The effect of Physiological changes on EEG

by
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Declaration

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Abstract

The study investigates the interaction between Electroencephalogram (EEG) signals and the following physiological parameters: heart rate, respiratory rate, finger temperature, galvanic skin response (GSR) and pupil diameter, due to emotion provoking stimuli. The project specifically focusses on investigating the correlation between physiological changes and changes in EEG-data due to emotional provoking images. The two primary research questions for this study are: Does exposure to the visual stimuli provoke an emotional state that can be perceived in the processed results? And: Does a statistical correlation exist between the physiological results and the EEG-data obtained?

The results show that the stimuli were only effective in provoking a measurable difference between the baseline and test-values for the EEG-data, not the physiological factors. The ANOVA-tests' results show that the specific participant always have a significant impact on the results, indicating a strong inter-participant variability. The results of the respiratory rate and skin temperature also indicated that the interaction between stimuli and participant had some influence on the resulting measurements.

To conclude, it is indeed possible to perceive a difference in EEG-measurements due to the emotional stimuli, but it wasn't possible to discern between different emotions based on the physiological and EEG-measurements. In the indication of change, the EEG-data proved to be the most effective, as this is the only parameter where statistically significant differences ($\alpha < 0.05$) could be established.

Uittreksel (Afrikaans)

Die studie ondersoek die interaksie tussen elektroenfalogram (EEG) seine en die volgende fisiologiese parameters: hartklop, respiratoriese tempo, vinger temperatuur, galvaniese vel reaksie (GSR) en pupil deursnee as gevolg van emosionele uitdagende stimuli. Die projek fokus spesifiek op die verhouding tussen fisiologiese veranderinge en veranderinge in EEG-data as gevolg van die emosioneel-uitdagende fotos. Die twee primêre navorsingsvrae vir hierdie studie is: Veroorsaak die blootstelling aan visuele stimuli 'n emosionele toestand wat in die verwerkte resultate waargeneem kan word? En: bestaan daar 'n statistiese korrelasie tussen die fisiologiese resultate en die EEG-data wat verkry word?

Die resultate toon dat die stimuli slegs 'n meetbare verskil tussen die basislyn en toetswaardes vir die EEG-data, nie die fisiologiese faktore nie, ontlok het. Die ANOVA-toetse se resultate toon dat die spesifieke deelnemer altyd 'n beduidende impak op die resultate het, wat 'n sterk wisselvalligheid tussen deelnemers aandui. Die resultate van die respiratoriese tempo en veltemperatuur het ook aangedui dat die interaksie tussen stimuli en deelnemer 'n mate van invloed op die gevolglike metings gehad het.

Ten slotte is dit inderdaad moontlik om 'n verskil in EEG-metings waar te neem as gevolg van die emosionele stimuli, maar dit was nie moontlik om tussen verskillende emosies te onderskei, gebaseer op die fisiologiese en EEG-metings nie. In terme van aanduiding van verandering, was die EEG-data die doeltreffendste, aangesien dit is die enigste parameter waar statisties beduidende verskille ($\alpha < 0.05$) bevestig kon word.

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In the completion of a Master's thesis there are many parts played by other people than the student themselves. I would like to acknowledge the following people for their part in my thesis:

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Dedication

I would like to dedicate this thesis submission to the following people who made it possible for me to complete it:

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Table of Contents

Page

List of Figures

Page

List of Tables

Nomenclature

Abbreviations and acronyms:

BERG	Biomedical Engineering Research Group
EEG	Electroencephalography
GSR	Galvanic Skin Response
HREC	Health Research and Ethics Committee
ICA	Independent Component Analysis
LED	Light Emitting Diode
OpenCV	Open Computer Vision
PC	Personal Computer
SAM	Self Assessment Manikin
PSD	Power Spectral Density
CNS	Central Nervous System
AV	Atrioventricular
SA	Sinoatrial
ECG	Electrocardiogram
SD	Standard Deviation

Symbols

Frequency	T	[Hz]
Voltage	V	[V]
Resistance	R	[Ω]
Impedance	I	[A]

Chapter 1

1 Introduction

The introduction chapter provides the reader with an overview of the thesis. The background and motivation for the research are described to explain why this research is done. The aims and objectives that is provided, clarifies how the study will be approached.

1.1 Background

The study originated from the need to monitor the EEG- and Physiological changes of a patient with Post Traumatic Stress Disorder (PTSD), with the goal of using a stimulus and physiological monitoring to rehabilitate the patients. It was decided that for this study only normal, healthy, participants would be involved. A different study using patients that suffer from PTSD is running concurrently, enabling the possible future comparisons between the two study's results. The decision to involve only normal participants will provide valuable information itself as it will enable us and future researchers to further understand the human brain and how it works.

This project is hypothesis-based and thus it is important to always keep the aim and objectives in mind. The experiment that is conducted needs to provide the necessary quantity and quality of data to enable the experimenter to make a logical finding regarding whether emotions can be discerned by monitored physiological responses and EEG signals obtained.

It is hypothesized that the results of this study would be able to indicate if it is possible to discern between different emotion groups based on EEG- and physiological measurements.

The idea of the project is to expose the participant to certain stimuli that would provoke different emotions and therefor different physiological states and changes in the EEG. The stimuli that will be used for this experiment is the pictures that were compiled by Bradley & Lang (2007) and is called the International Affective Picture System (IAPS). The test participants are monitored continuously to determine how their physiological states change. The test participants will also be subjected to an EEG throughout the duration of the test to determine whether there is any correlation between the EEG-signals obtained and their physiological state due to the emotion provoked by the stimuli.

The physiological effects included in the study are: Heart rate; Respiration rate; Finger temperature; Galvanic skin response; and Pupil dilation. These effects will be monitored in addition to obtaining EEG-data.

The project specifically focusses on investigating the correlation between physiological changes and changes in EEG-data due to emotion provoking stimuli. The biggest constraints of the project are that there is limited time in which the project should be finished and the financial expenses should be kept to a minimum. Ethical approval from the Health Research Ethical Committee (HREC) should be obtained before the testing of the participants can commence and thus it is a substantial constraint to the progress of the project. By starting the process of obtaining the ethical approval early, any unforeseen issues that might delay the project are avoided.

Since this project is highly dependent on participants to test the hypothesis on, the availability and willingness of participants to subject to these tests are also a major constraint. There is also the challenge that all the different physiological parameters (finger temperature, heart rate, respiratory rate, pupil dilation and galvanic skin response) must be recorded while an EEG is being recorded. This challenge provides an opportunity to design an experimental procedure that combines all these recordings.

1.2 Aims and Objectives

The aim of the project is to investigate the effect that emotional provoking stimuli have, by exploring the possible correlation between EEG-signals and the physiological state of the participant.

The objectives can be summarized as follows:

- Designing an experimental procedure that enables the experimenter to capture all the data needed for further analyses.
- Investigating the results of EEG-data with and without emotional stimuli present.
- Investigating the effect of emotional stimuli on physiological measurements
- Investigating the correlation between physiological factors and EEG-data, due to a change in emotions.
- Exploring the possibility of statistical discoveries between the physiological results and the EEG-data that arise from the processed results.
- Drawing conclusions from the results obtained and providing possible recommendations for future studies e.g. If any correlation exists, what is inferred by that particular correlation, and how does it contribute to the understanding of the human body?

1.3 Outline of Thesis

1.3.1 Chapter 2: Literature Review

Literature from past researchers are studied to determine if the present study is worth pursuing. The previous research provides the experimenters with possible outcomes and guidelines to construct their experimental procedure as well as pitfalls to avoid. The literature described in this section, is also used as a reference point from which to interpret and discuss the results from this study.

1.3.2 Chapter 3: Objectives

The objectives that will be investigated in this study are discussed after considering the literature that has been reviewed in the previous chapter.

1.3.3 Chapter 4: Hardware

All the equipment that was used during the thesis are described. The characteristics of the equipment as well as their functions are discussed.

1.3.4 Chapter 4: Methodology

This section describes the method that was used during the experiment, from the initial preparations to the final processing of the results. The statistical analyses that were applied to the results are also depicted in this section.

1.3.5 Chapter 5: Results and Findings

The results, after processing, are depicted in this section of the thesis. Several tables of the data and their descriptions are provided to allow the reader to follow the discussion in the next section.

1.3.6 Chapter 6: Discussion

This section provides the reader with the discussion of the results found in the study. The statistical significances are discussed and compared to existing literature. Further implications for this research field that arise from the processed results are debated and possible deficiencies in the results are discussed for possible future researchers.

1.3.7 Chapter 7: Limitations and Recommendations

All the complications that were encountered through the course of the thesis' projection is discussed with possible solutions for these limitations.

1.3.8 Chapter 9: Conclusion

A summary of the most profound discoveries that were made during the thesis. This section also marks the final chapter of the thesis and thus provides the implications of the discoveries that was made.

Chapter 2

2 Literature Review

Existing literature is reviewed to get a clear indication of what type of work has already been done, and where possible gaps are that can be addressed during the course of this project. In this project, the impact of several physiological phenomena on EEG-data is examined.

2.1 EEG

2.1.1 The Fundamentals of EEG

Electroencephalography (EEG) is a method that is used to determine where most electrical activity, generated by the structures within the brain, is present on the scalp. Recording an EEG is a completely non-invasive procedure as the electrodes are placed on the surface of the scalp. The biggest advantages of using EEG is that the EEG doesn't only record the standard and irregular electrical activity within the brain, but the temporal resolution are in the range of milliseconds, enabling the user to see changes as they occur. Because of the surface position of the cerebral cortex, the electrical activity from the cerebral cortex has the most profound impact on the EEG (Teplan, 2002). The electroencephalograph can be used to decipher neuroscientific anomalies that stem from the brain's response to stimuli (Daly *et al.*, 2012). It can therefore be used to identify abnormalities within the brain, like the symptoms of PTSD, which can then be further investigated and consequently, treated.

A worldwide convention, called the 10/20 system, specifies the placement of the electrodes on the scalp (Figure 1). The channels are grouped into 4 sections: the frontal channels - that is labelled with an F, the central channels - that is labelled with a C, the temporal channels - that is labelled with a T, and then the parietal and occipital region channels - that is labelled with either a P or an O. (Daly *et al.*, 2012). Once the EEG is recorded, the data accumulated can be presented within the five conventional frequency bands (shown in Figure 2): delta [0.5-4.0 Hz], theta [4.0-7.5 Hz], alpha [8.0-13.0 Hz], beta [12.0-30.0 Hz], and gamma [30-100 Hz]. (Dumont *et al.*, 2004; Sanei and Chambers, 2008; Daly *et al.*, 2012)

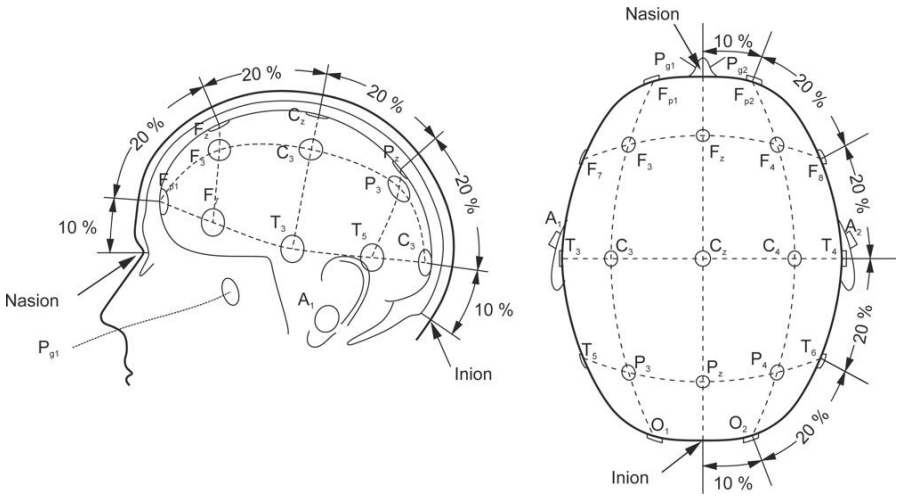

Figure 1: 10/20 placement of EEG electrodes on the scalp (Nicolas-Alonso and Gomez-Gil, 2012)

The frequency bands are used to map the mental and emotional activity that occurs within the brain, as described by Sanei and Chambers (2008) and BCI Developers (2015). The delta band is the slowest frequency band (0-4 Hz), and is primarily associated with relaxing and deep sleep, even though it may be present during waking state. If the brain produces too much delta waves, people would not be able to focus and possibly have learning disabilities and if the brain yields too little delta waves people will not be able to sleep well. The theta waves (4-7 Hz) are produced when sleeping or daydreaming. This specific frequency band is closely linked to emotions and arousal, as the absence of adequate theta waves can lead to poor emotional awareness and stress. According to Sanei and Chambers (2008) it is abnormal to observe large contingents of theta waves in waking adults, and could be caused by a range of pathological problems. Alpha frequency waves (8-12 Hz) are the range that connects the conscious thinking and the subconscious mind with each other, as it indicates relaxed awareness without any concentration or specific attention (Sanei and Chambers, 2008). Too much alpha activity would decrease your ability to focus, while the amount of alpha waves is reduced by anxiety, attention or mental concentration. The beta frequency waves (12-30 Hz) are the most commonly observed while we are awake, as it is associated with the conscious act of thinking. If your brain produces the optimal amount of beta-waves you can focus on your task at hand, and remember things more clearly.

Sanei and Chambers (2008) state that when a high-level of beta waves are present, it could be indicative of a panic state. The gamma waves (30-100 Hz) are involved in higher cognitive functions like learning, information processing and memory. Since there are minimal higher cognitive requirements during the experiment the investigation of the gamma waves are omitted from the investigation.

There are several characteristics that are associated with the different frequency bands, like the fact that alpha-rhythms are characteristically larger over the occipital regions than over the frontal regions. The amplitudes of the rhythms also vary between frequency bands, as the typical beta-rhythm will be lower than 30 µV while the alpha-rhythm usually have a value of 10 µV, but can range between 10 and 100 µV. (Daly *et al.*, 2012)

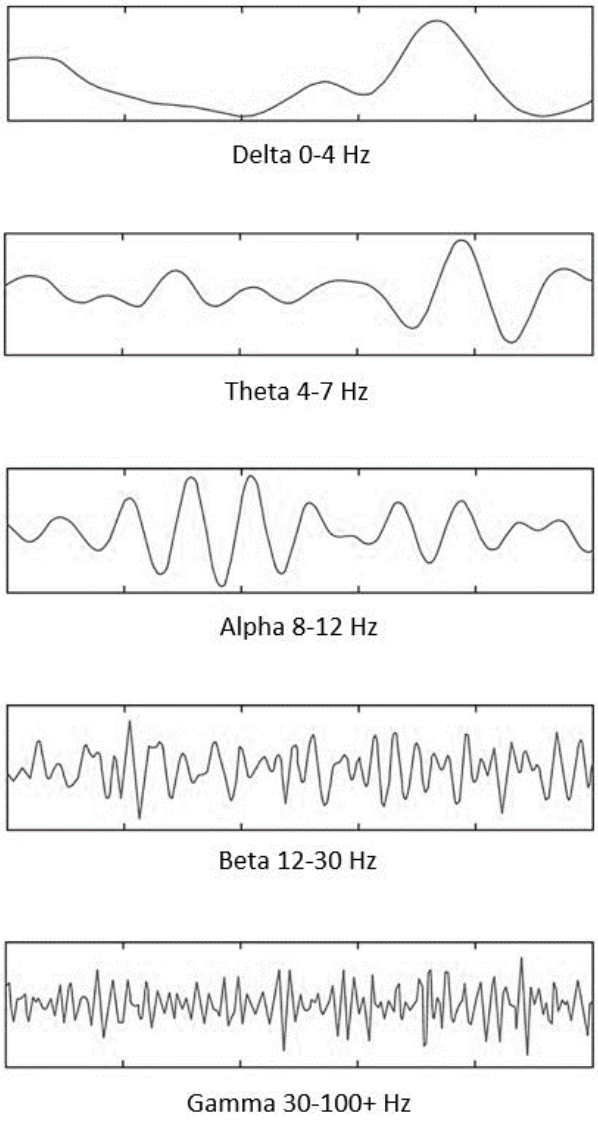

Figure 2: EEG Frequency Bands (BCI Developers, 2015)

After an EEG has been recorded it is important to know how to interpret the results obtained. There are different parameters that can be used to analyse the EEG-data, but the most prominent is Power spectral density (PSD). Power spectral density is usually calculated within the 0-40 Hz frequency range and the median of the power is calculated from 40 consecutive 1Hz frequency windows (Daly *et al.*, 2012). The calculations done to compute the Power Spectral Density are explained in section 5, Methodology.

2.1.2 Influence of Emotions on EEG

In order to correlate a change that is evoked by an emotional response, it is important to understand what an emotional response entails. Nakanishi & Imai-Matsumura (2008) and Lundqvist et al. (2008) clearly stated that there are three components involved in an emotional response: experience (how the person is feeling, for instance happy, sad etc.); expression (how the person behaves when feeling that emotion); and the physiological response (how your body reacts). We are specifically interested in the physiological response, and will investigate whether that response correlates with the EEG-data recorded.

For the compilation of the experimental procedure, it is crucially important that the stimuli are effective in causing physiological changes by triggering an emotional response. Bradley & Lang (2007) notes that pictures are an excellent form of stimuli for experimenters to use, as pictures are a representation of something e.g. a picture of a knife can scare a participant, but never harm them. The International Affective Picture System IAPS (Bradley & Lang, 2007) are constructed with pictures that are able to provoke certain affective reactions. This provides the experimenter with a stimulus that provokes an affective reaction, but the reaction subsides quickly, enabling further testing and no lasting effects on the participants. This is especially favourable, keeping in mind that the final application would involve PTSD-patients.

The stimuli used in an experiment has to be sorted into categories to ensure that it is possible for the experimenters to construct a valid experimental protocol. The IAPS (Lang et al., 2008) provides a great example of how stimuli are sorted into categories, as they provide ratings for the set of pictures. Lang et al. (2008) provide the user with the affective rating of all the pictures in the IAPS, as well as the instruction manual of how the IAPS can be used. The instruction manual clearly states that the participants were verbally instructed to look at the screen while the stimuli is shown, to make sure that the participants had seen the picture.

The dimensions used for rating the pictures (or stimuli) are: affective valence (where pictures are rated from pleasant to unpleasant); arousal (where pictures are rated from calm to exciting); and dominance (where pictures are rated from in-control to controlled). More detail on the IAPS and how the pictures are divided into dimensions are given in section 4, Hardware.

The studies done by Driscoll et al. (2009) showed that the deliberate attempt to regulate one’s emotion can lead to a variety of physiological changes. Their main focus was the effect of voluntary regulation of positive and negative emotion on psychophysiological responsiveness but also found that changes in specifically heart rate and galvanic skin response are significantly reduced when the patient decrease their emotional response, compared to overreacting.

Esslen et al. (2004) investigated whether the areas of the brain that is involved in emotional processing can be identified. Their results showed that the EEG-data can reveal the difference between emotions that are experienced by a participant. They did conclude that no significant cortical “emotion centres” was confirmed by the experiment.

2.1.3 Influence of Physiology on EEG

To ensure the validity of the study, it is important to identify the references in the literature that supports the possibility of EEG being influenced by the same stimuli that causes physiological changes. These extractions from the literature are discussed in length under the related physiological states.

2.2 Heart Rate

2.2.1 Heart rate and EEG

In the study conducted by Diego et al. (2004), the experimenters hypothesized that by making use of massage therapy you can differentiate between arousal and relaxation. They measured the effects of the different massaging therapies by recording a nine channel EEG (F3, F4, C3, C4, T3, T4, P3, P4, Cz) and heart rate. They discovered that when a participant is relaxing, the participant’s heart rate would decrease and the delta frequency band’s activity would increase simultaneously. The decreasing heart rate is also accompanied by a decrease in alpha and beta frequency band activity. In contrast, when the participant is aroused, their heart rate and beta frequency band activity would increase while the delta frequency band activity decreases.

Allen et al. (2014) investigated whether chewing gum can improve attention, by making use of the T3 and F7 EEG-electrodes and a heart rate monitor. They discovered that their stimulus, chewing gum, indeed influenced the participants’ heart rate and EEG-recordings. The heart rate of the participants who chewed gum increased, while the post-chewing EEG suggested that the beta power increased at both F7 and T3. These results show that it is indeed possible that a stimulus can influence both the heart rate and the EEG.

According to the cited literature above, it seems that there are indications that both the heart rate and EEG-signals can be affected by the same stimuli, and therefore we can explore the correlation.

2.2.2 Heart rate and Emotions

In the emotion-regulation study performed by Driscoll et al. (2009), it was revealed that heart rate reflects sympathetic as well as parasympathetic activation. The most important contribution that Driscoll et al. (2009) made

however, is that their participants exhibited a greater decrease in heart rate when viewing arousing pictures than when neutral pictures were viewed. They found no differences between the pleasant and unpleasant picture trails. Nevertheless, when (Bradley *et al.*, 2008) previously investigated emotional arousal, they found that when a participant is viewing an unpleasant picture, the participant would exhibit a larger decrease in heart rate.

According to Kassam & Mendes (2013), anger had a greater increase in heart rate than shame condition, and shame had greater increase in heart rate than the control condition. The study examined the physiological reaction of a participant when a specific emotion is measured. The participants who were asked to report their emotions had smaller increases in heart rate than those who did not report. Thus for our study we would expect the heart rate to increase for stimuli that could provoke shame or anger whereas stimuli with a neutral nature should not reveal such a great increase or deceleration in heart rate.

Mendes et al. (2003) investigated the response in cardiovascular activity, which can be translated to the heart rate, when a participant is asked to express or suppress their emotions. An expression of emotions, will render a participant vulnerable and maybe even trigger their flight-or-fight response. However, the suppression of emotions could have a negative effect on the participant's physiology, as suggested earlier by Petrie et al.(1998). The study by Mendes et al. (2003) revealed that a participant's heart rate will increase when they are expressing their emotions. Thus it became clear that the emotion exhibited by the participant are connected to their physiology and it is clear that we can assume that emotions experienced by the participants will have an effect on the physiology.

2.3 Respiratory Rate

2.3.1 Respiratory Rate and EEG

Bušek & Kemlink (2005) studied the influence of the respiratory cycle on the EEG. They found that there is an increase in the delta and total power, in the anterior temporal region when comparing the PSD during inhalation to the PSD during exhalation. Even though they made use of a 14 channel EEG (F3, F4, F7, F8, T3, T4, T5, T6, C3, C4, P3, P4, O1, O2) it could not be clearly defined whether the changes in the brainstem caused the changes in respiratory pattern or if it is just an accidental occurrence of neocortical arousal reaction.

In the assessment of accurately identifying mental workload, as investigated by Hogervorst et al. (2015), a correlation between respiratory rate and EEG-data was established. The channels that were recorded are: Fz, FCz, Pz, C3, C4, F3 and F4, while FPz was used as a reference electrode. The study showed that when a participant's mental workload increases, it would provoke an increase in

their respiratory rate. The study also verified that when mental workload increased, an increase in the activity in the theta frequency band, or decrease in activity in the alpha frequency band could be observed.

A link with a neural origin between respiration and the alpha frequency band is suggested by Yuan et al. (2013). Their results, from a 126 channel EEG, proved this link by correlating the changes in the alpha frequency band with the low-frequency oscillation of the respiration volume over time.

The above-mentioned literature thus clearly indicates that a factor, like mental workload, will have an influence on both the respiratory rate of a participant and their EEG-data. The exact correlation is to be investigated in this study.

2.3.2 Respiratory Rate and Emotions

Literature is reviewed in order to confirm that previous studies have indeed found a correlation between emotions that is provoked, and the physiological parameter respiration rate. It is important to determine that this correlation is a possibility before the study commences, to eliminate the collection of excessive data.

Rainville et al. (2006) hypothesized that if you observe the cardiorespiratory activity of a participant, it would be possible to predict their emotions. Their results were consistent with their hypothesis. The argument is further supported by Wu et al. (2012), as they state that physiological changes, like the respiration rate, can provide an indication of the human affective condition, i.e. emotional state.

Gomez & Danuser (2007) proved that there exists a positive correlation between the emotions a participant experiences and their respiratory rate by using different musical structures to obtain perceived emotions and measuring the breathing rates of the individuals participating in their study. Hogervorst et al. (2015) supported this finding in the assessment of mental workload, by linking an increase in emotional arousal with an increase in a participant's respiratory rate.

In 2008 the study by Homma & Masaoka (2008) indicated that it is indeed possible to differentiate between emotions by examining the breathing rate of a participant. This result, in conjunction with the above-mentioned literature, implies that different emotions would have different implications on the respiratory rate and thus we would possibly be able to see the effect of an emotion in the respiratory rate of a participant.

2.4 Galvanic Skin Response

2.4.1 Basics of GSR

Galvanic Skin Response (GSR) consists of the measurement of the conductivity of a person's skin. It can act as an indicator of changes in the sympathetic

nervous system (Shi *et al.*, 2007). GSR is measured as the change in conductance and thus the unit of measurement is micro-Siemens (µS) as investigated by Lacey & Siegel (1949) and Mindmedia (2016).

According to Montagu & Coles (1966) there are several experimental variables that can influence the results obtained from a GSR measurement. These variables include environmental variables and organismic variables. The environmental variables are: temperature, the room temperature; humidity; and time of day (during the day skin conductance is typically higher than at night). The organismic variables are: age; sex; race; personality traits; intelligence; habituation and adaption; and mental health.

Even though the difference in organismic variables are vital for the validity of the study, there has to be taken great effort to ensure that the environmental variables are kept at identical circumstances for the different participants to ensure that the environmental variables do not influence the results.

2.4.2 Psychophysiological Significance of GSR

Mundy-Castle & McKiever (1953) conducted a study that investigated the psychophysiological significance of the GSR and noted the important facts that Galvanic Skin Response (GSR) usually indicates an autonomic imbalance and that even though emotion is associated with GSR, it cannot be held solely responsible for it. Peuscher (2012) explained in depth the whole process of recording a GSR. They showed that the electrophysiological potential is generated by the sweat glands, although the vaso -dilatation and –constriction may also be significant. They also described that the reason for the good repeatability of GSR-tests are that the change in electrical properties are measured, and thus in essence the autonomic nerve responses are captured.

