electrode reference.

	Resting EEG			Weighted		
	Difference [dB]			Difference [dB]		
Film clip	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**
Positive 1	**3.935**	0.467	**3.852**	**1.522**	**-1.192**	-0.596
Positive 2	**1.673**	**1.819**	**3.961**	-0.740	0.160	-0.487
Negative 1	**2.777**	**1.543**	**3.853**	0.365	-0.116	-0.594
Negative 2	**2.047**	**2.298**	**5.547**	-0.366	0.638	**1.099**

Table 22 Power differences estimated from real data - subject 6 – Cz electrode reference.

	Resting EEG			Weighted		
	Difference [dB]			Difference [dB]		
Film clip	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**
Positive 1	0.624	-0.559	**0.956**	**0.781**	**-0.937**	0.454
Positive 2	-0.496	0.645	0.013	-0.339	0.268	-0.489
Negative 1	-0.654	0.854	0.382	-0.497	0.477	-0.120
Negative 2	-0.115	0.510	0.752	0.043	0.133	0.250

Table 23 Power differences estimated from real data - subject 6 – surface Laplacian reference.

	Resting EEG			Weighted		
	Difference [dB]			Difference [dB]		
Film clip	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**
Positive 1	0.276	**2.161**	**1.332**	-0.684	**-1.337**	-0.303
Positive 2	1.087	**4.159**	**1.470**	0.128	0.661	-0.165
Negative 1	1.067	**3.904**	**1.290**	0.108	0.406	-0.344
Negative 2	**1.220**	**3.519**	**2.126**	0.260	0.021	0.492

Results for subject 7 (20 years old right-handed female)

Table 24 Power differences estimated from real data - subject 7 – forehead electrode reference.

	Resting EEG			Weighted		
	Difference [dB]			Difference [dB]		
Film clip	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**
Positive 1	0.902	**-2.759**	-0.311	-0.553	0.233	**0.840**
Positive 2	**1.654**	**-2.945**	**-1.411**	0.199	0.047	-0.260
Positive 3	**2.443**	**-2.336**	0.480	**0.989**	0.656	**1.631**
Positive 4	0.717	**-3.635**	**-1.200**	-0.738	-0.643	-0.049
Negative 1	**2.090**	**-2.948**	**-1.505**	0.635	0.044	-0.354
Negative 2	**1.957**	**-2.752**	**-1.642**	0.503	0.240	-0.491
Negative 3	**1.984**	**-2.757**	**-1.344**	0.529	0.235	-0.193
Negative 4	**1.449**	**-2.939**	**-1.306**	-0.006	0.054	-0.155

Table 25 Power differences estimated from real data - subject 7 – Cz electrode reference.

	Resting EEG			Weighted		
	Difference [dB]			Difference [dB]		
Film clip	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**
Positive 1	-0.564	-0.084	-0.223	0.001	-0.071	0.109
Positive 2	-0.606	-0.108	-0.604	-0.041	-0.095	-0.273
Positive 3	-0.735	-0.296	-0.894	-0.169	-0.283	-0.562
Positive 4	-0.554	-0.063	-0.278	0.011	-0.050	0.054
Negative 1	-0.426	0.320	0.090	0.140	0.333	0.422
Negative 2	-0.599	-0.079	-0.563	-0.034	-0.066	-0.231
Negative 3	-0.696	-0.107	-0.467	-0.131	-0.094	-0.136
Negative 4	-0.476	0.199	-0.043	0.089	0.212	0.289

Table 26 Power differences estimated from real data - subject 7 – surface Laplacian reference.