2.4.3 GSR and EEG

Before testing can commence, it is important to investigate the grounds for the hypotheses of the study. This ensures that the testing does not involve parameters that could give worthless results. The literature reviewed in this section shows that it is possible for the GSR measurements and EEG-data to both be influenced by the same stimuli in one way or another.

Hogervorst et al. (2015) and Ohme et al. (2009) both confirmed that skin conductance, also known as GSR, is an indication of arousal, and more specifically emotional arousal. Hogervorst et al. (2015) further connected GSR and EEG by stating that an increase in arousal, by extension GSR, is related to an increase in neural activity that is measured by the EEG-recording. In the study done by Ohme et al. (2009), advertising stimuli was used to prove that when you combine the parameters EEG and skin conductance, you can positively identify small changes in stimuli, intended to emotionally arouse a participant. The 16 EEG electrodes they used were specifically distributed among the prefrontal,

frontal, temporal, parietal and occipital regions, using the standard 10/20 layout. The study investigated whether the effectiveness of an advertisement can be determined by looking at the neurophysiological reactions. The difference in stimuli used was a 4 second scene, and even though the difference is almost undistinguishable, according to Ohme et al. (2009), the combination of EEG and GSR were indeed able to track subtle changes in arousal. This outcome supports their hypothesis that EEG and GSR can be correlated.

In the study done by Kramer (2007), performance was used as a measure to correlate GSR with EEG. Kramer only used the temporal electrodes T3 and T4, with FPz as a reference electrode. GSR was positively correlated with performance, while the activity in the beta frequency band exhibited a negative correlation to performance. Thus when a participant's performance would increase, the activity in the beta frequency band would decrease, while the GSR increases. Hence the correlation between GSR and activity in the beta frequency band is a negative one.

2.4.4 GSR and Emotions

Driscoll et al. (2009) made the important statement that changes in specifically skin conductance, but also heart rate, unfold over the course of several seconds. They reported that there was no difference observed between the responses to pleasant and unpleasant picture stimuli. Just like in heart rate, they reported that the down-regulation of both positive and negative emotions lead to significantly reduced skin conductance responses, when compared to up-regulating your emotions.

The study done by Gomez & Danuser (2007) strongly correlated some musical structures with physiological measures (including GSR) obtained. The goal of the study was to determine to what extent arousal valence and physiological measurements are influenced by structural features of music. Their results revealed that for music with a fast tempo, high arousal, positive valence and high levels of GSR were recorded. Thus, it is can be deduced that the stimuli that increased the GSR also increased the arousal and brought forth a positive valence.

GSR, as a physiological indicator, can reveal when a psychological event is taking place, a stated by Montagu & Coles (1966) and Hughes et al. (1994). This expression implies that the GSR-measurements are influenced by emotional responses. This hypothesis is also confirmed by Bradley et al. (2008) and Lundqvist et al. (2008) when they established that skin conductance showed a larger increase when arousing pictures are viewed and happy music induced greater skin conductance, respectively.

Hughes et al. (1994) investigated how momentary changes in autonomic nervous system activity, like GSR, are influenced by the expression of emotions. They

asked participants in the study to write about a traumatic experience from their past and found that the psychological effects were profound. The GSR decreased as the participant were using positive emotion words or concluding sentences, while negative emotion words or denial increased the GSR.

The literature that was examined indicated that the measurements of the GSR and EEG would be influenced by the change of emotions, and therefore the grounds of its inclusion in this study is sound and valid.

2.5 Finger Temperature

2.5.1 Temperature Regulation

“The phenomenon of fever can be described as an imbalance between heat production and heat loss, controlled by centres in the brain” (Werner, 1980). This can be extrapolated to all types of change in temperature, as it is clear that the brain is the primary regulator of temperature throughout the body.

The decrease in skin temperature is defined by Nakanishi & Imai-Matsumura (2008) as the decrease of blood flowing to the skin’s surface because of the activation of the sympathetic nerves in that specific area of the skin, as long as the environment is kept at a constant temperature.

2.5.2 Correlation between EEG and Finger Temperature

It is important to know if and how finger temperature and the EEG signals are connected, to ensure that the experiment address all the possible obstacles that may exist in correlating the finger temperature with EEG signals.

In a study using music as a stimulus, Kibler & Rider (1983) and Lai et al. (2008) both reported significant increases in skin temperature in the fingers of the participants and less anxiety, after the stimuli had been presented. Yuan-Pin Lin et al. (2010) also used music as a stimulus, and proved that emotion processing can be identified in the frontal and parietal lobes.

The influence of a stimulus on finger temperature and EEG was also investigated by Yang et al. (2012), who found that it is possible to reduce a person’s anxiety by specifically making use of music therapy. The anxiety levels that they measured made use of EEG and finger temperature to quantify anxiety. Even though music therapy wasn’t used in the current study, these citations suggest that it is indeed possible that a stimulus can influence both the finger temperature and the EEG of a participant.

2.5.3 Influence of Emotions on Finger Temperature

A decrease in finger temperature was shown by Lundqvist et al. (2008), as the participants experience both happy and sad emotions. Lundqvist et al. (2008)

made use of music to induce the emotions, so proving that it doesn't matter how the emotion are provoked the conventions can be transferred. It is also noteworthy that Lundqvist et al. (2008) observed a large increase in finger temperature after an initial decrease was detected.

Following the aforementioned literature, we expect that the participants' finger temperature will react after the presentation of the stimuli, regardless of the emotion provoked by the stimuli.

2.6 Pupil diameter

2.6.1 Mental Effort

A pupil can dilate or contract for a number of reasons. The most commonly known cause is a change in lighting (Blackwell, Hensel and Sternthal, 1970). Mental effort, however, plays a great part in the size of the pupil as illustrated by the following studies. Wierda et al. (2012) studied the dynamics of attention at high temporal resolution, by making use of the pupil diameters.

They revealed that the size of a human pupil will increase as a function of the mental effort that is required. The study also showed that even though the pupil size slowly increases, it will peak after approximately 1 second. It is thus important in our experiment to closely examine the size of the pupil 1 second after the stimulus has been presented.

The Index of Cognitive Activity (ICA) is centred on the dilation or constriction of pupils that occur when a participant is presented with visual stimuli. The ICA was used by Marshall (2002) in the study to measure cognitive workload. They found that changes in pupil dilation does accompany effortful cognitive processing, and thus it would be advantageous for our experiment to make use of stimuli that require the participant to think about it.

Marshall (2002) and later Wierda et al. (2012) also confirmed the earlier results of Hyönä et al. (1995) that showed how pupillary response varies as a function of task difficulty. Hyönä et al. (1995) made use of language tasks to increase the processing load of the participant, and thus the conclusion can be reached that any task in which mental effort is necessary, will produce an increase in pupillary response.

2.6.2 Stimuli

It was decided that for this experiment, visual stimuli will be used to provoke the necessary pupil dilation and contraction. Blackwell et al. (1970) stated that pupillary dilation can be elicited by sensory or emotional stimuli. Since an emotion provoking picture is included in both those parameters, it can be expected that a

pupillary response will be provoked. It is important to note that Blackwell et al. (1970) found that the pleasantness of a stimulus does not determine whether the pupil dilates or constrict, but rather the intensity of emotion experienced at the viewing of the stimulus that influenced the degree of dilation or constriction.

As investigated by Goldinger & Papesh (2012), the pupil dilation is influenced by the creation and retrieval of memories. Hess (1965) reported that “observers’ pupils dilated in response to positively valenced images, political statements consistent with their beliefs, and sexually arousing images” (Hess, 1965). The participants in the present study will be adults, and even though they are only between the ages of 18 and 30 years old, their life experience will have an influence on their response to the stimuli.

The possibility of unpleasant stimuli causing pupil constriction was debated by Hess (1965) and Goldwater (1972). Chapman et al. (1999) tested this hypothesis by making use of a painful stimuli in varying intensities. Chapman et al., (1999) concluded that the pupil dilation responses that were observed, reflected the central processing of a threating event. Thus it can be hypothesized that in the present experiment, stimuli of a threatening nature would provoke a pupil response.

2.6.3 Timing

To validate the relevance of the monitoring of change in pupil diameter, Einhauser et al. (2010) gives us great insight as they discovered that the dilation of pupils reveals the time at which a person makes a decision. This emphasizes that a parameter as small as deciding what to do is betrayed by the change in pupil diameter, and thus the pupil diameter can be a very valuable parameter to monitor. In the abovementioned experiment, the act of making a decision caused the pupil diameter to increase.

Kawasaki (1999) reveals the importance of a participant’s overall physiological state when pupil diameter is monitored. They specifically investigated the influence of the participants’ wakefulness, and found that if a participant were to be drowsy, it would alter the amplitude as well as the frequency of natural pupillary fluctuations. This implies that for the present experiment, it should be required of the participants to obtain a decent night’s sleep the day before the test, to avoid drowsiness.

The literature was consulted to construct the parameters for executing the experiment. Kawasaki (1999) reported that after 5 seconds of darkness, a normal pupil will contract, and thus the time of total darkness should be restricted to less than 5 seconds. When a pain stimulus is used to evoke a response, as done by Chapman et al. (1999), the peak amplitude are visible after just 1.25 seconds, following the stimulus. The response from the pupil began at 0.33 seconds after

viewing the stimulus, and thus it is important to ensure that the correct time-stamp is adhered to the data, to confirm consistency with the presentation of the stimuli.

2.6.4 Correlation between Pupil and EEG

To confirm that the pupil diameter can be correlated with the EEG-signals measured, the experiment done by Qian et al. (2009) was examined. They investigated whether it is possible to synchronize the timing of a decision, by making use of the pupil dilation reflex and 64 channel EEG. The results obtained by Qian et al. (2009) confirmed that it possible for a decision to be reflected in pupillary features, including pupil diameter, and the EEG-data recorded.

The purpose of the study done by Merritt et al. (2004) attempted to determine a correlation between pupil diameter and the theta power band, by testing people with untreated narcolepsy, people with untreated obstructive sleep apnoea (OSA) and healthy controls. After recording an EEG from the C3, O1 and P3 electrodes, they found that the amount of theta activity on the EEG will increase as the pupil diameter decreases.

The literature regarding pupil diameter gives great insight into the design and setup of the experiment. It also suggested that the hypotheses to be tested are valid and the testing could yield valuable results.

2.7 Conclusion

In this section the existing literature on the different physiological effects and EEG-data were investigated. The literature confirmed that there is a significant connection between physiological changes and the emotions that a person experiences. The effects of emotions experienced by participants, are also present in recorded EEG-data. From the literature, some variables that should be considered during the design and setup of the experiment became apparent.

For the consistency of the physiological measurements, environmental changes should be kept to an absolute minimum. This is especially important in the measurement of the finger temperature and GSR as they are both influenced by room temperature. The literature also emphasized the fact that the testing conditions should be kept the same for all the participants, as something like a change in lighting, could affect the measurement of pupil diameter. It also became apparent that non-invasive stimuli have to be used. This only strengthened the choice of using the IAPS as described in section 4, Hardware.

Chapter 3

3 Objectives

After studying the literature, it is important to review the objectives set out in the Introduction chapter (1.2), as the literature might have revealed some important factors that needs to be incorporated into the objectives. When designing the experiment that encapsulates the objectives, it is important to keep in mind the factors that may influence the results, as pointed out by the cited literature in the previous chapter. It is also crucial that the data that is collected from the experiment, provide enough results that can be further analysed.

It is hypothesized that the results of this study would be able to indicate if it is possible to discern between different emotion groups based on EEG- and physiological measurements.

The objectives can be summarized as follows:

- Designing an experimental procedure that enables the experimenter to capture all the data needed for further analyses.
- Investigating the results of EEG-data with and without emotional stimuli present.
- Investigating the effect of emotional stimuli on physiological measurements
- Investigating the correlation between physiological factors and EEG-data, due to a change in emotions.
- Exploring the possibility of statistical discoveries between the physiological results and the EEG-data that arise from the processed results.
- Drawing conclusions from the results obtained and providing possible recommendations for future studies e.g. If any correlation exists, what is inferred by that particular correlation, and how does it contribute to the understanding of the human body?

The literature revealed that the presence of a stimuli will cause a change in the physiological and EEG measurements and therefor it is important that the experiment includes a baseline recording that omits the presence of the emotional stimuli. This will enable the experimenter to investigate the effect of the stimuli used in this specific experiment on both the EEG-data and the physiological measurements.

Since it is hypothesized that there will exist some correlation between the physiological factors and the EEG-data due to the change in emotions, it is necessary to ensure that the set of results are configured in such a way that it is possible to compare those results. It was elected to compare the time-configured results as it enables the experimenter to precisely determine which stimulus was viewed when the change occurred. A comparison between these results and another study's results are only relevant if the configuration that is used is the same, in this case: time-configured.

After the results are compared, with the help of statistical tests, it is inevitable that some statistical analogies will arise. It is important to investigate the meaning of these analogies to clearly determine what the results imply. The implications of the results convert them from simple numbers to value-adding data.

Finally, it is important to draw conclusions form the results that was obtained from the experiment, and provide possible recommendations for future studies. The conclusions from the experiment should be stated as simply as possible, while maintaining the accuracy of the statement, to avoided misunderstanding of the outcome of the experiment. The future recommendations consist of recognizable faults that were made during the execution of the experiment and can possibly help future researchers to avoid these mistakes.

Chapter 4

4 Hardware

Several types of equipment were used in the experiment, especially to capture the physiological changes within each participant as they were confronted with the stimuli. All the equipment is the property of the University of Stellenbosch, Mechanical Engineering Department, Biomedical Engineering Research Group (BERG).

4.1 Emotiv EPOC

Figure 3: Emotiv EPOC and its sensor placement in the standard 10/20 layout (Rodríguez, Rey and Alcañiz, 2013)

The Emotiv EPOC (Figure 3) is a wireless EEG-recording device that is connected to a PC by means of Bluetooth. The EPOC has 14 recording channels (AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, and AF4) and 2 reference points (P3, P4) that is placed in set points around the surface of the skull (See Figure 3). The reference points offer optimal positioning for accurate spatial resolution. Each channel records at a sampling rate of 128 Hz, and operates at a resolution of 14 bits. (EMOTIV Inc., 2016)

Data collected with the EPOC cannot be accurately interpreted if it is not used in conjunction with the program developed by Emotiv called Testbench (EMOTIV Inc., 2016). Testbench was also used as the interface to establish a good connection between the PC and the EPOC. Testbench recorded the data collected by the EPOC and was used to export the data to the appropriate format for processing.

4.2 NeXus 10

Figure 4: The NeXus 10 data aquisitioning system (Biofeedback Allgau, 2016)

The NeXus 10 (Figure 4) is a data acquisitioning system that is controlled through the PC desktop interface BioTrace+ (Mindmedia, 2016). The user interface of BioTrace+ enables the user to record different physiological signals simultaneously. For this experiment, heart rate, respiratory rate, finger temperature and GSR were all recorded. BioTrace+ also enables the user to place markers on the data while it is being recorded. A marker was used to separate the baseline-recordings from the actual testing phase.

For this experiment, heart rate, respiratory rate, finger temperature and GSR were all recorded. The heart rate was measured by a photoplethsmograph sensor, at 128 Hz, attached to the participant's index finger on their dominant hand, while the GSR was measured by electrodes attached to the participant's third and fourth fingers on their dominant hand, at 32 Hz. The respiratory rate and finger temperature was both measured at 32 Hz. The respiratory rate was measured by attaching a respiration sensor to the participant's thorax and the finger temperature by enclosing a temperature sensor on the participant's index finger on their non-dominant hand.

The NeXus 10 is able to record up to 128 Hz for the physiological parameters involved according to Mindmedia (2016). The noise recorded is less than 3 µV RMS and thus provide an approximate accuracy of 2%. Connections between the sensors and the NeXus 10 device are secured with a Lemo OB series 5 pins, while the Bluetooth that connects the deice to the PC have a connection up to 10 meters.

4.3 Point Grey Camera

Figure 5: Point Grey Grasshopper (SolarChat!, 2016)

Point Grey Grasshopper camera (Model GRAS-03K2M-C), shown in Figure 5, with a global shutter and a picture of 640x480 at 200 fps (FLIR Integrated Imaging Solutions Inc, 2016). The camera offers a 0.5-megapixel picture, with a high speed 14-bit A/C converter. The digital interface consists of two IEEE-1349b ports and transfer rates up to 800 Mb/s makes the Grasshopper ideal for our experimental application. An Ampro tripod was used to suspend the camera parallel to the participant's eye-line.

The lens that was used with the Grasshopper camera was the 35 mm Compact Fixed Focal Length Lens from Edmund Optics. Since the participants will all be seated at the same distance from the lens and would not move a lot, if at all, a fixed focal length lens can be used. The lens has a working distance of 165- ∞ mm while the field of view for the 1/3" sensor is 21.4 mm – 7.8° (Edmund Optics, 2016). The following equations were used to determine the specification of the lens:

$$f = \frac{h \times WD}{H - FOV} \tag{1}$$

f = focal length of the lens
h = number of pixels × pixel size
WD = working distance (between the lens and object)
H-FOV = horizontal field of vision (the size of the picture recorded)

According to the calculations, a lens with a focal length of 35 mm or 50 mm could be selected. We preferred the 35 mm Compact Fixed Focal Length Lens due to financial limitations.

4.4 Infrared Illuminator

In order to ensure that the participant's eyes, and especially pupils, were properly illuminated, an infrared illuminator was constructed around the lens of the camera. The illuminator, shown in Figure 6 made use of 24 Vishay TSUS 5400 infrared LED's. The LED's were connected in series, and powered by a power supply set to 33 V. Each LED had a peak forward current of 0.3 A, and a forward voltage of 1.3 V. Thus a resistor of 6 Ω was used.

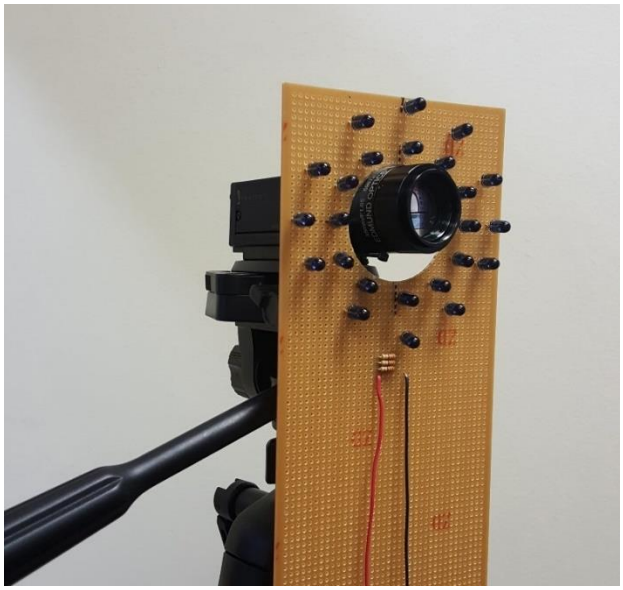

Figure 6: Infrared illuminator

4.5 The International Affective Picture System

The stimuli that was used in the experiment was a set of pictures compiled by Lang et al. (2008) and is called the International Affective Picture System (IAPS). This compilation of pictures are stimuli that evokes a range of emotions, and thus enables the experimenter to use this set of stimuli in the setup of the experiment, without the need for additional stimuli.

The IAPS are classified into different categories by the original compilers Lang et al. (2008). They made use of the Self-Assessment Manikin (SAM), also used by Bradley & Lang (2007) and Gomez & Danuser (2007) to provide ratings for each of the pictures in the set. The dimensions used for the classification are affective valence, arousal and dominance. For this experiment the rating provided for each picture are used to classify each picture into an emotion group.

The Self-Assessment Manikin (SAM) that is used to assess the dimensions are presented in Figure 7. The assessment is done by volunteers who look at a picture presented and evaluating their emotions based on the varying scale from negative to positive for valence, passive to active for arousal and dominated to dominant for dominance.

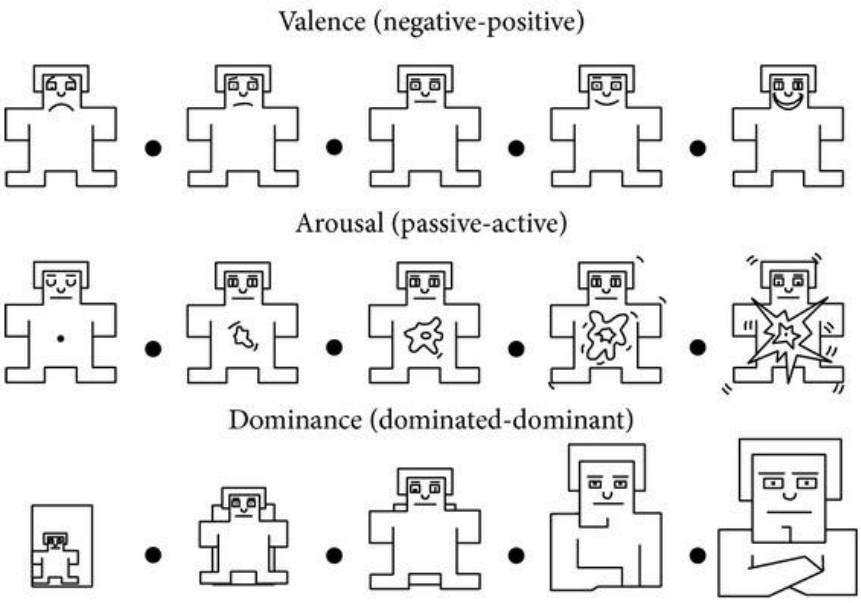

Figure 7: Self-Assessment Manikin (SAM) (Jirayucharoensak, Pan-Ngum and Israsena, 2014)

The dimension affective valence can be better described as a scale from unhappy to happy (left to right). At a high rating of negative valence, a participant would feel very unhappy, annoyed or even bored, while a high rating of positive valence, a participant would feel happy, satisfied of hopeful. The dimension arousal is rated on a scale from passive to active. A passive feeling (negative arousal) could be associated with feelings of relaxation, sleepiness and calmness and active feelings (positive arousal) associated with feelings of excitement, wakefulness and arousal. The dominance dimension is described on a scale from dominated to dominant. When negative dominance is experienced a participant would feel dominated, controlled, influenced and submissive, while a positive dominance would provoke feelings of importance, control, influential and dominating.

4.6 Conclusion of Hardware

The section, Hardware, described all the hardware used in the execution of this experiment. It included the Emotiv EPOC, the NeXus 10, a Point Grey Grasshopper camera, with a 35 mm fixed focal length lens and infrared illuminator; as well as the IAPS as emotion provoking stimuli. All the physical equipment is the property of BERG, and we are very thankful that it could be used for the experiment.

Chapter 5

5 Methodology

In the setup, implementation and processing of the experiment, several methods were utilized. This section describes all the physical procedures that were performed during the duration of the experiment.

5.1 Preparation for Testing

Before testing can commence, there are a few rules that needs to be adhered to. It is vital to obtain the necessary ethical clearance from the Human Research Ethics Committee (HREC), since the premise that emotions can be discerned by inspecting the physiological state and EEG signals, will be tested on humans. The committee granted the project clearance from 24 June 2015 to 24 June 2016. This clearance was tentatively extended to June 2017 to avoid the possibility of testing participants while the clearance is already suspended. The number allocated to this project is S15/02/042. See Appendix B

The emotional stimuli that was needed for the testing, was obtained through the University of Florida, and is called the International Affective Picture System (IAPS). The distribution of these stimuli are meticulously controlled as to prevent unruly circulation, and so decreasing the effectiveness of the stimuli (Bradley and Lang, 2007).The measuring of the pupils proved to be the most difficult as the participant had to be able to see the screen while being tested with minimal invasive apparatus, and thus it was decided that a conventional eye-tracker would not be used. It was decided to use a camera with a high sample rate, in combination with an infrared illuminator to make the pupils more visible. The image processing package OpenCV was used to determine and measure the size of the pupils.

The setup of the experiment was done as follows. Please refer to Figure 8.The participant was placed 2 m away from the screen upon which the stimuli was projected. MS PowerPoint was programmed with a timer to ensure that a stimulus was projected every 4 seconds, for 6 seconds at a time. While the stimuli were absent a black screen with a red cross in the middle of the screen was projected to keep the participants focussed on the screen. The screen used was a 40 inch Sony Bravia screen with screen resolution of 1920 x 1080.

The Emotiv EPOC was placed on the participant’s head, to record the EEG-signals throughout the experiment. The EPOC connects via Bluetooth to the computer that records the signals at rate of 128 Hz.

The camera, with infrared illuminator, was placed between the participant and the screen, and modified to each participant's height, to ensure that the camera is horizontally in line with the participant's eye, but not obstructing their view of the screen (See Figure 9). The pupil was then recorded at 200 fps to ensure that the smallest possible change in the diameter of the pupil could be detected.

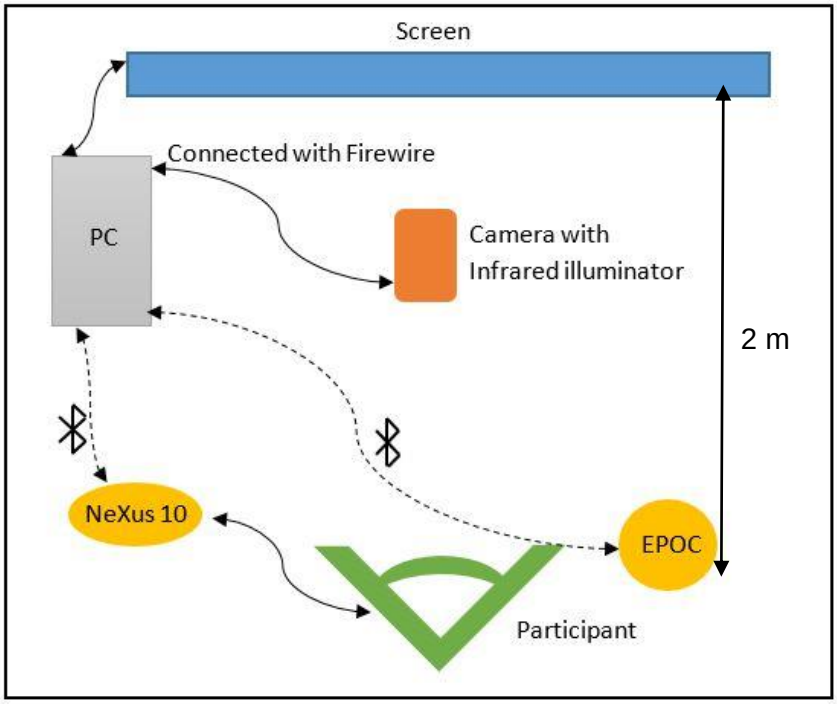

Figure 8: Experimental setup

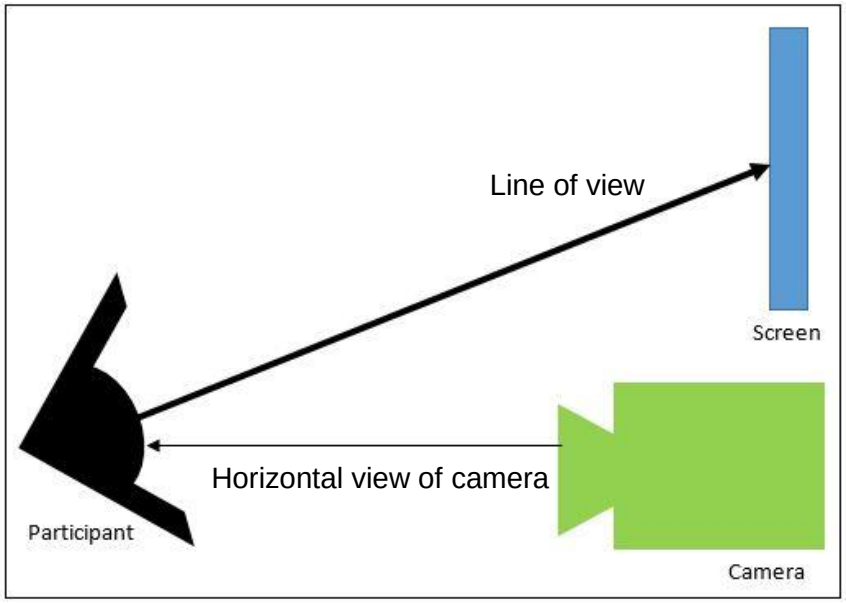

Figure 9: Camera setup

Physiological monitoring (heart rate, temperature, respiratory rate and GSR) was done with the NeXus 10 data acquisitioning system, see Figure 10. The respiratory sensor was placed around the participant's thorax, while the temperature sensor was placed on the index finger of the participant's non-dominant hand. The GSR-sensors was placed on the third and fourth fingers of the participant's dominant hand, and the dominant hand's index finger was used to record the heart rate of the participant. All these sensors were connected to the NeXus at their corresponding inlets. The respiratory rate, finger temperature and GSR was recorded at 32 Hz, while heart rate was recorded at 128 Hz.

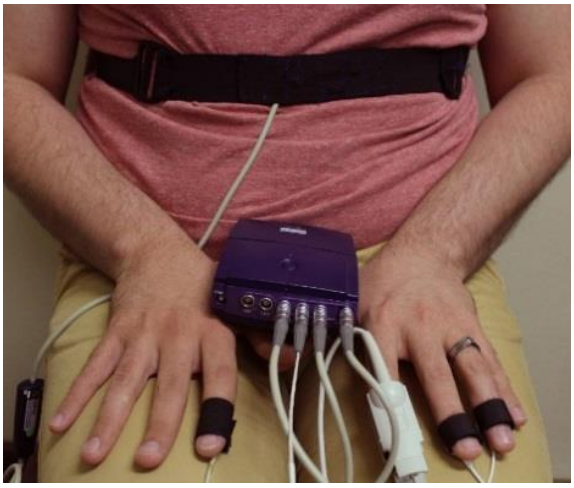

Figure 10: Participant attached to the NeXus data acquisitioning system

After all the apparatus were attached to the participants, they were given clear instructions to follow during testing. These instructions included:

- To sit as still as possible on the chair that was provided, as movement could influence the recordings.
- To pay close attention to the stimuli that was shown.
- To try to minimize the amount of blinking while the stimulus is shown, but remain comfortable.

5.2 Data Acquisitioning

As stated in the Ethical clearance, 11 male participants with a mean age of 24.09 (SD = 1.86) and 9 female participants with a mean age of 24.33 (SD = 1.87) were included in the study. The 20 participants were volunteers, and no compensation were given.

Preliminary testing was done between the 8th of June and 8th of July, to ensure that all the hardware was working accurately and to streamline the process of testing. Final testing commenced on the 11th July 2016 and completed on the 2nd August. All testing was done at the University of Stellenbosch, Department of Mechanical Engineering, Mechatronics laboratory.

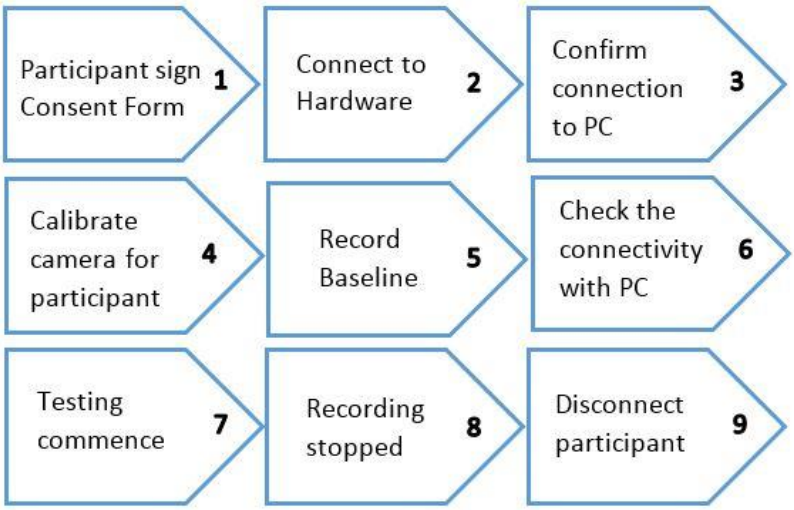

Figure 11: Testing procedure

The testing procedure shown in Figure 11 was carried out as follows:

1) The consent form can be found in Appendix C.
2) The procedure for connecting the participants to the EPOC and NeXus can be found in section 5.1 Preparation for testing.
3) The connection between the hardware and the PC is confirmed
4) The camera is calibrated for the individual participant.
5) An overall baseline of the physiological data was recorded for the participants to establish that the participants are healthy. The baseline questions (see Appendix D) was used to obtain approximately 10 minutes of baseline data and eliminate any psychological problems that might occur. The baseline questionnaire is based on the stimuli that the participant would be subjected to.
6) The connectivity between the hardware and PC is checked to ensure that the testing is properly recorded.
7) The testing commences with the start of the recordings
8) The recording of the data was stopped as soon as the slideshow of the stimuli ended.
9) As soon as the participant was disconnected from the sensors they were thanked for their contribution.

5.3 Data Processing

5.3.1 EEG

The EEG-data obtained with the Emotiv EPOC was processed by using the Matlab library EEG-lab (A Delorme and Makeig, 2004). The Emotiv EPOC records the following channels: AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, and AF4 and the P3 and P4 channels was used as reference electrodes.

After the data was visually inspected and markers were inserted into the data to mark the start of a stimulus being presented, the data was imported into EEG-lab. EEG-lab applied a bandwidth filter to the data that eliminated all data below 1 Hz and above 20 Hz. An Independent Component Analysis (ICA) was applied to the data to establish a coordinate frame where the temporal overlaps of the data projections are minimized (Arnaud Delorme and Makeig, 2004). The automated infomax ICA decomposition, **runica()**, was used in the data processing.

The data was divided into epochs according to the time that the stimuli was presented. Thus every epoch would be 10 seconds, and contain the 14 channels of the EEG. An epoch can be described as a time period during which a meaningful event occurred. Our epochs consist of a 4 second recording with a blank screen which served as the baseline recording and the 6 seconds of test recording during which the stimulus was shown. After the events were imported into EEG-lab, each channel's baseline mean was removed.

According to Stone (2002), "ICA is essentially a method for extracting individual signals from a mixture of signals". When ICA is then applied by EEG-lab the input from all the electrodes is divided into components. These components then include one or more components that might contain noise-artefacts produced by the surrounding physiological activities, like eye movement and muscular contractions. After all the components, created by the ICA, have been analysed, the components containing noise is manually extracted from the data, and the data is restructured into the original EEG channels. This "noise-less"-EEG was used for further calculations and analyses.

The Power Spectral Density (PSD) of the EEG was calculated across all the channels, but for the individual epochs. The standard function for calculating PSD in EEG-lab is **spectopo()**, this function was used in the present study's calculations. The **spectopo()**-function is normally used to plot the mean log spectrum of a set of data epochs at all channels as a bundle of traces. It is also able to plot the topographic distribution of power at specified frequencies. The **spectopo()**-function makes use of the Matlab built-in function **pwelch()**, from the signal processing toolbox, to compute the Fast Fourier Transform. The outputs produced by the function are the power over epochs in dB and the frequencies of the spectra in Hz.

To calculate the PSD of EEG-data the following formula is used:

$$PSD = |X(\omega)|^2 \tag{2}$$

Where $X(\omega)$ is the result of the Fast Fourier transform:

$$X(\omega) = \int_{-\infty}^{\infty} x(t) e^{-j\omega t} dt \tag{3}$$

The mean of the PSD is calculated for each frequency within the frequency band, for each individual epoch. The mean of the PSD is depicted as $(\mu V)^2/Hz$ and therefor shows the density of power for that specific frequency. It is thus possible to correlate the activity in the frequency bands for each of the epochs with the physiological activity in that same epoch.

5.3.2 Heart Rate and Respiratory Rate

In order to know whether a participant's heart rate or respiratory rate has increased or decreased it is important to know what their initial heart rate and respiratory rate has been. The baseline data recorded before the tests gives us an indication of the participant's current physiological state, whereas the baseline during the epoch are recorded to be used in the statistical comparisons. The heart rate and respiratory rate is calculated with the use of a programmed algorithm. The algorithm implements peak detection to determine the amount of peaks within a certain period of time to extrapolate the beats, or breaths, per minute (bpm).

5.3.3 GSR and Temperature

Similar to the heart rate and respiratory rate, it is important to have a baseline for the GSR and temperature as each person's physiological state is different. For the statistical comparisons, however the baseline recorded within the epochs are used. The data was processed by means of an algorithm that determines whether the GSR- or temperature- value has increased or decreased from within the epoch.

5.3.4 Pupil Diameter

The diameter of the participant's pupil was measured by constructing a c++ algorithm, making use of the OpenCV library within Microsoft Visual Studio (Microsoft, 2015; OpenCV developers team, 2015). There are different OpenCV image manipulations that was used to measure the pupils such as a Gaussian filter, Thresholding, retrieving the contours from the image, and ultimately the construction of a circle within the contour of the pupil.

The Gaussian filter that is applied depend on a kernel size of 5 and the sigma used to compute the Gaussian kernel standard deviation in both the X and Y directions, are automatically computed by the function **GaussianBlur()** as follows:

$$sigma = 0.3 \times \big((kernel\text{-}size - 1) \times 0.5 - 1\big) + 0.8 \tag{4}$$

The image was subjected to Binary Thresholding, with the function **threshold()**. Thresholding is applied to each pixel as follows:

$$output\ intensity = \begin{cases} maxValue & : if\ input\ intensity > thresh\text{-}limit \\ 0 & : otherwise \end{cases} \tag{5}$$

Thus if a pixel's value is larger than the thresholding limit (20) the pixel's intensity would be set to 255, which we know is the colour white. If the pixel's intensity is however below the thresholding limit, it would be set to 0, which is the colour black. The contours are identified by the function **findcontours()** that used a contour retrieval mode that doesn't establish any hierarchical relationships called **CV_RETR_LIST**. For the approximation of the contours **CV_CHAIN_APPROX_SIMPLE** is used as it requires significantly less memory for computation, and produces the same results.
The circle within the pupil provides us with the diameter of the pupil. For each epoch the baseline and test-data was averaged to provide the mean pupil size over the baseline and test period, respectively.

5.3.5 Excluded Data

The total number of 20 participants contributed to this study. Initially there was 11 male participants and 9 female participants. However, due to several reasons, described below, some of the data had to be excluded from the study. As the main objective of this study is to compare the physiological data to the EEG-data obtained, a data-set would be considered worthless if it could not be compared to another piece of data, and thus must be excluded. The EEG-data for 6 participants had to be excluded from the study due to hardware malfunction. This reduced the number of EEG data-sets used in the study to 14 sets. One of the heart rate recordings had to be excluded from the study, as the device did not record the participant's heart rate throughout the test. The final number of heart rate recordings included in the data-set were 13.

The GSR-measurements proved problematic, as the device failed after 14 participants were tested. After the exclusion of the unsatisfactory data of both the EEG- and GSR- measurements, only 6 participant data-sets remained for the GSR measurements. It was decided not to suspend testing and obtain new GSR-electrodes as more than half of the participants were tested, and there was limited time for the experiment. Literature revealed that the least amount of samples used in a study to produce valid conclusions was ten participants (Kramer, 2007; Driscoll, Tranel and Anderson, 2009), and thus the GSR results did not produce enough results to validate the conclusions.

During the processing of the pupil measurements, several data-sets had to be excluded from the study as the video-quality were too poor to extract data from it. After the rejection of the data-sets, only six data-sets remained, of which only four could be used in the statistical comparisons. The exclusion of the extra two data-sets were due to insufficient amount of results obtain from within the data-set. If an insufficient amount of data was procured from a data-set the mean values of each epoch could not be calculated correctly, and thus those data-sets were excluded. To yield valid conclusions, approximately 20 data-sets are needed, as shown by Hyönä et al. (1995); Chapman et al. (1999); Wierda et al. (2012), who each used 27, 20 and 18 participants respectively.

Even though the rejection of recorded data is never favourable, the amount of data included for all measurements, excluding the GSR and pupil measurements, can still produce valuable results. The GSR and pupil measurements did not produce enough results to make a valid conclusion, but the results obtained can still give some insight to the correlation between the EEG and GSR; and EEG and pupil measurements.

5.3.6 Statistical Analysis

Several statistical analyses are performed on the data to provide us with the appropriate conclusions regarding the results. The different methods used are the student t-test, Pearson sample correlation, and 2-way ANOVA-test. For all the test, where applicable, a significant level of $\alpha = 0.05$ was assigned. (Devore and Farnum, 2005) All statistical analyses were performed on Excel, the rest of this section describes the statistical analyses used, and how the results should be interpreted.

5.3.6.1 Student t-test

In the student t-test a paired t-test was used in determining the difference between the two means of the data. A paired t-test had to be used as the data was collected for the same participants, but for different parameters (the baseline and test recordings within the epoch).

The result of a student t-test indicates whether a statistical significant difference exists between two data-sets. If $p < 0.05$, which is our significance level, we can say with confidence that there exists a difference between the two compared data sets.

5.3.6.2 Pearson's sample correlation

The Pearson sample correlation is used to determine whether a linear relationship exists between a pair of samples. The relationship can be either a positive relationship, which suggests a distribution of data-points on a straight line which slopes upwards, or negative relationship, where the data would be distributed on a straight line with a downwards slope.

The result of a Pearson correlation will always be an r-value between +1 and -1, where +1 depicts a strong positive relationship and -1 a strong negative relationship. A weak, positive or negative, relationship is present when the r-value lies between -0.5 and +0.5. When the r-value is close to 0, no significant relationship can be established between the two data-sets involved, and further statistical analyses must be done.

5.3.6.3 Two-way ANOVA test

The purpose of the ANOVA-test is to detect a difference between several population means by comparing the variances of those populations. Since the

two-way ANOVA test is used, the test will be able to tell us if an independent variable influenced the results obtained.

The resulting data of the study is the dependent variable, while the factors that can influence the data are the independent variables. For the present study that would imply the following: does the specific participant have an influence on the result; does the specific stimulus have an impact on the result; and is there an interaction between the participant and the stimuli, that influences the results. Since the significance level is set at 0.05, if a p-value is less than 0.05, it would indicate that that specific variable does not have a statistical significant influence on the results.

5.4 Conclusion of Methodology

The section Methodology describes the procedures that was followed during the setup, execution and data processing of the experiment. The procedures include obtaining ethical clearance, collection of hardware to setup the experiment, executing the experiment, processing the data after it has been collected, and the statistical analyses that was used to interpret the results.

Chapter 6

6 Results and Findings

The participants were subjected to one of three sets of stimuli, and thus the results are reported in terms of the sets of stimuli. Set 1 contained 60 emotional stimulating pictures, while set 2 and 3 had 59 pictures, as provided by IAPS. Within the set of pictures, every picture that is presented to the participant is regarded as an event.

Unfortunately, the measurements of the GSR and Pupil diameter yielded to little data to ensure statistically viable results. The reasons for the exclusion of data can be found in section 5.3.5, and the processed results can be found in Appendix I-1 (Pupil diameter) and I-2 (GSR) respectively. Nevertheless, these results are discussed in section 7.3.

6.1 EEG results

6.1.1 Data Included

The data that is included in the results shown are from 14 participants, 9 male and 5 female. The data that was excluded from the results are due to mechanical difficulties, including hardware malfunctions and human error.

6.1.2 Results within each Emotion Group

Table 1 depicts the results obtained after the Power Spectral Density (PSD) was calculated for each of the frequency bands. The results are shown for each emotion group, positive and negative. The table shows the mean baseline and mean test-values for the PSD calculations. A t-test conducted to compare the baseline and test-values yielded the p-values displayed. Since $p << 0.01$ for all the values obtained, a significant statistical difference exists between the baseline and test-data with the exception of the beta frequency. The beta frequency revealed that the negative arousal group did not yield a p-value that indicates a statistical significant difference. The results of the t-tests for both sexes (Female: Table 2; Male: Table 3) revealed that there exists a statistical significant difference between the baseline and test-data for the delta, theta and alpha frequency bands. The results of the male participants showed that for none of the emotion groups in the beta-frequency band, a statistical significant difference could be confirmed.

Table 1: EEG-results within each emotion group; baseline vs test-value

	Mean Baseline-value	Mean Test-value	p-value
delta frequency band			
Positive valence group	0.0249	0.1311	0.0000
Negative valence group	0.0116	0.1317	0.0000
Positive arousal group	0.0271	0.1199	0.0000
Negative arousal group	0.0129	0.1402	0.0000
Positive dominance group	0.0220	0.1291	0.0000
Negative dominance group	0.0137	0.1392	0.0000
theta frequency band			
	Mean Baseline-value	Mean Test-value	p-value
Positive valence group	0.0271	0.1241	0.0000
Negative valence group	0.0125	0.1286	0.0000
Positive arousal group	0.0293	0.1180	0.0000
Negative arousal group	0.0141	0.1321	0.0000
Positive dominance group	0.0240	0.1228	0.0000
Negative dominance group	0.0148	0.1363	0.0000
alpha frequency band			
	Mean Baseline-value	Mean Test-value	p-value
Positive valence group	0.0079	0.0252	0.0000
Negative valence group	0.0037	0.0263	0.0000
Positive arousal group	0.0081	0.0243	0.0000
Negative arousal group	0.0044	0.0267	0.0000
Positive dominance group	0.0070	0.0247	0.0000
Negative dominance group	0.0044	0.0281	0.0000
beta frequency band			
	Mean Baseline-value	Mean Test-value	p-value
Positive valence group	0.0006	0.0008	0.0275
Negative valence group	0.0004	0.0009	0.0138
Positive arousal group	0.0005	0.0008	0.0587
Negative arousal group	0.0005	0.0008	0.0035
Positive dominance group	0.0006	0.0007	0.0192
Negative dominance group	0.0004	0.0010	0.0168

Table 2: EEG-results within each emotion group for female participants; baseline vs test-value

delta frequency band

	Mean Baseline-value	Mean Test-value	p-value
Positive valence group	0.0135	0.1418	0.0000
Negative valence group	0.0000	0.1441	0.0000
Positive arousal group	0.0000	0.1344	0.0000
Negative arousal group	0.0000	0.1491	0.0000
Positive dominance group	0.0115	0.1454	0.0000
Negative dominance group	0.0093	0.1388	0.0000

theta frequency band

	Mean Baseline-value	Mean Test-value	p-value
Positive valence group	0.0163	0.1369	0.0000
Negative valence group	0.0080	0.1406	0.0000
Positive arousal group	0.0070	0.1299	0.0000
Negative arousal group	0.0170	0.1448	0.0000
Positive dominance group	0.0139	0.1406	0.0000
Negative dominance group	0.0103	0.1361	0.0000

alpha frequency band

	Mean Baseline-value	Mean Test-value	p-value
Positive valence group	0.0054	0.0277	0.0000
Negative valence group	0.0021	0.0298	0.0000
Positive arousal group	0.0022	0.0254	0.0000
Negative arousal group	0.0053	0.0310	0.0000
Positive dominance group	0.0046	0.0284	0.0000
Negative dominance group	0.0028	0.0292	0.0002

beta frequency band

	Mean Baseline-value	Mean Test-value	p-value
Positive valence group	0.0005	0.0010	0.0000
Negative valence group	0.0004	0.0010	0.0153
Positive arousal group	0.0004	0.0008	0.0000
Negative arousal group	0.0005	0.0012	0.0057
Positive dominance group	0.0005	0.0010	0.0000
Negative dominance group	0.0004	0.0011	0.0263

Table 3: EEG-results within each emotion group for male participants; baseline vs test-value

delta frequency band

	Mean Baseline-value	Mean Test-value	p-value
Positive valence group	0.0310	0.1252	0.0000
Negative valence group	0.0140	0.1246	0.0000
Positive arousal group	0.0368	0.1126	0.0000
Negative arousal group	0.0120	0.1350	0.0000
Positive dominance group	0.0278	0.1207	0.0000
Negative dominance group	0.0162	0.1395	0.0000

theta frequency band

	Mean Baseline-value	Mean Test-value	p-value
Positive valence group	0.0330	0.1172	0.0000
Negative valence group	0.0151	0.1217	0.0000
Positive arousal group	0.0397	0.1120	0.0002
Negative arousal group	0.0124	0.1246	0.0000
Positive dominance group	0.0295	0.1137	0.0000
Negative dominance group	0.0174	0.1365	0.0000

alpha frequency band

	Mean Baseline-value	Mean Test-value	p-value
Positive valence group	0.0092	0.0238	0.0004
Negative valence group	0.0046	0.0243	0.0000
Positive arousal group	0.0110	0.0237	0.0063
Negative arousal group	0.0039	0.0241	0.0000
Positive dominance group	0.0082	0.0228	0.0001
Negative dominance group	0.0053	0.0275	0.0000

beta frequency band

	Mean Baseline-value	Mean Test-value	p-value
Positive valence group	0.0006	0.0007	0.4271
Negative valence group	0.0005	0.0008	0.1102
Positive arousal group	0.0006	0.0008	0.2030
Negative arousal group	0.0005	0.0006	0.1475
Positive dominance group	0.0006	0.0006	0.4684
Negative dominance group	0.0005	0.0009	0.1000

6.1.3 Results between Participants within Emotion Groups

A t-test was conducted on the PSD-values within the emotion groups, for each individual participant, and each frequency band. The results of the t-test (p-values) are depicted in Table 30 (Appendix H-1), and show the statistical difference between the baseline and test-data for each participant. The mean p-value for each participant is also displayed in Table 30, indicating the mean p-value of the different emotion groups for each individual participant. The p-values for all the participants, across all the frequency bands revealed $p << 0.01$, and thus a statistically significant difference for all participants, across all emotion groups, are confirmed.

6.1.4 EEG results between the emotion groups

The results of the t-test (p-values) comparing the different emotion groups are depicted in Table 4. These results reveal that for the delta and beta frequency bands a statistically significant difference exists between the negative dominance and the negative valence groups. When looking at the theta and alpha frequency bands, a statistically significant difference is revealed between the negative dominance group and both the positive and negative valence groups. The t-test compared the PSD-results of the EEG for each of the emotion groups, within each frequency band.

Table 4: EEG-results between emotion groups; baseline vs test-data

delta

	Positive Valence	Negative Valence	Positive Arousal	Negative Arousal	Positive Dominance
Negative Valence	0.48				
Positive Arousal	0.19	0.28			
Negative Arousal	0.16	0.15	0.12		
Positive Dominance	0.33	0.38	0.09	0.24	
Negative Dominance	0.09	0.03	0.14	0.42	0.30

theta

	Positive Valence	Negative Valence	Positive Arousal	Negative Arousal	Positive Dominance
Negative Valence	0.35				
Positive Arousal	0.30	0.31			
Negative	0.15	0.23	0.19		

Arousal					
Positive Dominance	0.35	0.48	0.17	0.26	
Negative Dominance	0.03	0.03	0.15	0.21	0.20

alpha

	Positive Valence	Negative Valence	Positive Arousal	Negative Arousal	Positive Dominance
Negative Valence	0.37				
Positive Arousal	0.34	0.38			
Negative Arousal	0.18	0.26	0.28		
Positive Dominance	0.36	0.45	0.23	0.30	
Negative Dominance	0.03	0.03	0.21	0.14	0.21

beta

	Positive Valence	Negative Valence	Positive Arousal	Negative Arousal	Positive Dominance
Negative Valence	0.39				
Positive Arousal	0.23	0.32			
Negative Arousal	0.18	0.47	0.38		
Positive Dominance	0.19	0.49	0.26	0.07	
Negative Dominance	0.10	0.03	0.33	0.16	0.08

6.2 Heart Rate Results

6.2.1 Included Data

The data that is included in the results shown are from 14 participants, 9 male and 5 female. The data that was excluded from the results are due to mechanical difficulties, including hardware malfunctions and human error.