	Resting EEG			Weighted		
	Difference [dB]			Difference [dB]		
Film clip	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**
Positive 1	-0.898	**-3.568**	**-1.536**	-0.169	-0.981	**1.594**
Positive 2	-0.565	**-2.196**	**-4.752**	0.164	0.391	**-1.622**
Positive 3	-0.083	**-3.750**	**-1.967**	0.646	**-1.163**	**1.164**
Positive 4	-1.063	**-3.173**	**-1.547**	-0.334	-0.586	**1.583**
Negative 1	-1.036	**-3.032**	**-3.220**	-0.307	-0.445	-0.090
Negative 2	-0.458	**-1.361**	**-4.378**	0.271	**1.226**	**-1.247**
Negative 3	-0.576	**-1.919**	**-4.399**	0.153	0.668	**-1.269**
Negative 4	-0.701	**-2.330**	**-3.409**	0.028	0.257	-0.279

Results for subject 8 (21 years old right-handed male)

Table 27 Power differences estimated from real data - subject 8 – forehead electrode reference.

	Resting EEG			Weighted		
	Difference [dB]			Difference [dB]		
Film clip	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**
Positive 1	**-2.639**	**-2.959**	**-1.644**	**-5.042**	-0.051	0.300
Positive 2	**5.178**	**-2.790**	**-1.748**	**2.775**	0.118	0.195
Positive 3	**4.728**	**-2.923**	**-2.411**	**2.325**	-0.014	-0.467
Negative 1	**-2.248**	**-2.823**	**-1.634**	**-4.650**	0.085	0.310
Negative 2	**5.404**	**-2.305**	**-1.267**	**3.001**	0.603	0.677
Negative 3	**4.281**	**-3.209**	**-2.275**	**1.878**	-0.301	-0.331

Table 28 Power differences estimated from real data - subject 8 – Cz electrode reference.

	Resting EEG			Weighted		
	Difference [dB]			Difference [dB]		
Film clip	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**
Positive 1	-0.873	**-1.031**	**-1.063**	0.264	0.035	0.130
Positive 2	**-1.244**	**-1.076**	**-1.075**	-0.107	-0.010	0.118
Positive 3	**-1.185**	-0.738	-0.921	-0.048	0.328	0.272
Negative 1	-0.881	**-1.318**	**-1.363**	0.256	-0.252	-0.170
Negative 2	**-1.244**	**-1.335**	**-1.522**	-0.107	-0.269	-0.329
Negative 3	**-1.358**	**-1.149**	**-1.389**	-0.220	-0.083	-0.196

Table 29 Power differences estimated from real data - subject 8 – surface Laplacian reference.

	Resting EEG			Weighted		
	Difference [dB]			Difference [dB]		
Film clip	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**
Positive 1	**-1.670**	**-3.326**	-0.359	**1.015**	-0.637	**1.045**
Positive 2	**-3.028**	**-2.528**	**-1.369**	-0.343	0.161	0.034
Positive 3	**-3.234**	**-2.279**	**-2.107**	-0.550	0.410	-0.704
Negative 1	**-1.527**	**-3.171**	-0.960	**1.158**	-0.482	0.443
Negative 2	**-2.867**	**-2.174**	**-1.812**	-0.182	0.515	-0.409
Negative 3	**-3.401**	**-2.589**	**-1.642**	-0.717	0.100	-0.239

Results for subject 9 (21 years old right-handed male)

Table 30 Power differences estimated from real data - subject 9 – forehead electrode reference.

	Resting EEG			Weighted		
	Difference [dB]			Difference [dB]		
Film clip	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**
Positive 1	**10.312**	**1.915**	0.022	**1.154**	0.275	0.036
Positive 2	**10.840**	**1.483**	-0.331	**1.681**	-0.157	-0.317
Positive 3	**9.659**	**2.155**	0.326	0.500	0.515	0.340
Positive 4	**7.548**	**1.189**	0.016	**-1.610**	-0.452	0.030
Negative 1	**10.754**	**1.790**	-0.287	**1.595**	0.150	-0.273
Negative 2	**10.118**	**1.819**	0.318	**0.959**	0.178	0.331
Negative 3	**8.955**	**1.291**	0.321	-0.204	-0.349	0.335
Negative 4	**7.887**	**1.597**	-0.377	**-1.271**	-0.043	-0.363

Table 31 Power differences estimated from real data - subject 9 – Cz electrode reference.