6.2.2 Results within each Emotion Group

Table 5 shows the results obtained after the heart rate was calculated for each of the emotion groups. The table shows the mean baseline and mean test-values for the heart rate calculations. A t-test conducted to compare the baseline and test-values yielded the p-values displayed. Since $p > 0.05$ for all the values obtained, no significant statistical difference was established between the baseline and test-data. The results for both sexes (Female results: Table 6 and Male results: Table 7) revealed that a statistical significant difference exists between the baseline and test-values for the negative dominance group. In addition to this result, the data for the male participants also revealed that there does exist a statistical significant difference between the baseline and test-values for the negative valence emotion group. The female results also revealed a statistical significant difference for the positive dominance emotion group.

Table 5: Heart rate results within each emotion group; baseline vs test-data

	Mean Baseline-value	*Mean Test-value*	*p-value*
Positive valence group	72.9932	72.7211	0.3202
Negative valence group	72.6618	73.5294	0.1207
Positive arousal group	74.0808	74.4847	0.2814
Negative arousal group	71.7676	71.8402	0.4535
Positive dominance group	73.0343	73.3266	0.3070
Negative dominance group	72.5000	72.6087	0.4443

Table 6: Heart rate results within each emotion group for female participants; baseline vs test-data

	Mean Baseline-value	*Mean Test-value*	*p-value*
Positive valence group	71.7665	72.8144	0.1054
Negative valence group	73.7594	72.7068	0.1901
Positive arousal group	73.0233	74.2636	0.1379
Negative arousal group	72.4107	71.6071	0.1884
Positive dominance group	72.2872	73.7234	0.0491
Negative dominance group	73.3486	71.1009	0.0335

Table 7: Heart rate results within each emotion group for male participants; baseline vs test-data

	Mean Baseline-value	*Mean Test-value*	*p-value*
Positive valence group	73.7409	72.6642	0.0854
Negative valence group	71.9565	74.0580	0.0127

Positive arousal group	74.6739	74.6087	0.4706
Negative arousal group	71.3265	72.0000	0.2121
Positive dominance group	73.4903	73.0844	0.2987
Negative dominance group	71.9461	73.5928	0.0495

6.2.3 Results between Participants within Emotion Groups

After the results of the heart rate calculations have been compared within the emotion groups, a t-test was conducted between the participants. The values depicted in Table 31 (Appendix H-2) reveals the statistical difference between the baseline and test-data for each participant. Each emotion group's p-values are showed, as well as the mean p-value for each participant.
The p-values of participant 009 proved to be the closest to our significance level ($p<0.05$), but for the mean $p > 0.05$ and thus no statistical significant difference could be confirmed.

6.2.4 Heart rate results between the emotion groups

Table 8 depict the results of the t-test when comparing the heart rate data of each of the emotion groups to each other. These results reveal that there does exists some statistical significant difference between these specific emotion groups: the positive arousal group when comparing it to both the negative and positive valence group; the negative arousal group when comparing to the positive valence and arousal groups; the positive dominance group when comparing to the negative valence and arousal groups.

Table 8: Heart rate results between emotion groups; baseline vs test-data

	Positive Valence	*Negative Valence*	*Positive Arousal*	*Negative Arousal*	*Positive Dominance*
Negative Valence	0.44				
Positive Arousal	0.01	0.01			
Negative Arousal	0.02	0.14	0.00		
Positive Dominance	0.24	0.04	0.07	0.01	
Negative Dominance	0.31	0.19	0.16	0.29	0.36

6.2.5 Results compared to EEG-results

The results obtained from the heart rate calculations was compared to the results of the PSD-calculations done on the EEG-results in three different statistical tests. The results of Pearson correlation test between the data of heart rate and EEG,

are shown in Table 9. The r-values obtained shows the relationship between the heart rate and calculated PSD-values. The r-values showed a weak linear relationship for all the emotion groups.

The results of a two-way ANOVA with replication between the test-data of heart rate and EEG, are shown in Table 10. The p-values obtained shows that the difference in participant influenced the data significantly ($p << 0.01$), but the stimuli and interaction between stimuli and participants only contributed to less than 50% of the change in measurements ($p > 0.5$).

The results of a two-way ANOVA with replication of the percentage difference between baseline and test-data for heart rate and EEG, are shown in Table 11. The p-values obtained displays that only the difference in participant made a significant difference ($p << 0.01$) in the results recorded. The stimuli and interaction between stimuli and participant had the following influences on the results: In the delta frequency band the influence was approximately 73%, while an 83% influence was present in the theta frequency band. The alpha frequency band also revealed a 70% influence from the abovementioned factors.

Table 9: Pearson Correlation between heart rate and EEG-results; test-data vs test-data

Positive Valence		*Positive Arousal*		*Positive Dominance*	
r-value		r-value		r-value	
delta	-0.07	delta	-0.12	delta	-0.05
theta	-0.08	theta	-0.13	theta	-0.05
alpha	-0.07	alpha	-0.13	alpha	-0.05
beta	-0.11	beta	-0.11	beta	-0.08
Negative Valence		*Negative Arousal*		*Negative Dominance*	
r-value		r-value		r-value	
delta	0.00	delta	0.02	delta	-0.03
theta	-0.01	theta	0.02	theta	-0.04
alpha	-0.02	alpha	0.02	alpha	-0.05
beta	-0.05	beta	-0.01	beta	-0.07

Table 10: Results of two-way ANOVA-test with replication between heart rate and EEG; test-data vs test-data

delta frequency band

Source of Variation	F	P-value	F crit
Participant	25886.1404	0	3.8479
Stimuli	0.9554	0.5726	1.3304
Interaction	0.9628	0.5567	1.3304

theta frequency band

Source of Variation	F	P-value	F crit

Participant	25888.7004	0	3.8479
Stimuli	0.9544	0.5747	1.3304
Interaction	0.9638	0.5545	1.3304

alpha frequency band

Source of Variation	F	P-value	F crit
Participant	25961.0256	0	3.8479
Stimuli	0.9583	0.5664	1.3304
Interaction	0.9599	0.5628	1.3304

beta frequency band

Source of Variation	F	P-value	F crit
Participant	25978.2240	0	3.8479
Stimuli	0.9591	0.5646	1.3304
Interaction	0.9591	0.5646	1.3304

Table 11: Results of two-way ANOVA-test with replication between the percentages differences of change from baseline to test-data for heart rate vs EEG

delta frequency band

Source of Variation	F	P-value	F crit
Participant	220.8188	0.0000	3.8480
Stimuli	1.1084	0.2710	1.3334
Interaction	1.1080	0.2716	1.3334

theta frequency band

Source of Variation	F	P-value	F crit
Participant	260.4350	0.0000	3.8480
Stimuli	1.1728	0.1788	1.3334
Interaction	1.1725	0.1792	1.3334

alpha frequency band

Source of Variation	F	P-value	F crit
Participant	365.3548	0.0000	3.8480
Stimuli	1.0862	0.3086	1.3334
Interaction	1.0845	0.3115	1.3334

beta frequency band

Source of Variation	F	P-value	F crit
Participant	109.9803	0.0000	3.8480
Stimuli	0.9304	0.6245	1.3334
Interaction	0.9319	0.6214	1.3334

6.3 Respiratory Rate Results

6.3.1 Included Data

The data that is included in the results shown are from 14 participants, 9 male and 5 female. The data that was excluded from the results are due to mechanical difficulties, including hardware malfunctions and human error.

6.3.2 Results within each Emotion Group

Table 12 displays the results obtained after the respiratory rate was calculated for each of the emotion groups. The table shows the mean baseline and mean test-values for the respiratory rate calculations. A t-test conducted to compare the baseline and test-values yielded the p-values displayed. Since $p > 0.05$ for all the values obtained, a significant statistical difference could not be established between the baseline and test-data for either the entire group (Table 12) or the groups where sexes were separated (Female results: Table 13 and Male results: Table 14).

Table 12: Respiratory rate results within each emotion group; baseline vs test-data

	Mean Baseline-value	*Mean Test-value*	*p-value*
Positive valence group	16.8103	17.0259	0.3318
Negative valence group	16.9210	16.6757	0.3302
Positive arousal group	16.5040	16.6491	0.3930
Negative arousal group	17.0667	17.0889	0.4826
Positive dominance group	16.8293	16.7542	0.4345
Negative dominance group	16.8624	17.1141	0.3465

Table 13: Respiratory rate results within each emotion group for female participants; baseline vs test-data

	Mean Baseline-value	*Mean Test-value*	*p-value*
Positive valence group	18.9329	18.7805	0.4197
Negative valence group	18.8346	19.1729	0.3469
Positive arousal group	18.1641	18.7500	0.2537
Negative arousal group	19.3750	19.1667	0.3895
Positive dominance group	18.5904	18.5638	0.4843
Negative dominance group	19.2661	19.7248	0.3261

Table 14: Respiratory rate results within each emotion group for male participants; baseline vs test-data

	Mean Baseline-value	*Mean Test-value*	*p-value*
Positive valence group	15.6500	16.0667	0.2601
Negative valence group	15.8333	15.2564	0.2141
Positive arousal group	15.6574	15.5777	0.4527
Negative arousal group	15.6915	15.8511	0.4078
Positive dominance group	15.8696	15.7681	0.4329
Negative dominance group	15.4762	15.6085	0.4359

6.3.3 Results between Participants within Emotion Groups

A t-test was conducted between the participants after the results of the respiratory rate calculations have been compared within the emotion groups. The values displayed in Table 32 (Appendix H-3), reveals the statistical difference between the baseline and test-data for each participant. Each emotion group's p-values are showed, as well as the mean p-value for each participant. The p-values of participant 006 showed the most promise of statistical significant difference, but since the significance level was chosen as $p < 0.05$, no statistical significant difference could be confirmed.

6.3.4 Respiratory rate results between the emotion groups

The results of the t-test comparing the respiratory rate data between the different emotion groups are depicted in Table 15, and reveal that there exists a statistical significant difference between the negative dominance group and all the positive emotion groups.

Table 15: Respiratory rate results between emotion groups; baseline vs test-data

	Positive Valence	*Negative Valence*	*Positive Arousal*	*Negative Arousal*	*Positive Dominance*
Negative Valence	0.13				
Positive Arousal	0.39	0.38			
Negative Arousal	0.08	0.43	0.20		
Positive Dominance	0.25	0.17	0.49	0.21	
Negative Dominance	0.01	0.22	0.05	0.12	0.02

6.3.5 Results compared to EEG

The results obtained from the respiratory rate calculations was compared to the results of the PSD-calculations done on the EEG-results in three different statistical tests. The results of Pearson correlation test between the data of respiratory rate and EEG, are shown in Table 16. The r-values obtained shows the relationship between the respiratory rate and calculated PSD-values. The r-values showed a weak linear relationship for all the emotion groups.

The results of a two-way ANOVA with replication between the test-data of respiratory rate and EEG, are shown in Table 17. The p-values obtained shows that the difference in participant influenced the data significantly ($p << 0.01$), also the stimuli and interaction between stimuli and participants contributed to approximately 60% of the change in measurements ($p < 0.4$).

The results of a two-way ANOVA with replication of the percentage difference between baseline and test-data for respiratory rate and EEG, are shown in Table 18. The p-values obtained displays that the different participants made a significant difference ($p << 0.01$) in the results recorded. There was also a contribution to the difference in the results of approximately 81% ($p = \pm 0.19$), 84% ($p = \pm 0.16$) and 92% ($p = \pm 0.08$) by the stimuli and interaction between stimuli and participant in the alpha, delta and theta bands respectively.

Table 16: Pearson Correlation between respiratory rate and EEG-results; test-data vs test-data

Positive Valence		*Positive Arousal*		*Positive Dominance*	
r-value		r-value		r-value	
delta	0.03	delta	0.00	delta	0.03
theta	0.04	theta	0.01	theta	0.04
alpha	0.05	alpha	0.02	alpha	0.05
beta	0.03	beta	0.02	beta	0.02
Negative Valence		*Negative Arousal*		*Negative Dominance*	
r-value		r-value		r-value	
delta	-0.02	delta	0.01	delta	-0.02
theta	-0.01	theta	0.02	theta	-0.01
alpha	0.00	alpha	0.03	alpha	0.00
beta	0.02	beta	0.02	beta	0.03

Table 17: Results of a two-way ANOVA-test with replication between respiratory rate and EEG; test-data vs test-data

delta frequency band

Source of Variation	F	P-value	F crit
Participant	*3074.164472*	*0*	*3.847426668*

Stimuli	*1.044753931*	*0.384854*	*1.329681989*
Interaction	*1.039696622*	*0.394895*	*1.329681989*

theta frequency band

Source of Variation	F	P-value	F crit
Participant	*3075.404592*	*0*	*3.847426668*
Stimuli	*1.044104555*	*0.386137*	*1.329681989*
Interaction	*1.040362921*	*0.393566*	*1.329681989*

alpha frequency band

Source of Variation	F	P-value	F crit
Participant	*3110.152304*	*0*	*3.847426668*
Stimuli	*1.042838409*	*0.388645*	*1.329681989*
Interaction	*1.041754048*	*0.390797*	*1.329681989*

beta frequency band

Source of Variation	F	P-value	F crit
Participant	*3118.649084*	*0*	*3.847426668*
Stimuli	*1.042455118*	*0.389405*	*1.329681989*
Interaction	*1.042145205*	*0.39002*	*1.329681989*

Table 18: Results of two-way ANOVA-test with replication between the percentage differences of change from baseline to test-data for respiration rate vs EEG

delta frequency band

Source of Variation	F	P-value	F crit
Participant	242.9741	0.0000	3.8475
Stimuli	1.1809	0.1685	1.3326
Interaction	1.1805	0.1690	1.3326

theta frequency band

Source of Variation	F	P-value	F crit
Participant	283.9339	0.0000	3.8475
Stimuli	1.2703	0.0853	1.3326
Interaction	1.2688	0.0863	1.3326

alpha frequency band

Source of Variation	F	P-value	F crit
Participant	394.7433	0.0000	3.8475
Stimuli	1.1627	0.1912	1.3326
Interaction	1.1576	0.1978	1.3326

beta frequency band

Source of Variation	F	P-value	F crit
Participant	111.1742	0.0000	3.8475
Stimuli	0.9833	0.5120	1.3326
Interaction	0.8946	0.6981	1.3326

6.4 Finger Temperature Results

In the experiment, it was possible for the finger temperature to increase, decrease, or remain constant with the presentation of each of the stimuli.

6.4.1 Included Data

The data that is included in the results shown are from 14 participants, 9 male and 5 female. The data that was excluded from the results are due to mechanical difficulties, including hardware malfunctions and human error.

6.4.2 Results within each Emotion Group

Table 19 shows the results obtained after the mean finger temperature values was calculated for each of the emotion groups. The table shows the mean baseline and mean test-values for finger temperature. A t-test conducted to compare the baseline and test-values yielded the p-values displayed. The p-values of the positive valence, positive arousal and positive dominance groups are all larger than our significance level ($p < 0.05$) and thus no statistical difference could be established for these emotion groups. For the rest of the t-test results however, $p << 0.01$ which indicates a strong statistical significant between the baseline and test-data.
This is true for both the combined group as well as the results for the male participants (See Table 21). The results for the female participants (Table 20), however, revealed only a statistical significant difference between for the positive dominance group.

Table 19: Finger temperature results within each emotion group; baseline vs test-data

	Mean Baseline-value	*Mean Test-value*	*p-value*
Positive valence group	27.1529	27.1534	0.7657
Negative valence group	27.1770	27.1840	0.0003
Positive arousal group	27.5474	27.5478	0.8194
Negative arousal group	26.8488	26.8546	0.0039
Positive dominance group	27.1588	27.1587	0.9572
Negative dominance group	27.1721	27.1817	0.0000

Table 20: Finger temperature results within each emotion group for female participants; baseline vs test-data

	Mean Baseline-value	*Mean Test-value*	*p-value*
Positive valence group	28.1029	28.0978	0.0939
Negative valence group	28.5041	28.5066	0.4619
Positive arousal group	27.6619	27.6633	0.6643
Negative arousal group	28.7265	28.7224	0.1949

Positive dominance group	28.0662	28.0600	0.0272
Negative dominance group	28.6557	28.6618	0.1075

Table 21: Finger temperature results within each emotion group for male participants; baseline vs test-data

	Mean Baseline-value	*Mean Test-value*	*p-value*
Positive valence group	26.6335	26.6371	0.0869
Negative valence group	26.4228	26.4323	0.0001
Positive arousal group	27.4890	27.4889	0.9037
Negative arousal group	25.7301	25.7419	0.0000
Positive dominance group	26.6643	26.6675	0.0832
Negative dominance group	26.3165	26.3280	0.0000

6.4.3 Results between Participants within Emotion Groups

A t-test was conducted between the participants after the results of the finger temperature calculations have been compared within the emotion groups. The values in Table 34 (Appendix H-5) shows the statistical difference between the baseline and test-data for each participant. Each emotion group's p-values are showed, as well as the mean p-value for each participant. A statistical significant difference could be established for all the participants, except participant 011, 013 and 019 as $p > 0.05$ for their mean p-values.

6.4.4 Finger temperature results between the emotion groups

The results (Table 22) of the t-test comparing the data of the finger temperature between the different emotion groups, reveal that there exists a statistical significant difference between the positive valence and arousal groups; as well as between all the positive emotion groups and the negative arousal group.

Table 22: Finger temperature results between emotion groups; baseline vs test-data

	Positive Valence	*Negative Valence*	*Positive Arousal*	*Negative Arousal*	*Positive Dominance*
Negative Valence	0.21				
Positive Arousal	0.00	0.09			
Negative Arousal	0.00	0.27	0.00		
Positive Dominance	0.49	0.11	0.01	0.00	
Negative	0.10	0.47	0.35	0.19	0.10

Dominance	

6.4.5 Results compared to EEG-results

The results obtained from the finger temperature calculations were compared to the results of the PSD-calculations done on the EEG-results in three different statistical tests. The results of the Pearson correlation test between the data of finger temperature and EEG, are shown in Table 23. The r-values obtained shows the relationship between the finger temperature and calculated PSD-values. The r-values showed a weak linear relationship for all the emotion groups.

The results of a two-way ANOVA with replication between the test-data of finger temperature and EEG, are shown in Table 24. The p-values obtained shows that only the difference in participant influenced the data measurements significantly ($p << 0.01$).

The results of a two-way ANOVA with replication of the percentage difference between baseline and test-data for finger temperature and EEG, are shown in Table 25. The p-values obtained displays that the difference in participant made a significant difference ($p << 0.01$) in the results recorded. The interaction between stimuli and participant also contributed to approximately 86% (alpha frequency band), 88% (delta frequency band) and 94% (theta frequency band) of the change in measurements.

Table 23: Pearson Correlation between finger temperature and EEG-results; test-data vs test-data

Positive Valence		*Positive Arousal*		*Positive Dominance*	
r-value		r-value		r-value	
delta	-0.21	delta	-0.27	delta	-0.20
theta	-0.21	theta	-0.27	theta	-0.20
alpha	-0.20	alpha	-0.28	alpha	-0.19
beta	-0.18	beta	-0.19	beta	-0.16
Negative Valence		*Negative Arousal*		*Negative Dominance*	
r-value		r-value		r-value	
delta	-0.18	delta	-0.15	delta	-0.19
theta	-0.18	theta	-0.14	theta	-0.19
alpha	-0.16	alpha	-0.12	alpha	-0.17
beta	-0.11	beta	-0.04	beta	-0.13

Table 24: Results of two-way ANOVA test with replication between finger temperature and EEG; test data vs test data

delta frequency band

Source of Variation	F	P-value	F crit
Participant	23376.3032	0.0000	3.8474
Stimuli	0.0388	1.0000	1.3297
Interaction	0.0389	1.0000	1.3297

theta frequency band

Source of Variation	F	P-value	F crit
Participant	23384.2842	0.0000	3.8474
Stimuli	0.0386	1.0000	1.3297
Interaction	0.0389	1.0000	1.3297

alpha frequency band

Source of Variation	F	P-value	F crit
Participant	23570.4266	0.0000	3.8474
Stimuli	0.0375	1.0000	1.3297
Interaction	0.0378	1.0000	1.3297

beta frequency band

Source of Variation	F	P-value	F crit
Participant	23611.7031	0.0000	3.8474
Stimuli	0.0376	1.0000	1.3297
Interaction	0.0376	1.0000	1.3297

Table 25: Results of two-way ANOVA-test with replication between the percentage difference of change from baseline to test-data for finger temperature vs EEG

delta frequency band

Source of Variation	*F*	*P-value*	*F crit*
Participant	245.3750	0.0000	3.8474
Stimuli	1.2162	0.1286	1.3297
Interaction	1.2162	0.1287	1.3297

theta frequency band

Source of Variation	*F*	*P-value*	*F crit*
Participant	287.0373	0.0000	3.8474
Stimuli	1.3040	0.0628	1.3297
Interaction	1.3040	0.0628	1.3297

alpha frequency band

Source of Variation	*F*	*P-value*	*F crit*
Participant	400.6173	0.0000	3.8474
Stimuli	1.2046	0.1404	1.3297
Interaction	1.2046	0.1404	1.3297

beta frequency band

Source of Variation	*F*	*P-value*	*F crit*

Participant	132.3663	0.0000	3.8474
Stimuli	0.9161	0.6564	1.3297
Interaction	0.9164	0.6556	1.3297

6.5 Conclusion

Some of the most prominent results to note from this section are that a statistical significant difference is confirmed between the baseline and test-data for the EEG-measurements and pupil diameter results both within emotion groups and between participants.

No statistical difference could however be confirmed between the baseline and test-data for the rest of the physiological parameters, except for finger temperature that revealed a statistical significant difference for half of the emotion groups and more than half of the participants.

All the Pearson correlation tests revealed a weak linear relationship between the test-data for the physiological parameters and the EEG-data. The most noticeable result from both the ANOVA-tests were the indication that for all the physiological parameters, the difference in participant had a significant influence on the resulting data.

This section revealed the results of the calculations done on all the raw measurements. The results are depicted in Tables 1 through 32 and the meaning of these results are elaborated on in the next section, Discussion.

Chapter 7

7 Discussion

This section discusses the results obtained from the experiment. Several comparisons between parameters are examined, and the importance of these correlations, or lack thereof, are explained.

7.1 EEG

The EEG-data was measured at 128 Hz, by the Emotiv EPOC with 14 electrodes according to the international 10/20 placement, as described in section 4, Hardware. The results were processed as described in the Methodology (section 5) and then compared within each emotion group (genders separately and together) and compared between participants as presented in the section Results and Findings (section 6).

7.1.1 Results within each Emotion Group

The results of the t-test within the emotion groups (valence, arousal and dominance), describes whether a statistical significant difference exists between the baseline and the test-data. For the EEG-results a student t-test was done for each of the four frequency bands (delta, theta, alpha and beta). The results indicate that a statistical significant difference ($p < 0.05$) exist for all the emotion groups, across all the frequency bands, except for the negative arousal emotion group ($p = 0.06$) within the beta frequency band (Table 1).

When differentiating between the results based on gender the results revealed that even though the female participants' data (Table 2) indicated that there exists a statistical significant difference for all the emotion groups across all the frequency bands, the male participants' data (Table 3) indicated that no statistical significant difference exists for any of the emotion groups in the beta frequency range.

When the results of the t-test were investigated for each individual participant the results indicated that a statistical significant difference ($p < 0.05$) exist for the majority (>85%) of the participants, in all the emotion groups, across the delta, theta and alpha frequency bands. The results are shown in Appendix H-1. The beta frequency band revealed a statistical significant difference for 57% of the participants. Since the majority of the results indicated a statistical significance, the data can be further explored for correlations.

The importance of the statistically significant difference in the data lie in the fact that if a statistical significant difference exists, it can be deduced that the stimuli caused a substantial change in EEG-data. Existing literature confirmed that EEG-

measurements should be affected by changes in emotion, and thus the results of the t-test supports the hypothesis that our stimuli will evoke emotions that can cause changes in EEG-measurements (Bradley and Lang, 2007; Lundqvist *et al.*, 2008)

When comparing the different emotional groups to each other the results indicated that there will be a statistically significant difference ($p = 0.03$) between the negative dominance and valence emotion groups. Additionally, the theta and alpha frequency bands also reveal a statistical significant difference between the negative dominance and positive valence groups. These results imply that the EEG-data reveals a significant difference between these emotion groups respectively, but not for the other emotional groups. Thus, the hypothesis that emotions can be discerned by looking at these EEG-measurements are proven untrue.

It can be concluded that the stimuli used in the experiment were effective in provoking a change in the collective group, the group of female participants and the majority of the individual participants.

7.2 Physiological factors

The results were processed as described in the Methodology (section 5) and then compared within each emotion group; compared between participants; between emotion groups; and finally compared to the EEG-results as presented in the section Results and Findings (section 6). The comparison within each emotion group was done with the genders separate and combined.

The results of the heart rate were measured at 128 Hz, by a photoplethsmograph sensor attached to the participant's index finger on their dominant hand, while the respiratory rate and finger temperature was both measured at 32 Hz, by attaching a respiration sensor to the participant's thorax and enclosing a temperature sensor that contains a thermistor on the participant's index finger on their non-dominant hand.

7.2.1 Results within each Emotion Group

When comparing the results of the physiological factors within each emotion group (valence, arousal and dominance) it became clear that a statistically significant difference between the baseline and test-data's values for heart rate, and respiratory rate doesn't exist. This conclusion is evident by the p-values of these physiological factors ($p > 0.05$ for all the emotion groups), see Table 5 (heart rate) and Table 12 (respiratory rate).

Somewhat promising results was produced by the negative valence (unhappy) group regarding heart rate measurements ($p = 0.12$) in Table 5. However, these

results do not fall within our proposed significance level, and are therefore not considered a statistical significant result. The absence of a statistical significant difference implies that the stimuli that was presented to the participants was not effective enough to provoke an emotion that causes a difference in the physiological measurements of the collective group.

Table 26: Statistically significant results within emotion groups for physiological parameters

	Heart rate	**Respiratory rate**	**Finger temperature**
Statistically significant results within emotion groups (both genders)			
	None	None	Only negative emotion groups
Statistically significant results within emotion groups (female participants)			
	Positive and Negative Dominance emotion groups	None	Positive Dominance emotion group
Statistically significant results within emotion groups (male participants)			
	Negative Valence and Dominance emotion groups	None	Only negative emotion groups

Table 26 provides a summary of the statistically significant results of the physiological parameters when compared to the EEG within emotion groups. Past research however, contradicts the absence of change in physiological measurements due to emotion as presented by our results. Hogervorst et al. (2015) showed that the respiratory rate would increase as the participants' arousal increased. It was also found by Kassam & Mendes (2013) that when a participant experiences shame, their heart rate would increase.

The results of the t-test for heart rate and respiratory rate indicated that the stimuli did not evoke a sufficient change in emotion for the participants. There could be several reasons for this error. The stimuli could not have been effective enough, as it is possible, as a participant, to distance yourself from a picture being shown. The small sample size per response (epoch) could also influence the measurement's accuracy. It could also be possible that the participant's physiology did not react as promptly, and thus the change that was caused, was not recorded.

The results of the finger temperature comparisons, found in Table 19, exhibited statistically significant differences ($p < 0.05$) in all the negative emotion groups: valence (unhappy); arousal (excited); and dominance (controlled). This implies that the stimuli presented to the participants made a significant difference in the finger temperature measurements for the negative emotion groups, but not for the positive emotion groups. The finger temperature increased for the negative emotion groups. The emotion provoked through the stimuli, was not satisfactory

to cause a significant change in the physiological measurements, but was indeed satisfactory for the negative emotions.

Lundqvist et al. (2008) confirmed that when a person experiences an intense emotion, through pleasant and stressful stimuli alike, that person's finger temperature should decrease. The results of the t-test confirms that the stimuli were effective in causing a change in temperature for the negative emotion groups, which could be due to the intensity of negative emotions. However, the finger temperature decreased in the present study, in contrast with the study done by Lundqvist et al. (2008). The lack of a significant change in the positive emotions, could be due to the small sample size within each epoch, only 32 samples per second, thus only 128 samples per epoch. Thus, if a small change in temperature occurred between the recordings of each sample, it would not have been logged. The type of stimuli used could have affected the results as Lundqvist et al. (2008) used music to induce the emotions, where pictures were used as a stimuli in the present study, and the music could be considered more invasive than viewing a picture.

When comparing the outcome of the gender-specific groups, the results (See Table 26) of the respiratory rate indicated no statistical significant difference between the baseline and test-values for male and female participants. The heart rate data revealed a statistical significant difference between the baseline and test-data in the negative valence and dominance groups for the male participants while the female participants revealed a statistical significant difference in the positive and negative dominance groups.

In the studies done by Bradley *et al.* (2008); Driscoll *et al* (2009); Wu *et al* (2012); Kassam and Mendes (2013); and Hogervorst *et al* (2015) no differentiation between results, based on gender, were reported which could indicate that the difference of gender has little to no effect on the results of experiments involving heart rate and respiratory rate. The small influence of gender is confirmed by this study's results, as less than half of the emotion groups' results differ due to a difference in gender.

The results for finger temperature revealed a statistical significant difference for the positive dominance group, and all the negative emotion groups for the female and male participants, respectively, when comparing the baseline and test-data to each other by means of a t-test. However, Lundqvist *et al.* (2008) and Chapman *et al.* (1999) reported that no differences due to gender was established in their studies that measured finger temperature in reaction to stimuli.

The literature thus only indicated that there should exist a difference in GSR test-data for adolescent participants, which were excluded from this study. The differences between genders that was indicated in the heart rate and finger

temperature results are concerning, but since the difference always existed in the minority of the results, it does not invalidate the results.

Even though the result of the t-tests that compared the baseline values to the test-values did not sufficiently prove that the stimuli were effective in causing a significant change for all the physiological parameters, the change that was recorded can still be examined for further correlations.

7.2.2 Results compared between Participants within Emotion Groups

The results of the t-test between participants, within emotion groups (Valence, Arousal and Dominance), investigates whether a statistical significant difference exists between the baseline and the test-data for each individual participant. Table 27 displays the summary of statistically significant results for all the physiological parameter included.

Table 27: Statistically significant results between participants

	Heart rate	**Respiratory rate**	**Finger temperature**
Statistically significant results between participants			
	None	None	11 participants (out of 14)

The results obtained for heart rate and respiratory rate (Heart rate: Table 31; Respiratory rate: Table 32) showed that none of the participants exhibited a statistical significant difference ($p > 0.05$ for all the participants) between the baseline and test-data. This implies that the stimuli shown did not provoke the necessary change in physiological state and thus cannot be considered effective enough to provoke an emotion that causes a recorded change in physiology.

These results do not correlate with existing literature (Homma & Masaoka 2008), as the literature show that even for individuals, respiratory rate should increase with an increase in arousal, and heart rate should decrease when a unpleasant picture is viewed (Bradley *et al.*, 2008). This absence of a correlation indicates that it is possible that the stimuli was ineffective, as it is possible to distance yourself from these non-invasive stimuli. However, it may also be possible that the experimental procedures of the different studies varied too much to enable a positive correlation. The implication of this result is that a significant change was not observed in the results, and thus a change in heart rate and respiratory rate cannot be correlated with the EEG-data. The measurements however, can still indicate some correlation even in the absence of a significant change.

For the finger temperature results obtained (Table 34) only participants 011, 013 and 019 did not show a statistical significant difference ($p > 0.05$) between the baseline and test-data. The rest of the participants exhibited a statistical significant difference ($p < 0.05$) in their measurements between baseline and test-data. This implies that for 11 participants, the stimuli shown provoked the necessary change in physiological state. Thus, the stimuli were effective enough

to provoke an emotion that causes change in the finger temperature measurements for most of the participants.

The results of the majority of the participants correlate with the results found by Lundqvist *et al.*, (2008) as they found that the finger temperature should decrease, implying an influence, when a participant is experiencing pleasant or stressful emotions. Because the results show a change in finger temperature due to the emotion, a correlation between these results and the changes in EEG-results can be investigated.

7.2.3 Results compared between emotion groups

To investigate the effect of the different emotions that the participants were exposed to, a t-test was conducted between the resulting test-values of the different emotion groups. The results indicate whether the type of emotion influenced the physiological results. If a statistical significant difference exists between two emotion groups, it indicates that the results of the corresponding physiological parameter are significantly different for those specific emotion groups.

The results in Table 28 reveal that the EEG-data indicated a statistically significant difference for the delta and beta frequency bands between the negative dominance and the negative valence groups. When looking at the theta and alpha frequency bands, a statistically significant difference is revealed between the negative dominance group and both the positive and negative valence groups. This is conclusive with existing literature as Esslen *et al.* (2004) differentiated between the emotions that they investigated, namely happy, sad and disgust.

Table 28: Statistically significant results between emotion groups

	EEG	**HR***	**RR***	**FT***
Statistically significant differences between emotion groups				
Between which emotion groups does the statistically significant difference lie	**Delta and Beta frequency band**: - Negative Dominance and Valence **Theta and Alpha frequency band**: Negative Dominance	- Positive Arousal and Positive and negative Valence - Negative Arousal and all positive emotion groups - Positive Dominance and Negative	- Negative Dominance and all positive emotion groups	- Positive Arousal and Positive Valence - Negative Arousal and all positive emotion groups

	and Positive & Negative Valence	Valence		
Amount of significant differences	6/60	6/15	3/15	5/15

***HR – Heart Rate; RR – Respiratory rate; FT – Finger Temperature**

In the heart rate results, several statistical significant differences exist between specific emotion groups (see Table 28). The results of the positive arousal group were significantly different to those of both the negative and positive valence group, while the negative arousal group's results were also significantly different when comparing to the positive valence and arousal groups. Furthermore, the positive dominance group's results also revealed a significant difference when comparing to the negative valence and arousal groups. It is proven that a difference in heart rate will be present when comparing the results from when a neutral vs either pleasant or unpleasant stimulus is observed (Driscoll *et al,* 2009). Kassam and Mendes (2013) also reported that their results indicated a difference in the heart rate when comparing the results when anger or shame was experienced by the participant.

It is revealed in the results of the t-test comparing the respiratory rate results between the different emotion groups there exists a statistical significant difference between the negative dominance group and all the positive emotion groups (Table 28). This is supported by the results of Homma and Masaoka (2008) that proved that different breathing rates are observed between different emotions (sad, happy, anxiety and fear) that the participants experienced.

The results of the t-test comparing the finger temperature-results between the different emotion groups reveal that there exists a statistical significant difference between the positive valence and arousal groups; as well as between all the positive emotion groups and the negative arousal group (Table 28). Lin *et al.* (2010) proved that a difference can be observed between two emotions by observing the finger temperature of a participant.

7.2.4 Results compared to EEG-results

After the results from all the physiological factors was compared within the emotion group, the results were compared to the results of the EEG-measurements by means of a Pearson Correlation test. The Pearson correlation test, which was done within the emotion groups and the four frequency bands, resulted in r-values between -0.5 and 0.5 for all the physiological factors, proving that a weak linear relationship exists between all the physiological factors and EEG-measurements.

The results of the Pearson Correlation test can be viewed in Table 9, for heart rate; Table 16, for respiratory rate; and Table 23, for finger temperature. Since the Pearson Correlation test did not yield any strong linear relationships, it was decided to further investigate the relationship between the physiological factors and EEG-measurements by means of a two-way ANOVA-test with replication.

The two-way ANOVA-test describes the influence that particular factors tested had on the results of the test. For the present experiment, the ANOVA describes: the influence of the participant taking part; the influence of the stimulus presented; and the influence that the participant and the stimulus had on each other.

After comparing the test-data of the Physiological factors and EEG-measurements, the results of the two-way ANOVA-test with replication was presented in the following tables: (heart rate: Table 10; respiratory rate: Table 17; finger temperature: Table 24). Table 29 provides a summary of the statistically significant as well as notable results from both the two-way ANOVA-tests.

Table 29: Notable results from the two-way ANOVA-tests

The two-way ANOVA-test between test-data of EEG and physiological parameters			
	HR*	RR*	FT*
Influence by participant	100%	100%	100%
Influence by stimuli and interaction between stimuli and participant	None	60%	None
The two-way ANOVA-test between percentage differences from baseline to test-data of EEG and physiological parameters			
	HR*	RR*	FT*
Influence by participant	100%	100%	100%
Influence by stimuli and interaction between stimuli and participant	delta:73% theta: 83% alpha: 70% beta: None	delta:84% theta: 92% alpha: 81% beta: None	delta:88% theta: 94% alpha: 86% beta: None

***HR – Heart Rate; RR – Respiratory rate; FT – Finger Temperature**

The results of the two-way ANOVA with replication between heart rate, respiration rate, finger temperature, respectively, and the EEG-data indicated that only the participants had a statistically significant influence on the results ($p < 0.05$). The results also revealed that, even though it is not considered statistically significant, the different stimuli and interaction between stimuli and participant had a 60% influence on the respiratory rate.

Past studies' result differ from the results presented here as Diego *et al.* (2004) established that an increase in arousal will be indicated by increased heart rate and accompanied by increase theta, alpha and beta activity and the EEG-signals and Hogervorst et al. (2015) showed that respiratory rate and mental workload could be linearly correlated. It was suggested by Kibler and Rider (1983) that if a participant's anxiety decreases, their finger temperature would increase.

Even though the results for the physiological parameters vs EEG infer that the different participants did have an influence on the results obtained, this influence is logical as the participants are all different individuals and will thus respond differently to the stimuli. The stimuli did however not have a significant influence on the results, which led us to gather that the stimuli did not have a sufficient effect on the physiological parameters. This inference is further supported by the t-test results, discussed in section 7.2.1 which also suggests that the stimuli did not make a statistical significant difference between the baseline and test-data.

The most interesting conclusion that can be drawn from this data is that there is no statistical evidence that proves an interaction between the physiological parameters and the EEG-data that influences the results of the measurements. Because the participant-specific changes were so prominent in most of the comparisons, we can speculate that there is a clear indication that all the participants' brain development were unique. This should be taken into consideration for any future work.

An additional two-way ANOVA-test with replication was done on the percentage change between the baseline and test-data for each of the physiological parameters vs EEG-data. This ANOVA -indicates whether the change that was caused by the emotional stimuli can be correlated between the physiological parameters and the EEG-data. The results of this ANOVA-test is depicted in the following tables: Table 11 (heart rate); Table 18 (respiratory rate); and Table 25 (finger temperature).

The results of these tables show that for the comparison between all the physiological parameters and EEG-data, the difference in participants had a significant influence ($p << 0.01$) on the resulting data. In the results of the heart rate comparison, it was indicated that the stimuli and the interaction between stimuli and participant would have a 73% influence ($p = \pm 0.27$) in the delta frequency range; an 83% influence ($p = \pm 0.17$) in the theta frequency range; and a 70% influence ($p = \pm 0.3$) in the alpha frequency range of the resulting EEG-data. These influences in the results of the heart rate are not statistically significant, but still noteworthy as it would certainly impact the results.

For the comparison of the respiratory rate, a significance of 84% ($p = \pm 0.16$), 92% ($p = \pm 0.08$) and 81% ($p = \pm 0.19$) was found in the delta, theta and alpha

frequency ranges, respectively, for the influence from the stimuli and the interaction between the stimuli and participants. This indicates that a difference in stimuli made a notable, albeit not statistical significant, difference in the results. The influence of the interaction between the stimuli and participants yields the result that there is an 84%, 92%, and 81% correlation at the corresponding frequency bands, between the EEG-data and respiratory rate for the percentage difference in their results. This implies that if the EEG-data would change due to an emotional event, you would see a difference in 84% the respiratory rate measurements in the delta frequency band, a 91% change in the theta frequency band, and an 81% difference in the alpha frequency band.

The comparisons of the finger temperature to EEG-data yielded a noteworthy influence of approximately 85% ($p = \pm 0.15$) in the beta frequency range and 90% ($p = \pm 0.1$) in all frequency ranges except the beta frequency range, respectively, for both the stimuli and the interaction between the stimuli and participants. This implies that the difference in stimuli had a significant effect on the results of the EEG and physiological parameters. It also indicates that the interaction of the stimuli and participants influenced the percentage difference in the measurements in a very dominant manner. These results infer that if a participant would experience an emotion, the percentage difference between their baseline and final condition, regarding finger temperature, would be 80% and 90% correlated between the physiological parameter and EEG-data.

Existing literature by Diego *et al.* (2004) showed that during arousal – which is the general emotion that participants would be experiencing – their heart rate would increase, and the activity in the beta and delta frequency bands would increase and decrease, respectively. Once again, the present study's results prove that the beta frequency band isn't influenced by the stimuli, and even though the influence on the delta frequency band is notable (73%), it is not considered statistically significant.

In the literature regarding respiratory rate, Hogervorst *et al*. (2015) stated that as the mental requirements for a specific task increases, the activity in the theta frequency band should increase while the activity in the alpha frequency band should decrease. Yuan *et al.* (2013) also confirmed a mutual link of neuronal origin between the alpha frequency band and respiration. Furthermore, Bušek and Kemlink (2005) proved that during spontaneous breathing – as supposed to breathing at a set rate – should increase the power in the delta frequency band. These references partially support the results obtained from the study as it suggests that a change in breathing rate should influence the delta, alpha and theta frequency bands, which is what the results also confirms. The results of the study do however not prove that these frequency bands are statistically significantly influenced

(Yang *et al.*, 2012) showed that decreases in anxiety are accompanied by an increase in alpha frequency band activity and a decrease in the beta frequency band. They did however not confirm any change in finger temperature for their experiment. The results showed that the alpha frequency band is influenced (86%) by the stimuli, but more significant influences are observed in the delta (88%) and theta (94%) frequency bands. The beta frequency band is not influenced by the stimuli at all according to these results.

7.3 Statistically invalid results

7.3.1 GSR

Montagu & Coles (1966) and Bradley *et al.*, (2008) both confirmed that a participant's GSR-measurements should be influenced by the emotions that they are experiencing. However, the results of the t-test for GSR indicated that the stimuli did not evoke a sufficient change in emotion for the participants. There could be several reasons for this error. The stimuli could not have been effective enough, as it is possible, as a participant, to distance yourself from a picture being shown. The small sample size per response (epoch) could also influence the measurement's accuracy. It could also be possible that the participant's physiology did not react as promptly, and thus the change that was caused, was not recorded.

When comparing the outcome of the gender-specific groups, the results of GSR indicated no statistical significant difference between the baseline and test-values for male and female participants. Montagu and Coles (1966) reported a difference between the GSR-data of sexes, but their results are confined to adolescent subjects. The current study includes only adult participants, and thus the absence of a difference between the results of different genders can be expected.

In the results obtain for GSR-measurements (Table 33) only participant 008 showed a statistical significant difference ($p = 0.05$) between the baseline and test-data. The rest of the participants did not show any statistical significant difference ($p > 0.1$) in their measurements between baseline and test-data. This implies that for these 5 participants, the stimuli shown did not provoke the necessary change in physiological state. It can thus be said that for the GSR-measurements, the stimuli only caused a significant change in the measurements for participant 008 in the collective group.

Hughes et al. (1994) however, confirmed through their study that the GSR-measurements should be influenced by a change in emotion. The contrast in the results could be due the difference in stimuli used, or simply because the participants weren't interested by the pictures, and thus lost focus on the task of observing. Hughes et al. (1994) used the task of writing about an emotional event

that occurred throughout the participant's life, as a stimulus, which involves the participants more intensely and focusses their attention on the task. Even though a significant change in GSR-measurements was not confirmed, the measurements can still be correlated with the change in measurements found in the EEG-data. This inconsistency between the present study's data and Hughes et al.'s data could be an indication that the participants' emotions needed time to develop, before being present in the GSR-measurement. Because Hughes et al.'s participants had more than a few seconds, maybe even years, to develop an emotional connection regarding the stimulus, it is possible that the GSR-measurement are more pronounced regarding those developed emotions, rather than the specific emotion that the present study's stimuli attempted to extract.

The GSR-results reveal that there only exists a statistical significant difference between the negative dominance and positive arousal emotion group. Bradley *et al.* (2008) found that there isn't necessarily a difference between the result obtained from viewing unpleasant vs pleasant pictures, but when comparing the results from viewing neutral pictures vs either pleasant or unpleasant pictures, a difference is established.

The comparison of the GSR to EEG-data yielded a noteworthy influence of approximately 85% ($p = \pm 0.15$) in the beta frequency range and 90% ($p = \pm 0.1$) in all frequency ranges except the beta frequency range, respectively, for both the stimuli and the interaction between the stimuli and participants. This implies that the difference in stimuli had a significant effect on the results of the EEG and physiological parameters. It also indicates that the interaction of the stimuli and participants influenced the percentage difference in the measurements in a very dominant manner. These results infer that if a participant would experience an emotion, the percentage difference between their baseline and final condition, regarding GSR, would be 80% and 90% correlated between the physiological parameter and EEG-data.

When using performance to connect the effects on GSR and EEG, Kramer (2007) proved that when a participant's performance would increase, so would their skin conductance as well as the activity in the theta and beta frequency bands. The results of the study however, shows that for the GSR-results only the beta frequency band is influenced by the stimuli, and the influence isn't considered statistically significant (85%).

7.3.2 Pupil diameter

A statistical significant difference ($p << 0.01$) was found for the pupil diameter, within emotion groups between the baseline and test-values. This result implies that with the viewing of the stimuli a change in pupil diameter was observed. Past research by Blackwell et al. (1970) confirms the results obtained as they proved

that emotional stimuli will have an effect on the pupillary response. Even though the reduced sample size (4 participants) limits the applicability of the results obtained in this part of the study, the results are promising and therefor the correlation between the changes in pupil diameter to the change in EEG-data should be investigated.

The male participants (two participants) revealed a statistical significant difference in all the emotion groups for the pupil diameter results, while the female participants (two participants) only indicated a statistical significant difference in the positive dominance group. However, Lundqvist *et al.* (2008) and Chapman *et al.* (1999) reported that no differences due to gender was established in their studies that measured pupil dilation in reaction to stimuli.

For the pupil diameter results, a statistical significant difference ($p < 0.05$) could only be confirmed for half of the participants when comparing the results of the baseline to the test-values. This indicates that the stimuli were only effective to cause a change in pupil diameter for half of the participants. This is contradicted by past research Blackwell et al. (1970) as they proved that emotional stimuli will have an effect on the pupillary response. The reason for this absence of statistical correlation is possibly because the stimuli wasn't as effective as possible, or the participants got distracted and did not pay as close attention to the stimuli. Chapman et al. (1999) made use of painful stimuli to evoke a pupil diameter difference, and obtained very good results as the stimuli actively involve participants and retained their attention. Because of the small sample size, when the measured data is compared to the EEG-measurements, extreme caution should be applied. However, the possibility for a correlation does exist, since the change in pupil diameter and the presentation of the stimuli did occur simultaneously.

A statistical significant difference for all the comparisons of the pupil diameter between the emotion groups- with the exception of the comparison between the positive valence and negative dominance groups – was established. Nevertheless, it is not the pleasantness, but rather the intensity of a stimulus plays the most important part in influencing the results of pupil dilation, and therefore pupil diameter according to Blackwell *et al*. (1970)

The results between the pupil diameter and EEG-data revealed that not only the participants ($p << 0.01$), but also the stimuli and interaction between the stimuli and participant (for both $p = \pm 0.1$) had an influence of approximately 90% on the resulting data. The results for the comparison between pupil diameter and EEG-data correlates with existing literature, as Wierda et al. (2012) confirmed in their study that the pupil response should increase as the participants' mental effort increase. The participants of the current study were instructed to focus on the screen, and as the stimuli is shown, just to look at it, not necessarily respond.

This action of non-response surely evokes mental effort, especially if the picture shown was something that would usually upset the participant.

Since the results for the pupil diameter shows that the different participants, different stimuli and interaction between the stimuli and participants had an influence on the results, it can be speculated that the experiment succeeded in proving that a promising statistical relationship exists between the pupil diameter and the EEG-data. However, the number of participants used to establish this correlation are too small to conclude that this correlation exists for all individuals.

The literature regarding the pupillary response indicate that the pupil response is linearly linked to mental effort required for a specific task (Hyönä *et al*., 1995; Wierda *et al.*, 2012). The results of the current study indicate that only the alpha frequency is somewhat influenced (89%) by the stimuli presented. The presentation and, processing of the stimuli shown is considered a mental task for the present study.

7.4 Conclusion

It can be concluded that the most prominent discoveries by the study can be divided into two sections: the differences in the EEG-measurements and physiological factors; and the comparisons made.

The differences between the baseline and test-data for the EEG-measurements revealed that there exists a statistical significant difference not only for the combined group of participants, but also for most individual participants. This indicates that the stimuli induced a change in the EEG-measurement. The physiological factors however, did not indicate the same statistically significant change, indicating that the EEG-measurements are a better indication of the influence of the stimuli.

When comparing the measurements for the different emotion groups, the only statistically significant results were obtained for the pupil diameter parameter, but because of the small sample size of the pupil diameter, the results aren't considered statistically viable. Therefore, the results imply that it was not possible to distinguish between the emotion groups. Furthermore, the only statistically significant influence indicated by the ANOVA-tests were the difference in participant, implying that the results are patient specific. The ANOVA-tests verified the correlation between the change in EEG and the physiological parameters.

Chapter 8

8 Limitations and Recommendations

The limitations that developed as the thesis progressed are presented here as well as the solutions for the limitations, depicted as recommendations for future work.

8.1 Hardware

8.1.1 NeXus

Even though the NeXus 10 system simplified the data acquisitioning, more accurate measurements of the heart rate and respiratory rate could be obtained if a higher sample rate was possible, the current rate is 32 Hz for all the measurement except heart rate (128 Hz). It is very important to ensure that an alternative method of obtaining the same results are possible, if a hardware malfunction should occur.

8.1.2 Camera

The camera that was used, Point Grey Grasshopper, produced a poor quality of video and required a Firewire connection to the PC it was running from. It is advisable to use a more recent version of the camera that has the necessary specifications. A much simpler solution would be to use a modern eye-tracker that automatically calibrates and focusses.

8.2 Experimental Method

To simplify the data processing, it would be advisable to equalizing the amount of stimuli used, e.g. use the same amount of each type of stimuli. (20 happy pictures, 20 unhappy pictures etc.) This would ensure that it could be possible to compare any of the parameters with each other and obtain a correlation.

Some of the participants exhibited exceptionally cold hands in the start of the experiment as the experiment took place in the winter, which could have influenced the baseline results. Even though the environmental factors should have little effect on the results obtained, the reality that human physiology changes according to the weather cannot be excluded. It would be preferable to do the testing during warmer months, to eliminate the possibility that the participant is unknowingly sick, and thus exhibit symptoms like fever.

Since the results of the pupil diameter measurements indicated potential significant correlations it would certainly be valuable to conduct future studies comparing the relationship between pupil diameter and EEG. The results for all

the parameters of the current study also revealed that patient-specific changes require additional attention in future studies.
The EEG-measurements proved to be the most significant indicator for emotional state, possibly since the measurements are more exact. It should be taken into account in future studies that the physiological parameters' measurements can easily be less accurate than the EEG-measurements.

In future studies, the importance of patient specificity should be emphasized, as this study clearly shows how significant the differences between participants can be.

Chapter 9

9 Conclusion

This study aimed to investigate the effect that emotional provoking stimuli have by exploring the possible correlation between several physiological factors and the EEG-signals of participants.

Section 2 outline the existing literature that was reviewed for this study, while section 3 define the Objectives that the study aims to achieve. The Hardware and Methodology are described in sections 4 and 5 respectively. All the Results and Findings obtained from this study are represented in section 6, and they are discussed in section 7, Discussion. Unfortunately, the final results of the GSR and pupil diameter measurements yielded too little data to make a valid conclusion. The reasons for the exclusion of the data are depicted in section 5.3.5.