	Resting EEG			Weighted		
	Difference [dB]			Difference [dB]		
Film clip	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**
Positive 1	-0.449	-0.583	-0.594	-0.017	0.194	0.064
Positive 2	-0.458	-0.607	-0.613	-0.369	-0.197	0.089
Positive 3	-0.526	-0.569	-0.579	-0.110	-0.438	-0.115
Positive 4	-0.770	-0.615	-0.594	0.077	0.038	-0.068
Negative 1	-0.387	-0.590	-0.610	0.007	-0.204	-0.160
Negative 2	-0.440	-0.585	-0.579	0.179	-0.405	-0.150
Negative 3	-0.671	-0.618	-0.580	-0.114	0.042	0.153
Negative 4	-0.780	-0.600	-0.614	0.005	0.430	0.175

Table 32 Power differences estimated from real data - subject 9 – surface Laplacian reference.

	Resting EEG			Weighted		
	Difference [dB]			Difference [dB]		
Film clip	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**
Positive 1	**-3.451**	-0.336	**-2.714**	0.231	0.471	-0.075
Positive 2	**-4.279**	-0.558	**-3.618**	-0.598	0.250	-0.979
Positive 3	**-3.055**	-0.877	**-2.381**	0.626	-0.070	0.259
Positive 4	**-4.047**	**-1.488**	**-2.633**	-0.365	-0.680	0.006
Negative 1	**-3.526**	-0.642	**-2.774**	0.156	0.166	-0.134
Negative 2	**-3.474**	-0.574	**-2.059**	0.207	0.233	0.580
Negative 3	**-3.700**	-0.635	**-2.125**	-0.019	0.172	0.514
Negative 4	**-3.888**	-0.813	**-3.002**	-0.207	-0.005	-0.363

Results for subject 10 (20 years old right-handed female)

Table 33 Power differences estimated from real data - subject 10 – forehead electrode reference.

	Resting EEG			Weighted		
	Difference [dB]			Difference [dB]		
Film clip	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**
Positive 1	0.541	**-1.690**	0.789	0.513	-0.170	-0.167
Positive 2	-0.023	**-1.314**	**1.217**	-0.051	0.205	0.262
Positive 3	-0.168	**-1.320**	**1.409**	-0.196	0.199	0.453
Positive 4	-0.183	**-1.710**	0.848	-0.211	-0.191	-0.108
Negative 1	0.193	**-1.999**	0.224	0.165	-0.480	-0.732
Negative 2	0.191	**-1.311**	**1.296**	0.163	0.208	0.340
Negative 3	-0.057	**-1.422**	0.814	-0.085	0.097	-0.142

Table 34 Power differences estimated from real data - subject 10 – Cz electrode reference.

	Resting EEG			Weighted		
	Difference [dB]			Difference [dB]		
Film clip	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**
Positive 1	-0.570	-0.601	-0.603	-0.180	-0.152	-0.108
Positive 2	-0.599	-0.587	-0.585	0.027	0.045	0.112
Positive 3	-0.606	-0.588	-0.577	-0.066	-0.377	-0.178
Positive 4	-0.606	-0.604	-0.600	-0.116	-0.243	-0.088
Negative 1	-0.588	-0.619	-0.626	-0.098	0.098	-0.064
Negative 2	-0.588	-0.585	-0.582	-0.071	0.285	0.395
Negative 3	-0.600	-0.594	-0.602	0.300	0.358	0.024

Table 35 Power differences estimated from real data - subject 10 – surface Laplacian reference.

	Resting EEG			Weighted		
	Difference [dB]			Difference [dB]		
Film clip	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**	**El. 1 and 3**	**El. 5 and 9**	**El. 13 and 17**
Positive 1	**-1.276**	-0.195	**-2.138**	0.254	-0.032	-0.894
Positive 2	**-1.495**	-0.359	-0.790	0.035	-0.195	0.454
Positive 3	**-1.645**	-0.005	-0.515	-0.115	0.158	0.729
Positive 4	**-1.525**	-0.284	-1.198	0.005	-0.121	0.046
Negative 1	**-1.976**	-0.403	**-1.797**	-0.446	-0.240	-0.553
Negative 2	**-1.533**	-0.793	-0.570	-0.003	-0.630	0.674
Negative 3	**-1.528**	0.368	**-1.559**	0.002	0.531	-0.315

4 DISCUSSION

In this chapter, the results of the pre-processing of the physiological signals, results of algorithm testing on the simulated data and application on the real data are discussed. Also, methodological weaknesses and advices for the future experiments are included.