The responses to the objectives that were addressed during the course of the study are as follows:

1. **Investigating: the results of EEG-data with and without emotional stimuli present; the effect of emotional stimuli on physiological measurements; and the correlation between physiological factors and EEG-data, due to a change in emotions.**

The student t-tests, which was conducted between the baseline and test-data for each parameter, revealed that the stimuli were effective in provoking a change in the EEG-results. This finding was true for both the gender groups as well as the combined group of participants. However, this was not the case for the included physiological parameters. The physiological parameters did not show any statistically significant difference between the baseline and test-data for heart rate, respiratory rate. The results for finger temperature only reveal a statistical significant difference for half of the emotion groups that were investigated. Thus, the stimuli were ineffective in provoking a change in the heart rate and respiratory rate, and only the negative emotion groups' stimuli effectively caused a change in the finger temperature.

When the difference between emotion groups were investigated, no statistical significant difference was found when comparing the emotion groups to each other. Therefore, it cannot be concluded that a specific emotional change can be identified from the processed results. The EEG-results did provide the most promising results and should be focussed upon in future research.

2. **Exploring the possibility of statistical discoveries between the physiological results and the EEG-data that arise from the processed results.**

When a Pearson Correlation test was done between the test-data of the physiological parameters and EEG-signals, only a weak linear correlation could be found for all factors. This does not indicate the absence of any relationship, and thus the correlation was further investigated by means of two-way ANOVA tests. All the two-way ANOVA-tests confirmed that the difference in participant will influence the resulting measurements of both the EEG and physiological factors, indicating that the results obtained lean towards patient specificity. The results of the two-way ANOVA-test that compared test-data of the respiratory rate and EEG indicated that the different stimuli and the interaction between participant and stimuli, had a 60% influence on the results. This indicates that even though the results are very participant specific, the stimuli also contributed to a change in the results.

The two-way ANOVA-test that compared the percentage difference of the baseline and test-data between the EEG and physiological parameters yielded the following results:

- For the comparison between EEG and heart rate, the stimuli and the interaction between stimuli and the participant had an influence of approximately 75%, averaged across the delta, theta and alpha frequency bands.
- For the comparison between EEG and respiratory rate, the stimuli as well as the interaction between stimuli and participants had a mean influence of 85% on the results, for the delta, theta and alpha frequency bands.
- For the comparison between finger temperature and EEG, the interaction between the stimuli and participant had an influence of approximately 89%, when averaged across the delta, theta and alpha frequency bands.

These final results show that there does exists some relationship between the change in heart rate and EEG; change in respiratory rate and EEG; as well as between the change in finger temperature and EEG. These percentages indicate that when a change is observed in the physiological parameter, for instance respiratory rate, there is an 85% chance that a corresponding change will be observed in the EEG-data. However, none of these correlations are statistically significant (>95%). The changes due to the difference in participant indicated a statistical significance, for each of the comparisons between physiological parameters and EEG-data.

3. **Drawing conclusions from the results obtained and providing possible recommendations for future studies e.g. If any correlation exists, what is inferred by that particular correlation, and how does it contribute to the understanding of the human body?**

In the two-way ANOVA-tests between the test-values of the physiological parameters and the EEG, the results indicate that there is a definite difference in the results between participants, since the influence of a participant had a statistical significant influence on the results. This infers that each participant's reaction was unique to the stimuli. This is true since no two people are the same, and it is valuable knowledge as it infers that even though the participants all reacted as individuals, the result that indicate other correlations that result from this experiment are true for a group of people that acted in their uniqueness. The indication that the influence of a participant is statistically significant also holds true for the results of the percentage differences between all of the physiological parameters and the EEG.

The correlation between the test-values of the respiratory rate and EEG indicates that if a person were to experience an emotion that affects their EEG, there is a 60% chance that a change in the respiratory rate could occur. While the relationship between the percentage difference of the respiratory rate and EEG indicated that emotion provoking stimuli that affects the respiratory rate will have an approximately 85% chance of influencing the delta, theta and alpha frequency bands of the EEG.

The relationship between the percentage change in finger temperature and EEG indicated that emotional evoking stimuli, that causes a change in finger temperature, will have a 90% probability in evoking a change in the delta, theta and alpha frequency bands of the EEG. Similarly, the percentage change in the heart rate indicates an approximate probability of 75% that the emotion provoking stimuli affects both the percentage change in heart rate and the delta, theta and alpha frequency bands of the EEG.

In conclusion, the study indicates that it is possible to observe a change in EEG-data when an emotion-provoking picture is viewed. It is, however, not possible to statistically distinguish between different types of emotion that is experienced when these pictures are viewed, as the hypothesis suggested. The indication by the results that the difference in participant are statistically significant, lead the conclusion that these participants reacted differently to the stimuli presented.

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Appendix A-1: Anatomy of the Brain

The brain and spinal cord form the central nervous system (CNS) which consists of billions of neurons that are the pathways that carry information, in the form of a signal, from one part of the body (or brain) to another. The neuron (see Figure 12) consists of four major parts: The Cell body which encloses the nucleus of the neuron; the Dendrites which is very sensitive and receive the incoming signals; the Axon that is that elongated part of the neuron and carries the outgoing signals to the Axon terminals; the Axon terminals connect with other cells, and therefor communicates with these cells. (Martini and Bartholomew, 2013)

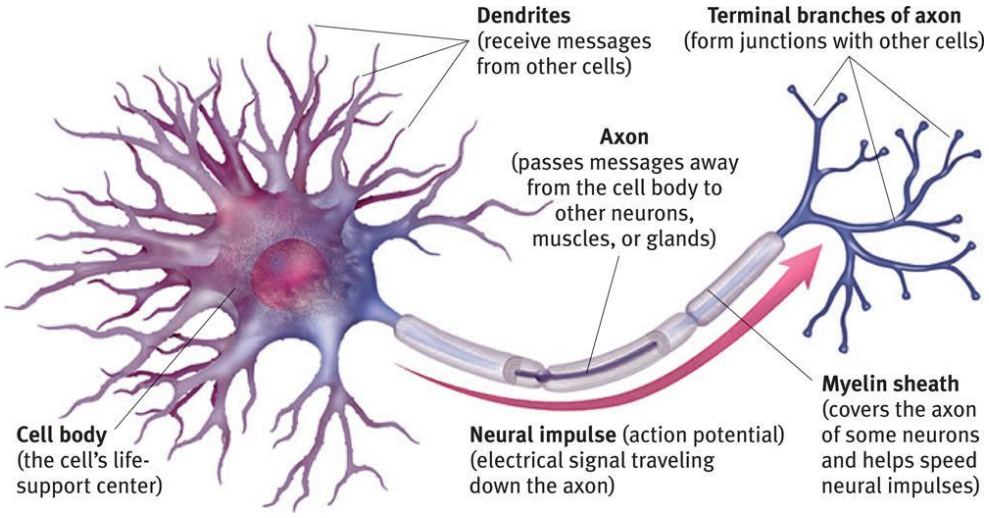


Figure 12: The anatomy of a neuron (Martini and Bartholomew, 2013)

There are also different functional classifications of neurons.

- The Sensory neurons are responsible for receiving information from sensory receptors, and thus monitoring the environment. (internal and external)
- The Motor neurons carry the instructions from the CNS to the organ systems, specific organs and other tissues.
- Interneurons are only found in the brain and spinal cord, and are responsible to connect the neurons to each other. They play an important role in higher functions such as planning, learning and memory.

The surface of the brain is divided into different hemispheres, also called the cerebral hemispheres (See Figure 13). These are the Frontal lobe, the Temporal lobe, the Parietal lobe and the Occipital lobe. The functions associated with the lobes are as follows: (Martini and Bartholomew, 2013)

- Frontal lobe: Motor control, speech, smell, concentration and planning
- Temporal lobe: Hearing and facial recognition
- Parietal lobe: Taste, touch (pressure) and body awareness
- Occipital lobe: Vision

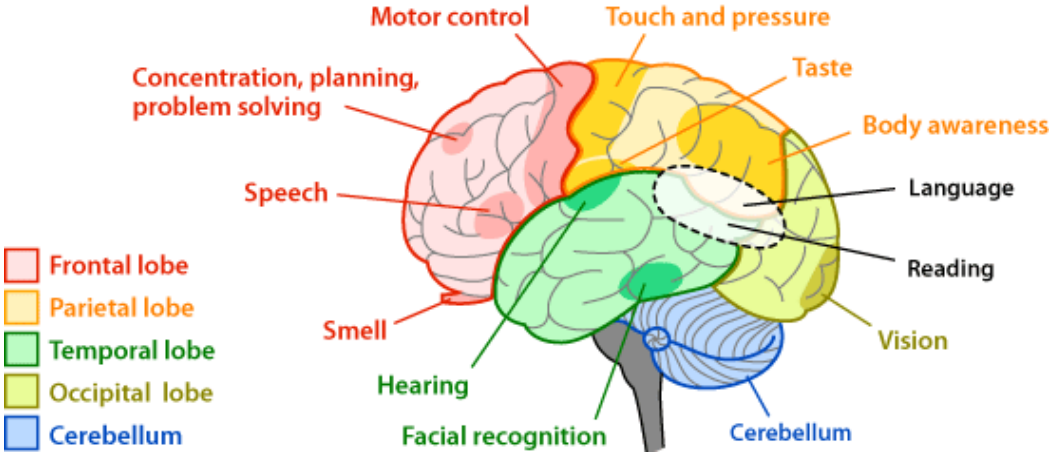


Figure 13: Different parts of the Cerebral Hemisphere ***(Martini & Bartholomew 2013)***

Since the EEG records on the surface of the brain it would record the electrical activity that is taking place on the outer surface of the cerebral hemisphere.

Appendix A-2: Anatomy of the Heart

The heart is the organ that is responsible for circulating blood through the whole body, essentially acting as a pump. A person's heart rate can be described as the amount of times the heart beats in one minute and therefore it is measured in beats per minute (bpm). Blood that is circulated is responsible for transporting several vital elements to the organs, including oxygen. The oxygenation of the blood is discussed in the next section, Respiratory Rate.

Circulation of blood through the heart occurs as follows: (Figure 14)

- Deoxygenated blood enters the right atrium of the heart through the superior and inferior vena cava
- When the heart contracts the blood is forced from the right atrium to the right ventricle
- The blood within the right ventricle is also forced to the lungs through the right and left pulmonary arteries
- Oxygenated blood enters the left atrium through the left and right pulmonary veins
- As the heart contracts the blood in the left atrium is forced into the left ventricle
- The blood in the left ventricle is forced out of the heart through the aorta, where it proceeds to circulate through the entire body

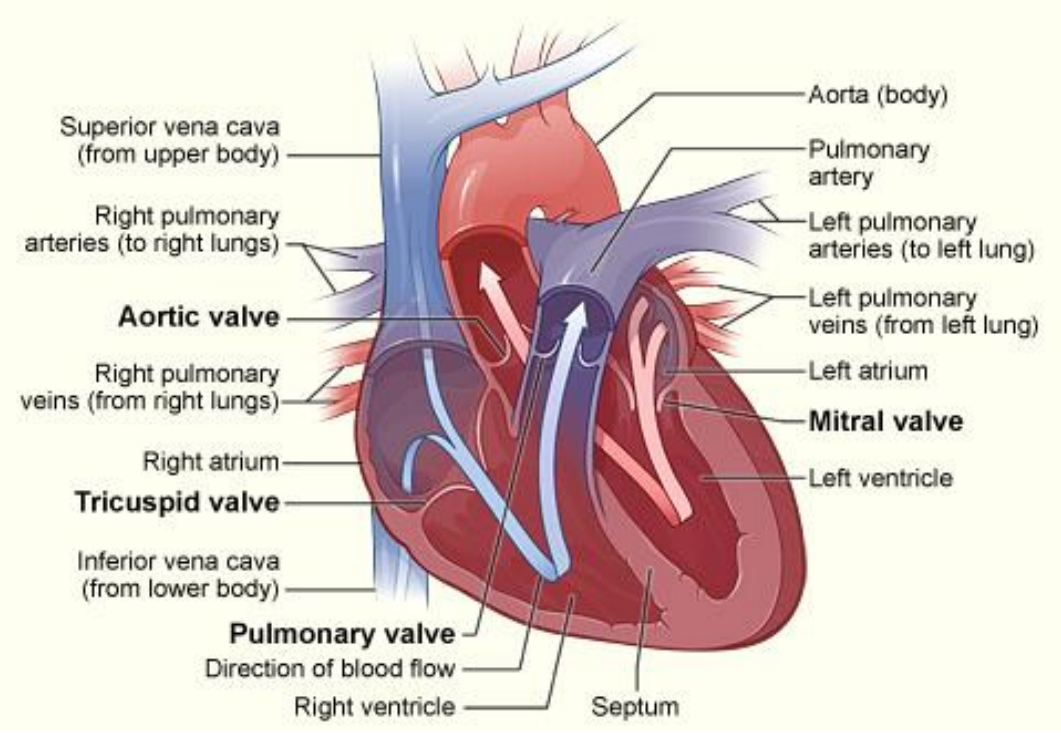


Figure 14: Circulation system of the heart ***(Boundless 2016)***

The conducting system plays arguably the most important role in the whole process of the heartbeat, as it has to signal the muscles of the heart when to contract. The sequence of contraction is as follows: (see Figure 15)

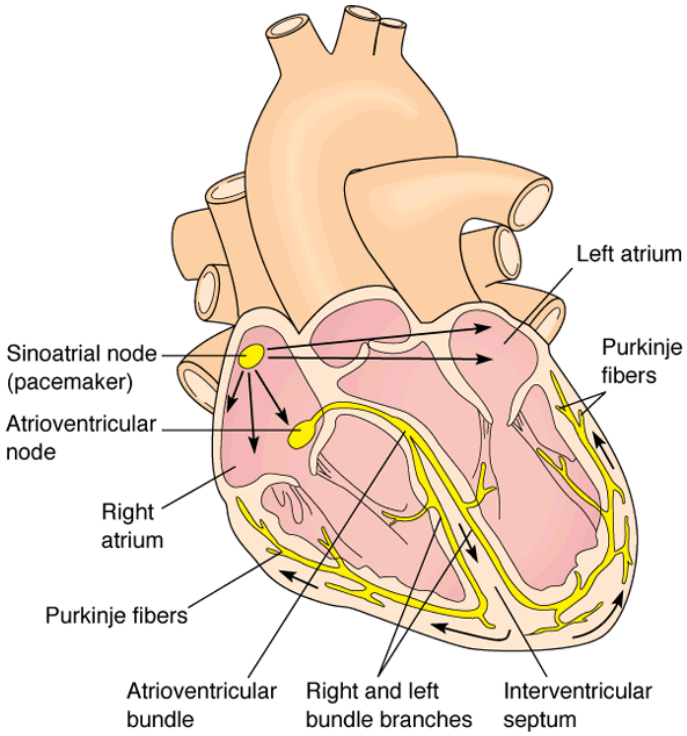


Figure 15: Conducting system of the heart ***(Martini & Bartholomew 2013)***

The Sinoatrial (SA) node receives the impulse and atrial activation begins. In the 50 ms to follow the stimulus spreads across the atrial surfaces and reaches the Atrioventricular (AV) node. A 100 ms delay at the AV node is present and the atriums contract. It takes the impulse 25 ms to travel along the interventricular septum within the AV bundle and the bundle branches to the Purkinje fibers. The Purkinje fibers then take 50 ms to distribute the impulse throughout the ventricular myocardium, to signal ventricular contraction to begin. (Martini and Bartholomew, 2013)

The rate at which the heart contracts, the heart rate, is influenced by several factors. This fact is further examined as can be seen in the literature reviewed in the remainder of this section.

Appendix A-3: Anatomy of the Lungs

The lungs are responsible for oxygenating blood that is circulated through the body. Oxygenation is the act of exchanging carbon dioxide for oxygen within the lungs. (Martini and Bartholomew, 2013)
The blood is circulated by the heart, see and past the lungs as follows: (See Figure 16) The heart pumps deoxygenated blood to the right and left lungs via the respective pulmonary arteries

- Oxygenation occurs
- The resulting oxygenated blood is transported to the heart via the pulmonary veins
- The heart circulates the oxygenated blood through the body to the tissue capillaries where the blood becomes deoxygenated
- The deoxygenated blood is carried back to the heart via the inferior and superior vena cava to be oxygenated

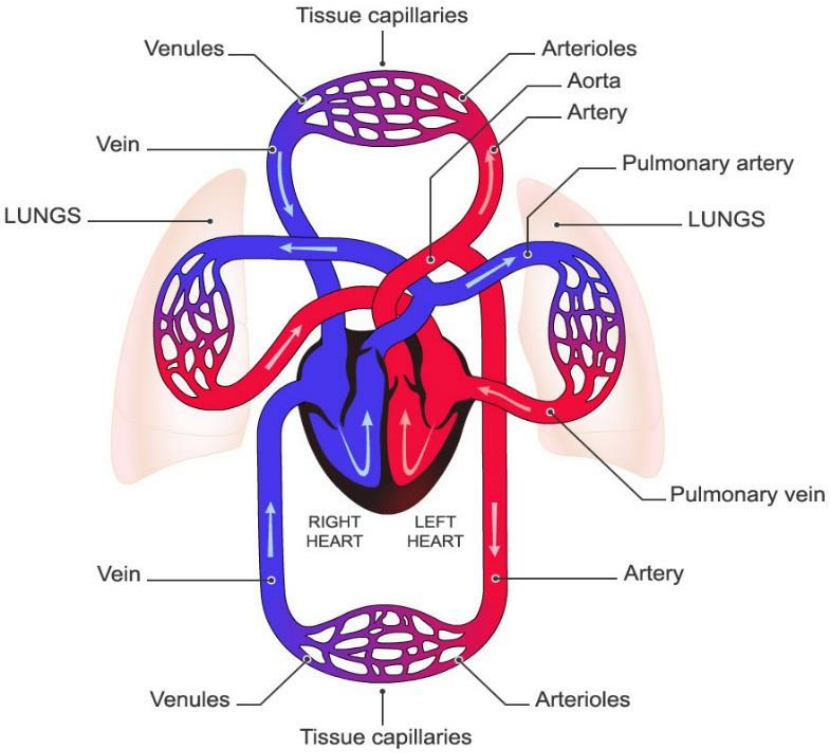


Figure 16: The Cardiovascular system ***(Martini & Bartholomew 2013)***

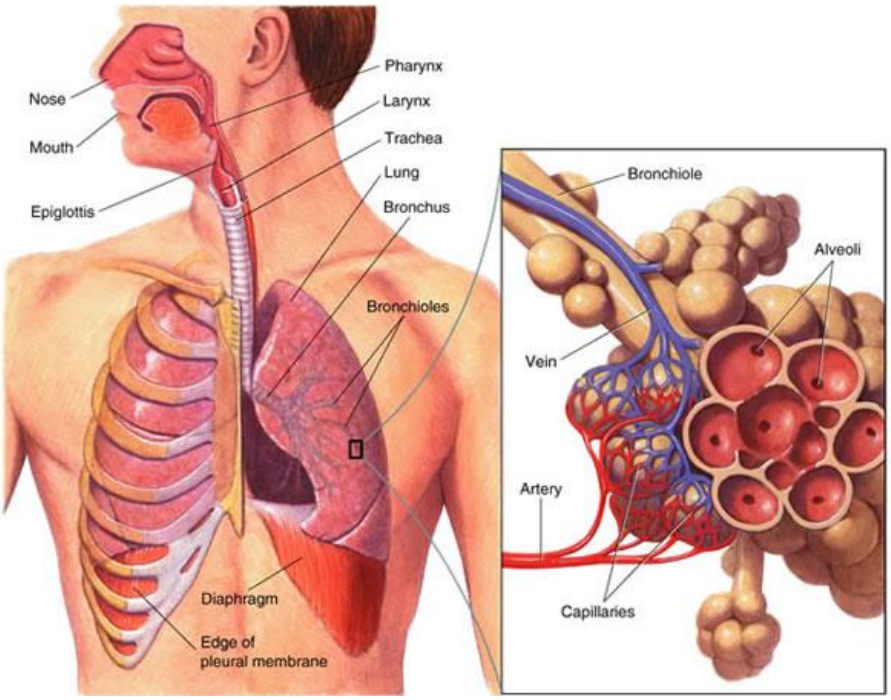


Figure 17: Respiratory system ***(Martini & Bartholomew 2013)***

In order to fully understand if and how the EEG-signals correlates with the change in respiratory rate, we have to understand the act of respiration. The respiratory cycle starts with inhalation via the mouth or nose, the air travels through the Pharynx, larynx (the voice box), trachea, bronchus and into the lungs. (See Figure 17)

In the lungs the bronchi branch out into bronchioles, which lead to the alveolus. Surrounding the alveoli are capillaries that are the point at which the oxygen and carbon dioxide exchange. During inspiration (inhalation) the muscles surrounding the lungs, of which the diaphragm is the most important, force the air into the lungs by expanding the rib-cage and lowering the diaphragm, thus creating a vacuum.

A normal respiratory rate, called eupnea (sometimes eupnoe), will be between 12 and 16 breaths per minute (bpm). Abnormally slow breathing (bradypnoea) is anything below 12 bpm and rapid breathing (tachypnoea) is breathing more than 20bpm. (Martini and Bartholomew, 2013) The danger of bradypnoea is that the necessary amount of oxygen isn't reaching the brain and the rest of the patient's organs, thus hindering optimal performance and can even cause fainting or death. Tachypnoea set the patient at the risk of hyperventilation, which is the body removing more carbon dioxide from the blood stream than can be produced by the body. This causes the body to try to compensate for this metabolically, thus leading to a rise in the pH level of the blood.

Appendix A-4: Anatomy of the Skin

The skin is the largest organ of the human body with the most prominent role, protecting the internal organs. There are many functions that the skin is responsible for, including secreting fluid like sweat, discussed in this section, and regulating the bodily temperature, discussed in section 2.5.1, Temperature Regulation.

The sweat glands, see Figure 18, produce a discharge, known as perspiration or sweat, which is secreted directly onto the surface of the skin. The main purpose of this secretion is to regulate the bodily temperature. Perspiration is also secreted when a person experiences distress, or a change in arousal. The excess of perspiration changes the conductivity of the skin and thus enables the measurement of Galvanic Skin Resopnse (GSR).

Even though the primary purpose of sweating is to regulate the body temperature, there are several other parameters that can cause people to perspire. (Roth, 2016) Some examples include: Hormonal changes, Food ingested, Fighting infections, Emotional situations and stressful situations. For this study the last two parameters will be investigated.

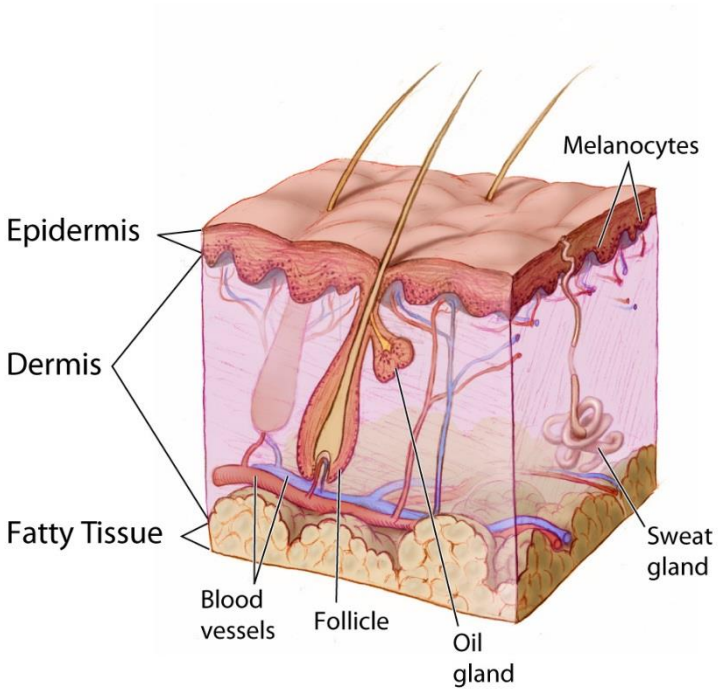


Figure 18: Basic anatomy of the skin ***(Martini & Bartholomew 2013)***

Appendix A-5: Anatomy of the Regulatory System

Temperature regulation of the human body is in essence a negative feedback system, as seen in Figure 19. If the normal state (a bodily temperature of approximately 37°C) is disturbed, the body's temperature sensors will send the information to the brain, which will in turn send a command to the effectors to change the incorrect state. The effectors in the regulatory system is blood vessels of the skin and sweat glands in the skin. (Martini and Bartholomew, 2013)

When the body becomes too warm the blood vessels of the skin would widen to allow for more blood flow to the skin, and the sweat glands would increase their secretion. This combination promotes rapid heat loss to the environment. In contrast when the body's temperature falls below the normal temperature, the brain would indicate to the blood vessels of the skin to contract and the sweat glands to reduce their secretion. This prevents the current heat to be lost to the environment. In addition to these precautions, the skeletal muscles would also generate heat by contracting randomly, which is commonly known as shivering.

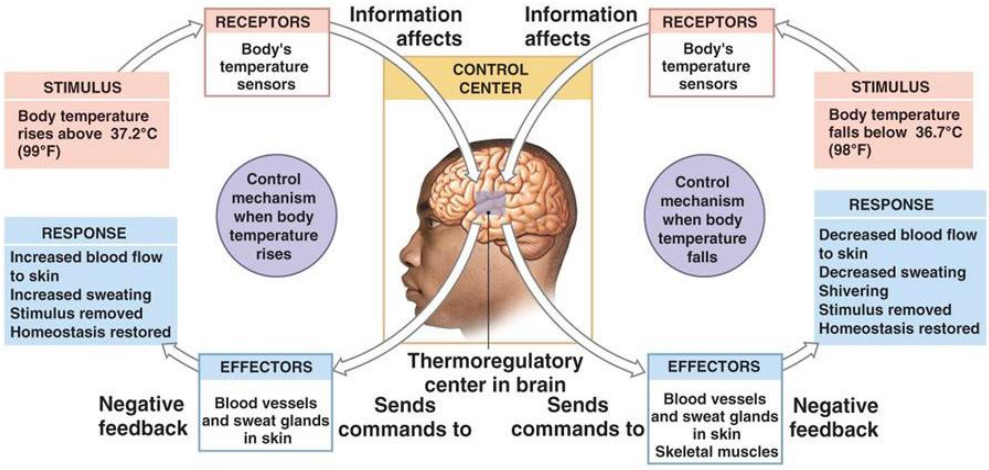


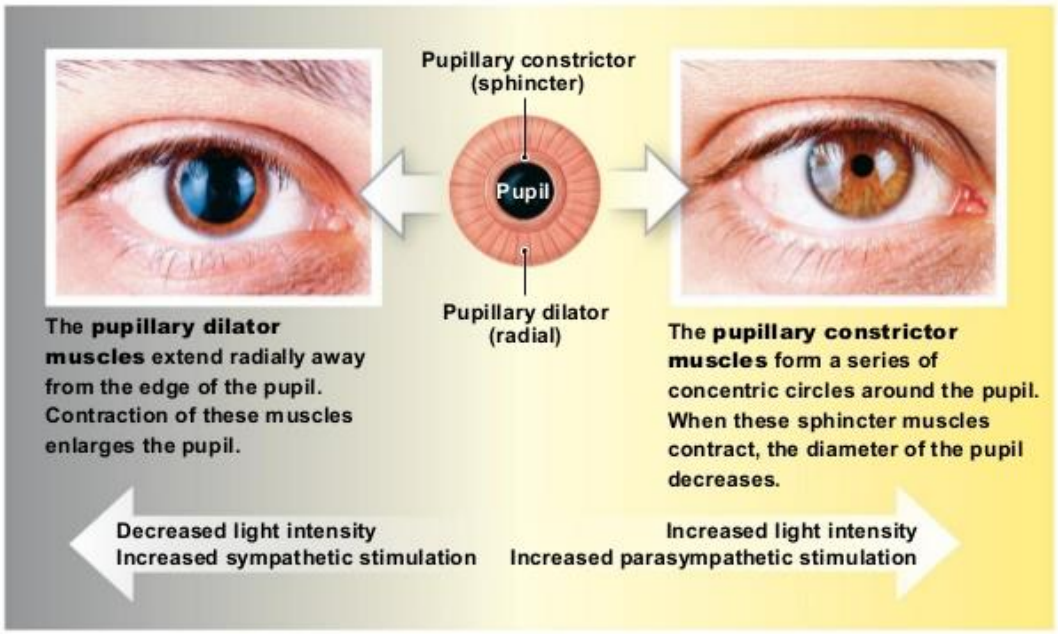
Figure 19: Thermoregulatory system ***(Martini & Bartholomew 2013)***

There are numerous reasons why the bodily temperature could be disturbed. Some of the medical reasons are: Hyperthyroidism, Adrenal fatigue, Infection, Diabetes, Hormonal changes and even Body growth as stated by Holland (2016). However, we intend to investigate the change in temperature due to the influence of emotions.

Appendix A-6: Anatomy of the Eye

Pupil diameter reveal a lot about the physiology and psychology of a person. For this experiment, we want to determine whether there is a correlation between the pupil dilation or contraction and the pattern displayed by the EEG-signals from the brain.

The diameter of the pupil is regulated by the pupillary muscles, as can be seen in Figure 20. The pupillary dilator muscles are responsible for enlarging the diameter of the pupil, and they are extended radially away from the pupil. The pupillary constrictor muscles are located concentrically around the pupil and will reduce the diameter of the pupil if they were to contract. (Martini and



Bartholomew, 2013)

Figure 20: Pupillary muscles ***(Martini & Bartholomew 2013)***

It is generally known that the pupils would dilate of constrict when there is a change in the light intensity. There are however several other reasons why the pupils can change their size (DeRemer, 2015). Some of these reasons are: Sleepiness, Sexual interest, Racial bias, Autism, Depression, Moral judgement, Memory recall, Arousal, The act of making a decision and an Increase in mental activity. For this study we are primarily interested in the effects of arousal and an increase in mental activity as those are the parameters that we would be provoking.

Appendix B Ethical Clearance

UNIVERSITEIT·STELLENBOSCH·UNIVERSITY
jou kennisvennoot • your knowledge partner

Approval Notice
Response to Modifications- (New Application)

24-Jun-2015
Van Der Schyff, Emzy E

Ethics Reference #: S15/02/042
Title: Effects of Physiological changes on the EEG.

Dear Miss Emzy Van Der Schyff,

The **Response to Modifications** - *(New Application)* received on **07-May-2015**, was reviewed by members of **Health Research Ethics Committee 2** via Expedited review procedures on **17-May-2015** and was approved.
Please note the following information about your approved research protocol:

Protocol Approval Period: **24-Jun-2015 -24-Jun-2016**

Please remember to use your **protocol number** (**S15/02/042**) on any documents or correspondence with the HREC concerning your research protocol.

Please note that the HREC has the prerogative and authority to ask further questions, seek additional information, require further modifications, or monitor the conduct of your research and the consent process.

After Ethical Review:
Please note a template of the progress report is obtainable on www.sun.ac.za/rds and should be submitted to the Committee before the year has expired. The Committee will then consider the continuation of the project for a further year (if necessary). Annually a number of projects may be selected randomly for an external audit.
Translation of the consent document to the language applicable to the study participants should be submitted.

Federal Wide Assurance Number: 00001372
Institutional Review Board (IRB) Number: IRB0005239

The Health Research Ethics Committee complies with the SA National Health Act No.61 2003 as it pertains to health research and the United States Code of Federal Regulations Title 45 Part 46. This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki, the South African Medical Research Council Guidelines as well as the Guidelines for Ethical Research: Principles Structures and Processes 2004 (Department of Health).

Provincial and City of Cape Town Approval

Please note that for research at a primary or secondary healthcare facility permission must still be obtained from the relevant authorities (Western Cape Department of Health and/or City Health) to conduct the research as stated in the protocol. Contact persons are Ms Claudette Abrahams at Western Cape Department of Health (healthres@pgwc.gov.za Tel: +27 21 483 9907) and Dr Helene Visser at City Health (Helene.Visser@capetown.gov.za Tel: +27 21 400 3981). Research that will be conducted at any tertiary academic institution requires approval from the relevant hospital manager. Ethics approval is required BEFORE approval can be obtained from these health authorities.

We wish you the best as you conduct your research.
For standard HREC forms and documents please visit: www.sun.ac.za/rds

If you have any questions or need further assistance, please contact the HREC office at 219389207.

Appendix C Consent Form

PARTICIPANT INFORMATION LEAFLET AND CONSENT FORM

TITLE OF THE RESEARCH PROJECT:

Effect of Physiological changes on the EEG

REFERENCE NUMBER:

PRINCIPAL INVESTIGATOR: Emzy van der Schyff

ADDRESS: Room 616, Mechanical Engineering building
Corner of Banghoek and Joubert Streets
Stellenbosch

CONTACT NUMBER: 079 511 0197

You are being invited to take part in a research project. Please take some time to read the information presented here, which will explain the details of this project. Please ask the study staff or doctor any questions about any part of this project that you do not fully understand. It is very important that you are fully satisfied that you clearly understand what this research entails and how you could be involved. Also, your participation is **entirely voluntary** and you are free to decline to participate. If you say no, this will not affect you negatively in any way whatsoever. You are also free to withdraw from the study at any point, even if you do agree to take part.

This study has been approved by the **Health Research Ethics Committee at Stellenbosch University** and will be conducted according to the ethical guidelines and principles of the international Declaration of Helsinki, South African Guidelines for Good Clinical Practice and the Medical Research Council (MRC) Ethical Guidelines for Research.

What is this research study all about?

- The study will take place in Stellenbosch and Tygerberg, depending on the availability of equipment. If you have to be transported, the costs will be covered by die study. There will be a total of 15 participants in the study and all the participants' tests will be conducted at the same site.
- This project aims to explore whether there is a link between physiological changes and EEG-signals. The physiological changes are changes in your body, like a rise in temperature and EEG-signals are the signals from the brain that connect the brain to the rest of the body. The five physiological changes that we are going to investigate are temperature, heart rate, respiratory rate (how fast you breathe), pupil dilation (changes in your eyes), and Galvanic skin response (Are your palms sweating?). For this project we would typically want to know if your heart rate is faster, will it always give the same EEG-signal.

- To be able to record an EEG-signal, we would need to place an EEG-cap on the participant's head. It looks a lot like a normal hat you would wear in the winter to keep your head warm, and therefor the discomfort should be minimal.

  For the pupil dilation, temperature, heart rate and the respiratory rate, there is a special camera that will be set up, and recording the proceedings. In processing the data we would then separate the pupil dilation, heart rate, respiratory rate and the temperature.

  The Galvanic skin response (GSR) we have to measure with a device much like a lie-detector test. It will be attached to your hand and will only measure the amount and rate at which you are sweating.

  Once all the apparatus have been connected, the test would start and all you have to do is look at the pictures that will be shown to you on a screen, and let your body react to them.

  The tests will take up 3 hours of your time at the most.

Why have you been invited to participate?

- You have been invited to participate in this study as you are between the ages of 18 and 30, thus have a properly developed brain, with minimal deficiencies. This will ensure results that are reliable.

What will your responsibilities be?

- Your responsibilities will be to be honest with the researches regarding medical history and any drug use, as this may influence the results of the tests.

Will you benefit from taking part in this research?

- You will not benefit from this research directly. This research will however benefit future patients, as the result of this research will simplify the way patients are monitored while inside an MRI-machine.

Are there in risks involved in your taking part in this research?

- The risks of participating are very small as the tests that you will be participating in are non-invasive. The only risk is the equipment malfunctioning, and even then, it would only cause a small pinching. The equipment will be checked for a possible malfunctioning before each new participant, and you are welcome to let us know if you experience any discomfort.
- If there is any medical emergency or faulty equipment, the tests will be terminated, or postponed if there is another available date that suits all the participants.

Who will have access to your medical records?

- Your identity will remain anonymous, and any data collected will be considered confidential. To ensure this a random number will be assigned to your name, and the principal investigator is the only one with access to the list that connects your identity to the specific random number.

What will happen in the unlikely event of some form injury occurring as a direct result of your taking part in this research study?

- You will promptly be given the necessary attention and emergency response will be called if required. In case of serious injury and need of hospitalisation, your normal medical aid will cover any injury incurred.

Will you be paid to take part in this study and are there any costs involved?

No, you will not be paid to take part in the study. There will be no costs involved for you, if you do take part.

Is there any thing else that you should know or do?

- No
- You can contact Dr Dawie van den Heever at tel 083 556 8311 if you have any further queries or encounter any problems.
- You can contact the Health Research Ethics Committee at 021-938 9207 if you have any concerns or complaints that have not been adequately addressed by your study doctor.
- You will receive a copy of this information and consent form for your own records.
- You can withdraw from the study at any point without jeopardising the study.

Declaration by participant

By signing below, I ..... agree to take part in a research study entitled *Effect of Physiological changes on the EEG*.

I declare that:

- I have read or had read to me this information and consent form and it is written in a language with which I am fluent and comfortable.
- I have had a chance to ask questions and all my questions have been adequately answered.
- I understand that taking part in this study is **voluntary** and I have not been pressurised to take part.
- I may choose to leave the study at any time and will not be penalised or prejudiced in any way.
- I may be asked to leave the study before it has finished, if the study doctor or researcher feels it is in my best interests, or if I do not follow the study plan, as agreed to.

Signed at (*place*) ..... on (*date*) ..... 2016.

....

Signature of participant **Signature of witness**

Declaration by investigator

I *(name)* ..... declare that:

- I explained the information in this document to .....
- I encouraged him/her to ask questions and took adequate time to answer them.
- I am satisfied that he/she adequately understands all aspects of the research, as discussed above
- I did not use a interpreter.

Signed at (*place*) ..... on (*date*) ..... 2016.

....

Signature of investigator **Signature of witness**

Appendix D Baseline Questionnaire

Mini-screen (Participant history)		
1)	Have you, on more than one occasion, had panic attacks, even in situations where most people would not feel that way?	Y N
	Did the attack last longer than 10 minutes?	Y N
	Did any of those attacks come on unexpectedly or occur in an unpredictable and unprovoked manner?	Y N
2)	In the past month, did you have persistent fear or significant anxiety in one of these situations?	
	☐ Speaking in public	
	☐ Eating in public/with others	
	☐ Writing while someone watches you	
	☐ Being in social situations (party/dates)	
3)	Have you ever had to deal with one of these extremely traumatic events that include actual or threatened death or serious injury to you or someone else?	
	☐ Serious car accident	
	☐ Plane crash	
	☐ Sexual/Physical assault	
	☐ Terrorist attack	
	☐ Being held hostage/at gunpoint?	
	☐ Kidnapping	
	☐ Fire	
	☐ Discovering a body	
	☐ Sudden death of someone close to you	
	☐ War	
	☐ Natural disaster	
	☐ Animal attack (snake, spider, dog, crocodile)	
4)	Do you consider yourself an animal lover?	Y N
5)	Do you have a pet at home?	Y N
6)	On a scale of 1-10 how much does animal cruelty bother you?	
7)	Do you approve of hunting?	
8)	Do you consider your family as an important part of your life?	Y N
	Do you have kids?	Y N
9)	Do you like kids?	Y N
10)	Do you enjoy traditional family events like Christmas, Sunday-lunch, going to a restaurant as a family?	Y N
11)	Has any of your relatives had serious illnesses that require them to be in hospital or be operated on?	Y N
12)	Has any of your relatives died in a hospital?	Y N
13)	Have you ever lived inside a city?	Y N
	Which city?	
	Did you enjoy it?	Y N
14)	Did you have any farming-experiences growing up?	Y N
15)	If you had to choose, would you pick nature or city?	N C
16)	Did you immigrate from another country? Parents? Grandparents?	Y N
	What country?	
17)	Do you enjoy travelling?	Y N
18)	How often do you travel? (For longer than a week) Once a:	month
	Business or Leisure?	year
		2 years
19)	Would you prefer outside activities like water sports or indoor activities like reading?	O I

20)	Do you enjoy going to big music festovals/concerts?	Y N
21)	On a scale of 1-10 how active are you?	
	What type of sports do you do?	
22)	On a scale of 1-10 how much does pollution bother you?	
23)	On a scale of 1-10 how much do you do to reduce the amount of pollution you are responsible for?	

Appendix E EEGLAB code

Code for importing and preparing initial Raw-data:

```
clc;clear;
% import data from testbench csv file
eegdata = importdata('Test_recording_006_10.mat');

% remove unwanted fields
eegdata(:,23:42) = [];
eegdata(:,19:21) = [];
eegdata(:,1:4) = [];
eegdata = eegdata';

% Prepare data in EEGLAB
eeglab
EEG = pop_importdata('data',eegdata,'srate',128); % im-port data
from MATLAB array
[ALLEEG EEG CURRENTSET] = pop_newset(ALLEEG, EEG,
0,'setname','eegdata','gui','off');
EEG = eeg_checkset( EEG );
EEG = pop_chanevent(EEG,15,'edge','leading','edgelen',1); % event
channel
EEG = pop_chanedit(EEG, 'load',{'epoc.ced' 'filetype'
'autodetect'}); % channel locations
EEG = pop_eegfilt(EEG, 7, 0, [], [0]); % highpass fil-tering at
1Hz
EEG = pop_eegfilt(EEG, 0, 13, [], [0]); % low pass fil-tering at
20Hz
eeglab redraw
EEG = pop_saveset(EEG,'data');
sample_rate = 128; %Hz
channel = 1:14;
```

Code for adding events into the data:

```
EEG = pop_epoch(EEG, {'chan15'}, [-3 3], 'newname', 'epochs_v'); %
visual targets
[ALLEEG EEG CURRENTSET] = pop_newset(ALLEEG, EEG, 1,'gui','off');
EEG = eeg_checkset( EEG );
EEG = pop_rmbase( EEG, [-400 0]); % remove baseline
eeglab redraw
EEG = pop_saveset(EEG,'epochs_t');
```

Code for computing the PSD:

```
for i = 1:60;
%frequency bands
% delta = [0.5:4];
low_delta = 0.5;
high_delta = 4;

%computing log spectrum for different frequencies
```

```
[power_d,freq_d] = spectopo(EEG.data(channel,:,i),0,sample_rate);
%average power within the predefined frequency range
mean_delta(i) = mean(10.^(power_d(freq_d >= low_delta & freq_d
<=high_delta)/10));

% theta = [4:8];
low_theta = 4;
high_theta = 8;

%computing log spectrum for different frequencies
[power_t,freq_t] = spectopo(EEG.data(channel,:,i),0,sample_rate);
%average power within the predefined frequency range
mean_theta(i) = mean(10.^(power_t(freq_t >= low_theta & freq_t
<=high_theta)/10));

% alpha = [8:13];
low_alpha = 8;
high_alpha = 13;
%computing log spectrum for different frequencies
[power_a,freq_a] = spectopo(EEG.data(channel,:,i),0,sample_rate);
%average power within the predefined frequency range
mean_alpha(i) = mean(10.^(power_a(freq_a >= low_alpha & freq_a
<=high_alpha)/10));

% beta = [13:30];
low_beta = 13;
high_beta = 30;
%computing log spectrum for different frequencies
[power_b,freq_b] = spectopo(EEG.data(channel,:,i),0,sample_rate);
%average power within the predefined frequency range
mean_beta(i) = mean(10.^(power_b(freq_b >= low_beta & freq_b
<=high_beta)/10));

i = i+1
end

power_spec = [mean_alpha; mean_beta; mean_delta; mean_theta];
```

Appendix F OpenCV code

```
#include<opencv2/core/core.hpp>
#include<opencv2/highgui/highgui.hpp>
#include<opencv2/imgproc/imgproc.hpp>

#include<iostream>
#include<fstream>
#include<conio.h>

#include "Blob.h"

using namespace cv;
using namespace std;

ofstream file_;
Mat c;
Mat b;
Mat a;

// global variables
///////////////////////////////////////////////////////////////////////////////
///
const Scalar SCALAR_BLACK = Scalar(0.0, 0.0, 0.0);
const Scalar SCALAR_WHITE = Scalar(255.0, 255.0, 255.0);
const Scalar SCALAR_BLUE = Scalar(255.0, 0.0, 0.0);
const Scalar SCALAR_GREEN = Scalar(0.0, 200.0, 0.0);
const Scalar SCALAR_RED = Scalar(0.0, 0.0, 255.0);

///////////////////////////////////////////////////////////////////////////////
////////////////////////
int main(void) {

	VideoCapture capVideo;

	Mat imgFrame1;
	Mat imgFrame2;

	//capVideo.open("006.mp4");
	capVideo.open("003.mp4");
	//capVideo.open("018_0.avi");

	if (!capVideo.isOpened()) {
// if unable to open video file
		cout << "\nerror reading video file" << endl << endl;	//
show error message
		_getch();			// it may be necessary to change
or remove this line if not using Windows
		return(0);
// and exit program
	}

	if (capVideo.get(CV_CAP_PROP_FRAME_COUNT) < 2) {
		cout << "\nerror: video file must have at least two frames";
		_getch();
```

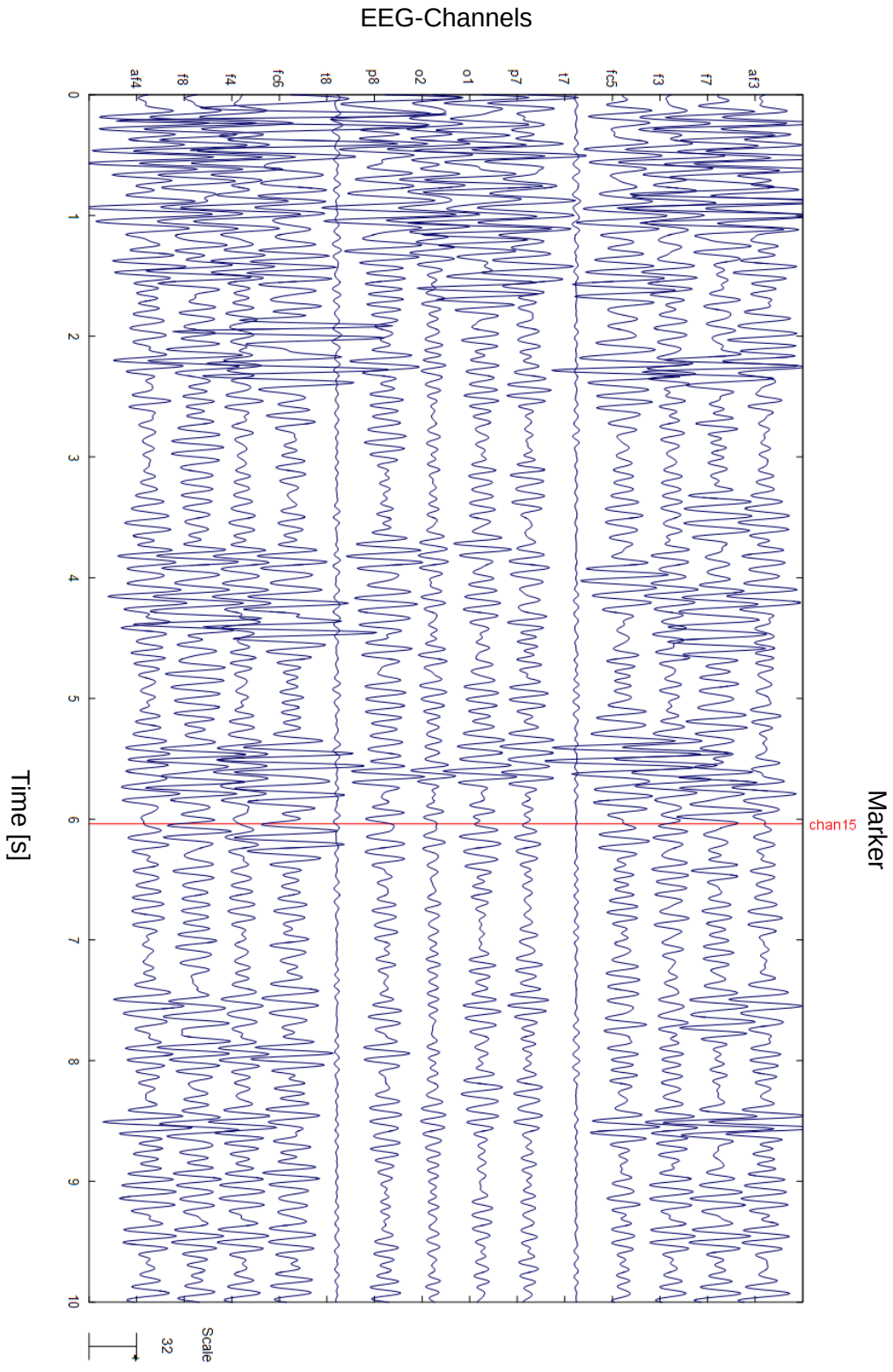
```
		return(0);
	}

	cout << capVideo.get(CAP_PROP_POS_FRAMES) << "*";


	capVideo.read(imgFrame1);
	capVideo.read(imgFrame2);

	char chCheckForEscKey = 0;

	//file_.open("radius_all_006.txt");
	file_.open("radius_all_003.txt");
	file_ << " frames: 0:all \n";
	//file_ << capVideo.get(CV_CAP_PROP_FPS);

	while (capVideo.isOpened() && chCheckForEscKey != 27)
	{
		/*for (c = 1; ; c=c+1) {
			a = 255;
			b = 316;*/
			/*file_.open("1_radius.txt");
			file_ << "018_1 frames: :  \n";*/
		vector<Blob> blobs;
		if (capVideo.get(CV_CAP_PROP_POS_FRAMES) > 0 )  // position of
the epoch
		{

		Mat imgFrame1Copy = imgFrame1.clone();
		//Mat imgFrame2Copy = imgFrame2.clone();
		Mat imgThresh;

		cvtColor(imgFrame1Copy, imgFrame1Copy, CV_BGR2GRAY);

		//cv::Rect myROI(100, 100, 200, 200);                  // for
participant 018
		cv::Rect myROI(100, 150, 200, 250);
	// for participant 003
		//cv::Rect myROI(275, 75, 250, 250);                   // for
participant 006
		//cv::Rect myROI(0, 50, 300, 300);                     // for
participant 007
		//cv::Rect myROI(350, 100, 250, 300);                  // for
participant 008
		//cv::Rect myROI(50, 50, 250, 300);
	// for participant 009
		//cv::Rect myROI(50, 50, 250, 300);
	// for participant 012
		//cv::Rect myROI(300, 75, 300, 275);                   // for
participant 013
		//cv::Rect myROI(50, 100, 300, 300);                   // for
participant 014
		//cv::Rect myROI(0, 50, 300, 300);                     // for
participant 016
		//cv::Rect myROI(0, 50, 300, 300);                     // for
participant 017
```

```
		//cv::Rect myROI(50, 100, 300, 250);					// for
participant 019
		//cv::Rect myROI(75, 50, 275, 250);
	// for participant 020

		Mat croppedRef(imgFrame1Copy, myROI);
		Mat cropped;

		croppedRef.copyTo(cropped);
		//imshow("Cropped img", cropped);

		GaussianBlur(cropped, cropped, Size(5, 5), 0);

		//imshow("imgblurred", imgFrame1Copy);

		threshold(cropped, imgThresh, 26, 255.0, CV_THRESH_BINARY);

		imshow("imgThresh", imgThresh);

		Mat structuringElement3x3 = getStructuringElement(MORPH_RECT,
Size(3, 3));
		Mat structuringElement5x5 = getStructuringElement(MORPH_RECT,
Size(5, 5));
		Mat structuringElement7x7 = getStructuringElement(MORPH_RECT,
Size(7, 7));
		Mat structuringElement9x9 = getStructuringElement(MORPH_RECT,
Size(9, 9));

		//dilate(imgThresh, imgThresh, structuringElement5x5);
		dilate(imgThresh, imgThresh, structuringElement3x3);
		erode(imgThresh, imgThresh, structuringElement3x3);

		Mat imgThreshCopy = imgThresh.clone();

		vector<vector<Point> > contours;

		findContours(imgThreshCopy, contours, RETR_LIST,
CHAIN_APPROX_NONE);

		Mat imgContours(imgThresh.size(), CV_8UC3, SCALAR_BLACK);

		drawContours(imgContours, contours, -1, SCALAR_GREEN, -1);

		//imshow("imgContours", imgContours);

		vector<vector<Point> > convexHulls(contours.size());

		for (unsigned int i = 0; i < contours.size(); i++) {
			convexHull(contours[i], convexHulls[i]);
		}

		for (auto &convexHull : convexHulls) {
			Blob possibleBlob(convexHull);

			if (possibleBlob.boundingRect.area() > 500 &&
				possibleBlob.boundingRect.area() < 1500 &&
				possibleBlob.dblAspectRatio >= 0.9 &&
```