4.1. Signal Pre-processing

The functionality of the algorithm for the pre-processing of the physiological signals was verified visually. As mentioned in Results, the inspection of the EEG pre-processing was performed in the real data from two randomly selected subjects. Based on the visual inspection it could be concluded, that the detection of movement and blinking was performed correctly.

4.2. Testing of the Algorithm on the Simulated Data

The algorithm detected correctly asymmetry of frontal brain sources in the simulated data, therefore it could be concluded, that the algorithm works properly.

4.3. Application of the Algorithm on the Real Data

When the algorithm was applied on the real data, it did not detect any frontal asymmetry that would correspond to the valence of presented stimuli. The obtained results mainly differ depending on the power normalization.

When the resting EEG normalization was used, the algorithm detected a lot of falsely significant results. This could be explained by several difficulties related to both the measurement procedure and the temporal evolution of brain signals. In the measurement signals the tags, which were available in the records, were saved incorrectly; the tags did not match with the intervals of the resting EEG record. Therefore, the time intervals were found manually. Moreover, in records from several subjects, parts with the resting EEG in the end of the record were missing. Hence, only the estimate of the power of the resting EEG from the

beginning of the record was used. For the evaluation, it would be more appropriate to use the power estimate from the beginning and from the end of the record and average it, because the baseline power could increase or decrease during the time period.

When the weighted average normalization was used, the algorithm detected only a small number of the falsely significant results, which did not seem to correspond to the valence of the film clips. While this normalization approach did not detect the frontal asymmetry, it provided much less false positive estimates than the resting EEG normalisation. Therefore, it is concluded that the weighted average normalization was more appropriate choice.

According to the results, the best combination of the reference electrode choice and the power normalization was the Cz electrode reference and the weighted average normalization, because in this combination the lowest amount of the falsely significant results appeared in comparison with other possibilities.

In comparison with the results presented in the literature, the lack of frontal asymmetry evoked by emotional stimuli is not completely unusual. While many works have presented some frontal asymmetry that corresponded to the stimuli valence, some works also did not detect this behaviour.

In work [46] the frontal brain asymmetry evoked by the positive and negative stimuli was not found, when the asymmetry was examined across the whole time period of the film clips. This paper illustrates the utility of using facial behaviour for evaluation. This findings supported results of this thesis, where facial behaviour was not involved.

Paper [49] showed decreased level of frontal asymmetry in a positive stimulus which came after a negative stimulus. This also supported results presented in this thesis, because the positive and negative stimuli were combined.

4.4. Methodological Weaknesses

The reasons of missing significant results which would have allowed the classification of physiological correlates of emotions are concluded.

The first problem was in the choice of the subjects. The selection was not based upon any research or according to the common interests or features. Subjects were chosen randomly as they were willing to undergo the experiment. In work [48] the selection of the subjects was based upon the personality questionnaire and according to the rate of the reaction to the stimuli.

The second problematic part was the duration of the placement of the EEG cap. It took about an hour, the process was tedious, the subjects might have been tired after one hour sitting in the chair and waiting.

Also, the film clips were selected to be strongly comical, sad or disgusting. But the reaction to the stimuli could not be uniform, e.g. stimuli that elicit disgust in one person could be boring or even interesting in the positive sense for the other person. Also, very disgusting clip could affect emotions for the whole measurement and appropriate reaction to the positive stimuli does not appear. The selection of the stimuli could be supported by additional study that would evaluate the effect of stimuli as in paper [46].

Next, the stimuli were presented immediately one after the other, time between two stimuli for recovery was just 30 seconds and the stimuli were combined randomly (in was mixture of positive, negative and neutral film clips) which could have affected the outcomes. Twenty-nine stimuli were presented and subjects might have not been able to react enough to all of them because it is a lot of emotions to be expressed in only one hour. The problem with combining negative and positive stimuli was mentioned in work [49], where the frontal brain asymmetry was found in response to the negative film clip, which went first in comparison with the positive film clip, which followed the negative and the asymmetry was not significant.

Last, no additional measurement was employed to detect time periods, where subjects made certain facial expressions. Work [46] showed, that no reliable differences in frontal brain asymmetry are found, if the analysis is made from the whole movie, contrarily, it was found in periods of time with facial expression.

4.5. Suggestions for Future Experiment

For the future study, there are some proposed methodological improvements regarding to the measurement, subjects selection and stimuli choice.

In the first place, the EEG measurement apparatus should be selected in respect to the shorter time of installation, so that the subjects are not tired from the long waiting. The replacement of the high density EEG cap is now available. The apparatus consists of the network of electrodes connected with the flexible fibre which is positioned on the head easily and quickly; the other advantage is that no conductive gel is necessary.

Next to the GSR method, other secondary measurement evaluating the reactivity and arousal should be employed. For example the facial expression should be assessed. In the processing of the signal only the time intervals with the facial expressions of happiness or disgust should be used from the whole film clip period. The camera recording could be used.

The right selection of subjects is one of the most important issues in the field of evaluation of emotions in response to the film clips. People in the similar age and all right-handed or left-handed should be recruited. To assure the comparable reaction to the stimuli, the uniform group of the subjects should be enrolled, e.g. people with similar hobbies and opinions should be found.

Last, the stimuli should be chosen precisely in respect to the group of examined subjects.

5 SUMMARY

This thesis was motivated by the need to classify emotions in response to the film clip stimuli. The common method of the emotion evaluation is the questionnaire, which suffers from several disadvantages. The disadvantages include subjectivity, misinterpretation of the feelings, untrue information etc. Therefore, aim of the thesis was to suggest and implement the algorithm for the classification of emotions.

Based on the reviewed literature, the EEG signal was selected for the algorithm. In the EEG signal, the frontal brain asymmetry in the alpha band was evaluated. The algorithm was designed in the following steps.

In the first step, the EEG signal was pre-processed. The technical artifacts were eliminated and biological artifacts were detected. After, the different electrode references were used. The forehead and Cz electrode reference and the reference-free technique, the scalp surface Laplacian were employed. Next, the signal was filtered to the alpha band. The last step of the pre-processing was normalization using the power of the resting EEG or the weighted average of the powers of all film clips. Last, the difference of the powers in two symmetrical leads was computed.

The Monte Carlo method was used for the statistical evaluation. The distribution of power difference in the left and right frontal lobe of the head model with zero asymmetry was obtained, and this distribution was used to establish the thresholds that were used for the testing of statistical significance of power differences estimated from real data.

Once the algorithm was implemented, the function of the algorithm was validated using the head model simulation with asymmetries in the frontal brain area. The results showed that the algorithm was able to identify the frontal brain asymmetry

When the algorithm was applied to the real it did not detect any frontal asymmetry that would correspond to the valence of the presented stimuli. The weighted average of the powers normalization brought negligible amount of the significant results and in case of the resting EEG normalization, no relation appeared between the emotional valence of the film clips and the frontal brain asymmetry.

For the future experiment some improvements were proposed. The selection of the subjects and the stimuli should be more precise. Also, the measurement tool for the EEG recording should enable faster application.

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APPENDIX

Structure of the DVD

The electronic version of the diploma thesis and data measured from one subject are recorded on the DVD attached to the thesis. The structure of the CD is following:

Folder: Diploma Thesis

- ClassificationOfPhysiologicalCorrelatesOfEmotions.pdf

Folder: Diploma Thesis Files

- **06** – the data measured from one subject
- **functions** – functions used in the algorithm
- **RUN_ClassificationOfPhysiologicalCorrelatesOfEmotions.m** – the algorithm implemented in MATLAB environment