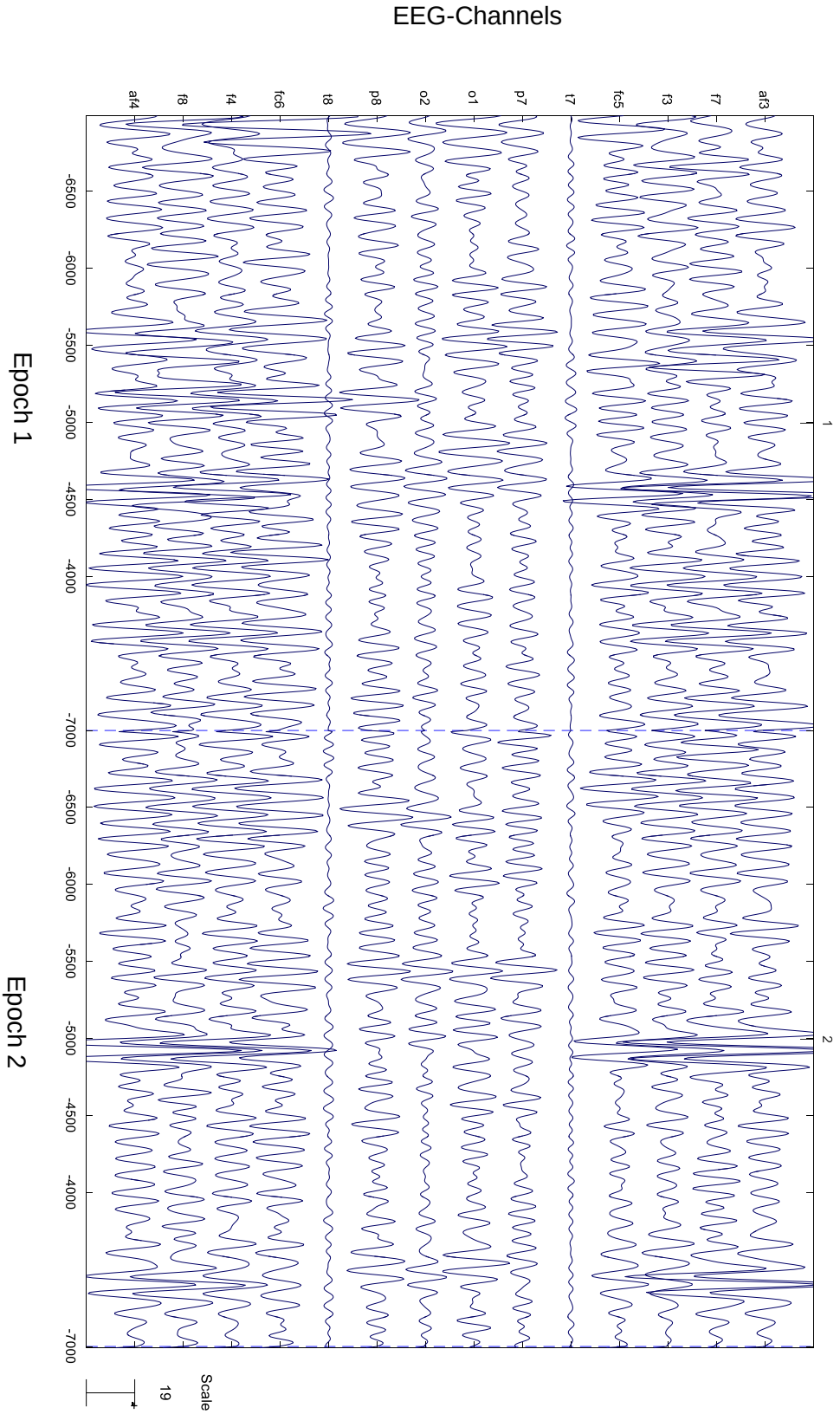
```
                        possibleBlob.dblAspectRatio <= 1.1 &&
                        possibleBlob.boundingRect.width > 10 &&
                        possibleBlob.boundingRect.height > 10 &&
                        possibleBlob.dblDiagonalSize > 40)
                {
                        blobs.push_back(possibleBlob);
                }
        }

        Mat imgConvexHulls(imgThresh.size(), CV_8UC3, SCALAR_BLACK);

        convexHulls.clear();

        for (auto &blob : blobs) {
                convexHulls.push_back(blob.contour);
        }

        drawContours(imgConvexHulls, convexHulls, -1, SCALAR_WHITE, -
1);

        //imshow("imgConvexHulls", imgConvexHulls);

        Mat cropped_show = croppedRef.clone();

        for (auto &blob : blobs) {
// for each blob
                rectangle(cropped_show, blob.boundingRect,
SCALAR_WHITE, 2);             // draw a red box around the blob
                circle(cropped_show, blob.centerPosition,
(blob.boundingRect.width / 2), SCALAR_WHITE, 1);// draw a filled-in green
circle at the center
                cout << "circle radius = " << (blob.boundingRect.width
/ 2), "\n";
                cout << "-----------------------------------------------
--------\n";
                file_ << capVideo.get(CAP_PROP_POS_FRAMES) << ";" <<
(blob.boundingRect.width / 2) << "\n";

        }

        imshow("cropped_2", cropped_show);

        // now we prepare for the next iteration
        imgFrame1 = imgFrame2.clone();           // move frame 1 up to
where frame 2 is

        if ((capVideo.get(CV_CAP_PROP_POS_FRAMES) + 1) <
capVideo.get(CV_CAP_PROP_FRAME_COUNT)) {
                capVideo.read(imgFrame2);                               //
read it
                cout << capVideo.get(CAP_PROP_FRAME_COUNT) << "\n";

        }
        else {                                                    //
else
                cout << "end of video\n";                       // show
end of video message
```

```
                    break;                                                  //
and jump out of while loop
                }
                    }
        else        {
         if ((capVideo.get(CV_CAP_PROP_POS_FRAMES) + 1) <
capVideo.get(CV_CAP_PROP_FRAME_COUNT) )//&&
capVideo.get(CV_CAP_PROP_POS_FRAMES) <1801)
                    {  capVideo.read(imgFrame2);
// read it
                    }
         else {                                                   // else
                cout << "end of epoch\n";                       // show end of
video message
                break;                                              // and
jump out of while loop
                 };
                            }
               chCheckForEscKey = waitKey(1);      // get key press in case
user pressed esc
               }
        if (chCheckForEscKey != 27) {               // if the user did not
press esc (i.e. we reached the end of the video)
               waitKey(0);                          // hold the windows open
to allow the "end of video" message to show
        }
        // note that if the user did press esc, we don't need to hold the
windows open, we can simply let the program end which will close the windows

        file_.close();

        return(0);
}
```

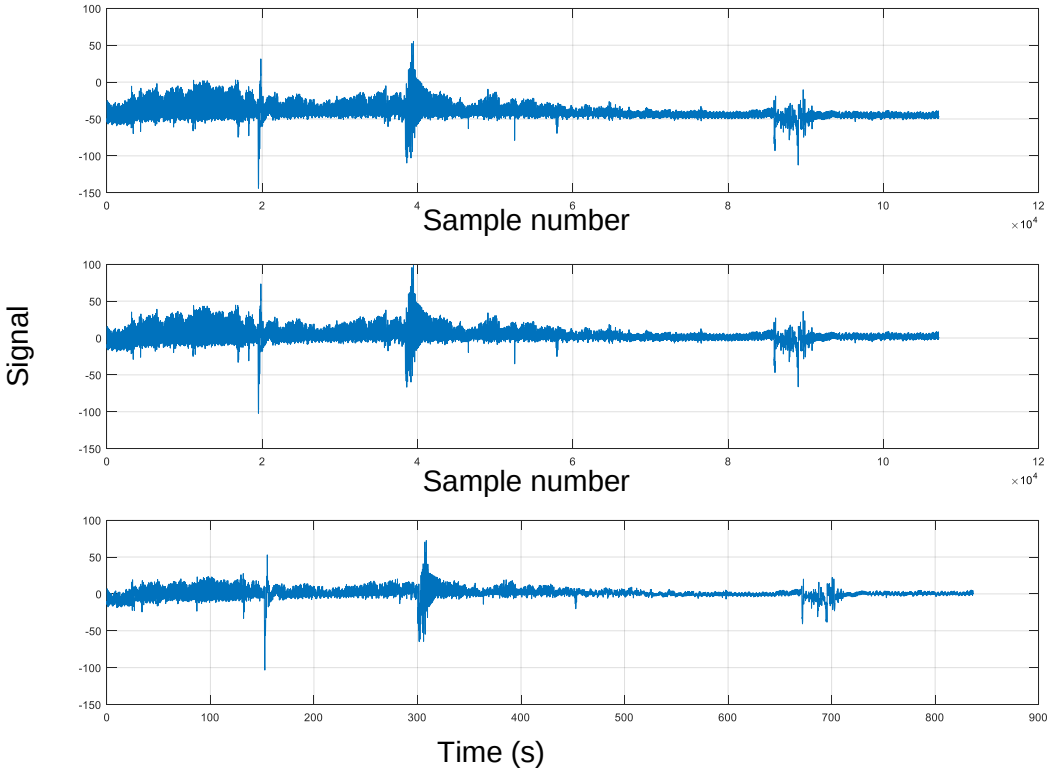
Appendix G-1: Raw EEG-data



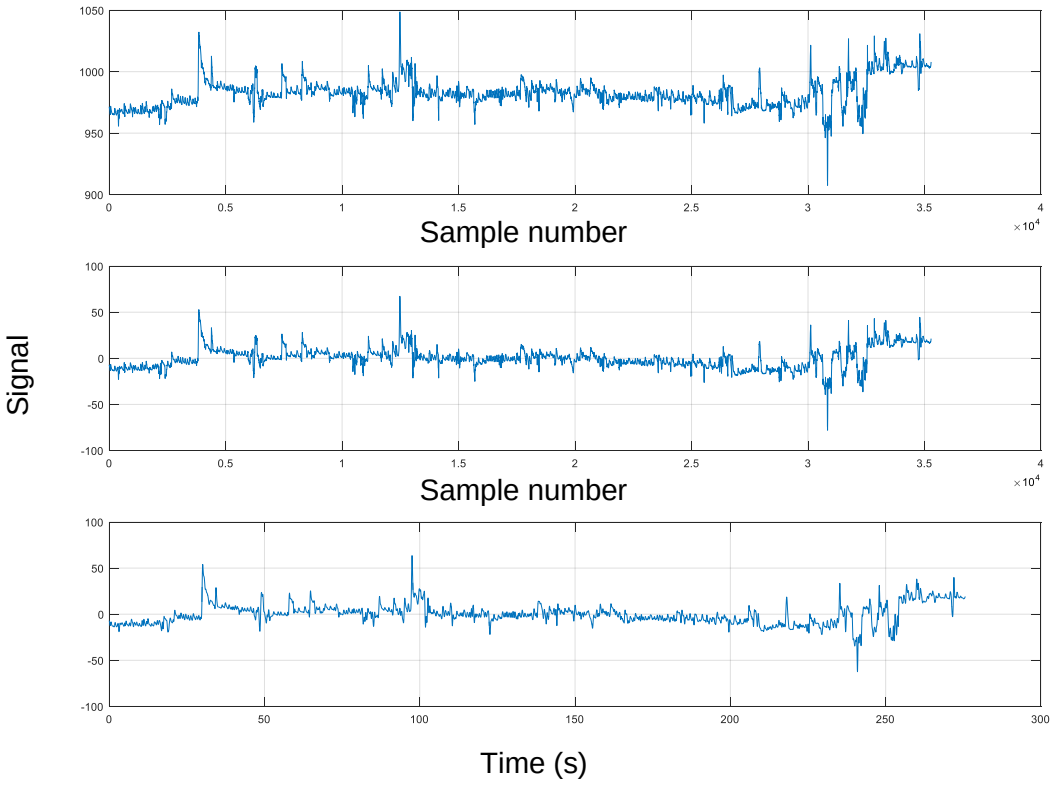
Appendix G-2: EEG data after implementing the ICA



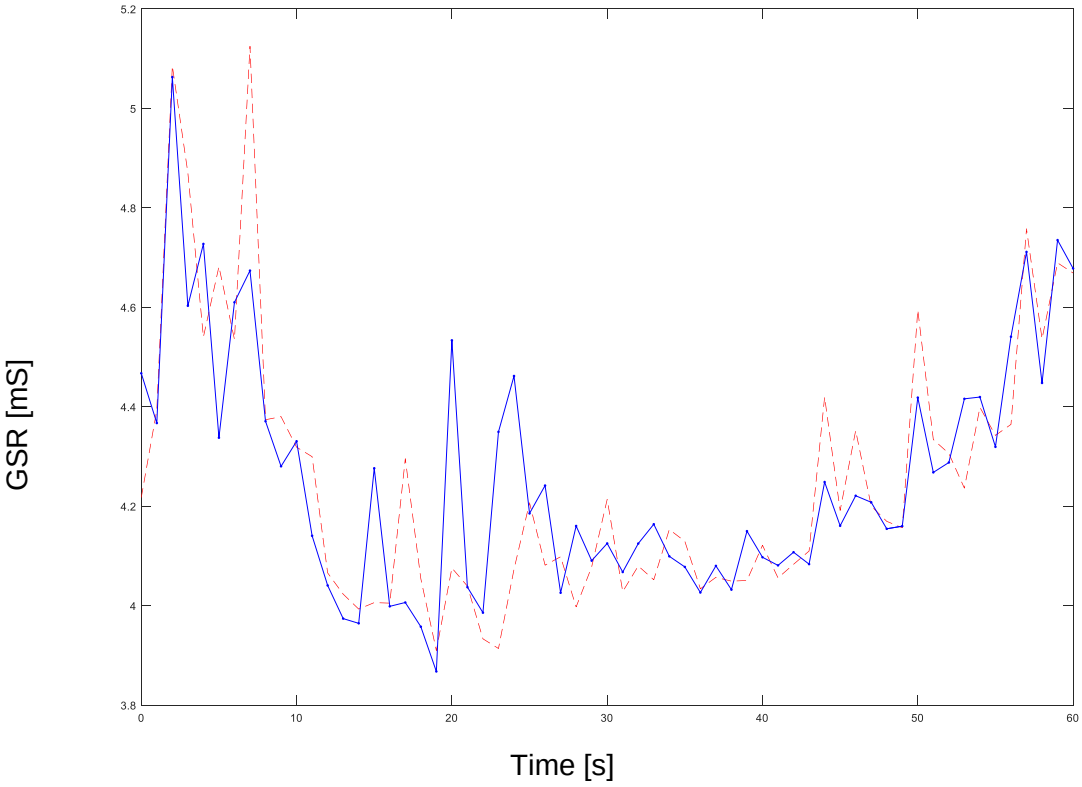
Appendix G-3: Raw HR data



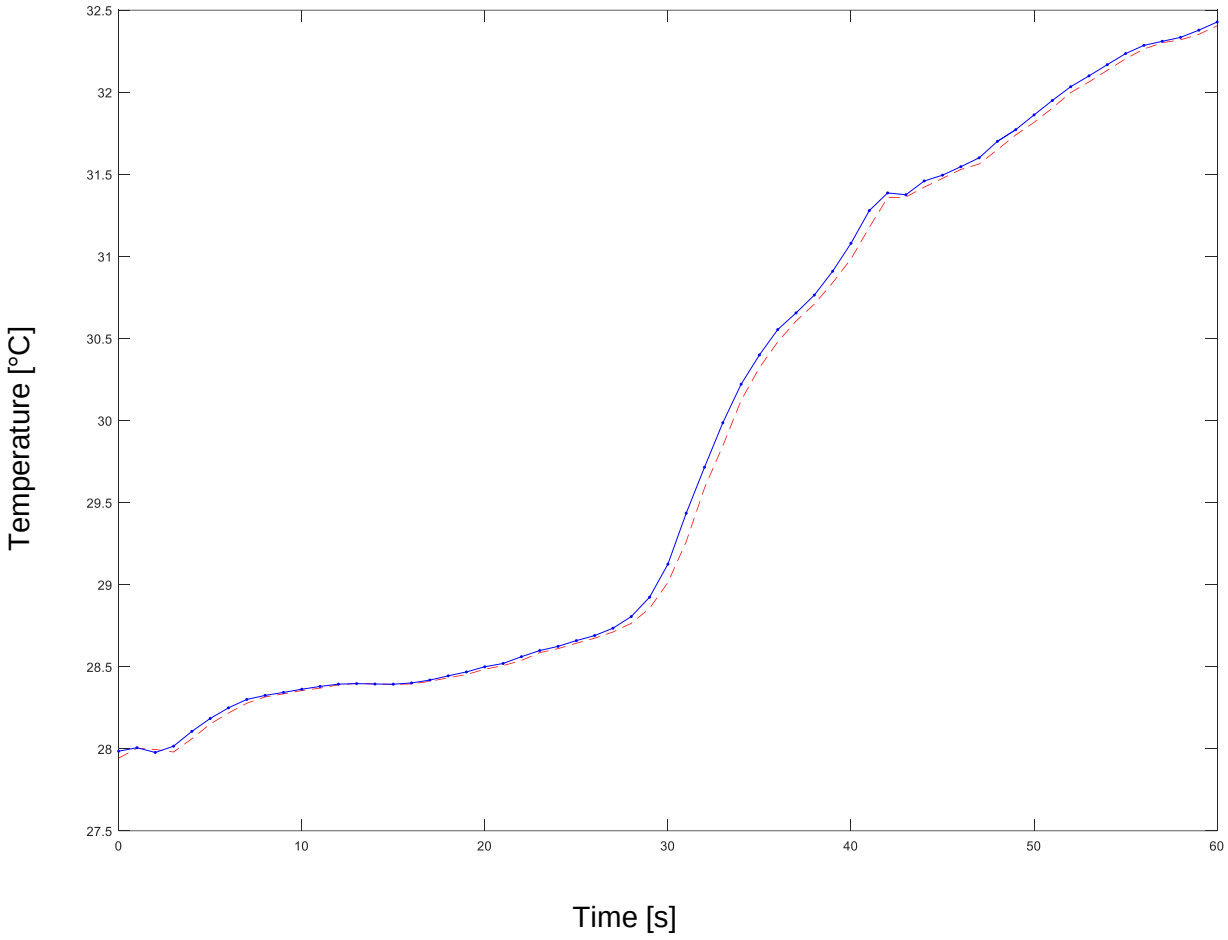
Appendix G-4: Raw RR data



Appendix G-5: Raw GSR data



Appendix G-6: Raw FT data



Appendix H-1: Baseline EEG vs 6 Emotion groups EEG

Table 30: EEG results between participants within emotion groups; baseline vs test data

delta frequency band							
Participant	PV*	NV*	NA*	PA*	ND*	PD*	Mean
003	0.00	0.00	0.00	0.00	0.00	0.00	0.00
006	0.00	0.00	0.00	0.00	0.00	0.00	0.00
007	0.00	0.00	0.00	0.00	0.00	0.00	0.00
008	0.01	0.00	0.00	0.00	0.00	0.00	0.00
009	0.36	0.00	0.33	0.00	0.00	0.31	0.17
011	0.00	0.00	0.00	0.00	0.00	0.00	0.00
012	0.01	0.00	0.00	0.01	0.00	0.00	0.00
013	0.00	0.00	0.00	0.00	0.00	0.00	0.00
014	0.26	0.00	0.00	0.48	0.00	0.21	0.16
016	0.00	0.00	0.00	0.00	0.00	0.00	0.00
017	0.00	0.04	0.01	0.00	0.05	0.00	0.02
018	0.00	0.00	0.00	0.00	0.00	0.00	0.00
019	0.00	0.00	0.00	0.00	0.01	0.00	0.00
020	0.00	0.00	0.00	0.00	0.01	0.00	0.00
theta frequency band							
Participant	PV*	NV*	NA*	PA*	ND*	PD*	Mean
003	0.00	0.00	0.00	0.00	0.00	0.00	0.00
006	0.00	0.00	0.00	0.00	0.00	0.00	0.00
007	0.00	0.00	0.00	0.00	0.00	0.00	0.00
008	0.00	0.00	0.00	0.00	0.00	0.00	0.00
009	0.41	0.00	0.37	0.00	0.00	0.36	0.19
011	0.00	0.00	0.00	0.00	0.00	0.00	0.00
012	0.01	0.00	0.00	0.01	0.01	0.01	0.01
013	0.00	0.00	0.00	0.00	0.00	0.00	0.00
014	0.34	0.00	0.00	0.43	0.00	0.29	0.18
016	0.00	0.00	0.00	0.00	0.00	0.00	0.00
017	0.00	0.04	0.01	0.00	0.05	0.00	0.02
018	0.00	0.00	0.00	0.00	0.00	0.00	0.00
019	0.00	0.00	0.00	0.00	0.00	0.00	0.00
020	0.00	0.00	0.00	0.00	0.01	0.00	0.00
alpha frequency band							
Participant	PV*	NV*	NA*	PA*	ND*	PD*	Mean
003	0.00	0.00	0.00	0.00	0.00	0.00	0.00
006	0.00	0.00	0.00	0.00	0.00	0.00	0.00
007	0.00	0.00	0.00	0.00	0.00	0.00	0.00

008	0.00	0.00	0.00	0.00	0.00	0.00	0.00
009	0.47	0.00	0.49	0.00	0.00	0.48	0.24
011	0.00	0.00	0.00	0.00	0.00	0.00	0.00
012	0.07	0.10	0.08	0.08	0.12	0.06	0.08
013	0.00	0.00	0.00	0.00	0.00	0.00	0.00
014	0.50	0.00	0.00	0.36	0.00	0.45	0.22
016	0.00	0.00	0.00	0.00	0.00	0.00	0.00
017	0.00	0.04	0.01	0.00	0.05	0.00	0.02
018	0.00	0.00	0.00	0.00	0.00	0.00	0.00
019	0.00	0.00	0.00	0.00	0.00	0.00	0.00
020	0.00	0.02	0.01	0.00	0.04	0.00	0.01

beta frequency band

Participant	PV*	NV*	NA*	PA*	ND*	PD*	Mean
003	0.00	0.00	0.00	0.00	0.00	0.00	0.00
006	0.00	0.01	0.00	0.00	0.00	0.00	0.00
007	0.00	0.04	0.00	0.03	0.00	0.01	0.01
008	0.29	0.07	0.08	0.18	0.10	0.29	0.17
009	0.23	0.02	0.24	0.03	0.01	0.23	0.13
011	0.00	0.00	0.00	0.00	0.00	0.00	0.00
012	0.26	0.28	0.08	0.20	0.26	0.22	0.22
013	0.00	0.01	0.08	0.00	0.03	0.00	0.02
014	0.34	0.00	0.00	0.27	0.01	0.42	0.17
016	0.00	0.43	0.42	0.04	0.48	0.03	0.23
017	0.03	0.03	0.02	0.00	0.06	0.01	0.03
018	0.01	0.21	0.00	0.45	0.25	0.01	0.16
019	0.05	0.00	0.01	0.01	0.00	0.02	0.02
020	0.00	0.10	0.07	0.01	0.11	0.00	0.05

*Positive Valence
Negative Valence
Negative Arousal
Positive Arousal
Negative Dominance
Positive Dominance

Appendix H-2: Baseline HR vs 6 Emotion groups HR

Table 31: Heart rate results between participants within emotion groups; baseline vs test-data

P-values

Participant	Negative Valence	Positive Valence	Negative Arousal	
003	0.41	0.93	0.29	
006	0.63	0.81	0.57	
007	0.06	0.75	0.41	
008	0.09	0.68	0.33	
009	0.03	0.07	0.30	
011	0.91	0.09	0.67	
012	0.67	0.06	0.91	
013	0.68	0.25	0.03	
014	0.11	0.39	0.06	
016	0.36	0.85	0.73	
018	0.51	0.41	0.94	
019	0.23	0.29	0.83	
020	0.36	0.47	0.05	
Participant	Positive Arousal	Negative Dominance	Positive Dominance	Mean
003	0.77	0.42	0.82	0.54
006	0.61	0.25	0.88	0.59
007	0.04	0.56	0.06	0.23
008	0.53	0.93	0.16	0.41
009	0.16	0.07	0.09	0.13
011	0.09	0.43	0.20	0.46
012	0.14	0.09	0.81	0.52
013	0.65	0.13	0.69	0.43
014	0.59	0.70	0.07	0.31
016	0.24	0.91	0.39	0.53
018	0.76	0.75	0.94	0.78
019	0.88	0.42	0.43	0.56
020	0.61	0.26	0.53	0.36

Appendix H-3: Baseline RR vs 6 Emotion groups RR

Table 32: Respiratory rate results between participants within emotion groups; baseline vs test-data

P-values

Participant	Negative Valence	Positive Valence	Negative Arousal	
003	0.35	0.33	0.28	
006	0.10	0.10	0.17	
007	0.43	0.01	0.01	
008	0.23	0.07	0.21	
009	0.17	0.40	0.01	
011	0.46	0.19	0.37	
012	0.16	0.13	0.39	
013	0.42	0.34	0.33	
014	0.46	0.50	0.37	
016	0.28	0.25	0.01	
017	0.29	0.44	0.20	
018	0.23	0.36	0.17	
019	0.26	0.01	0.04	
020	0.14	0.06	0.11	
Participant	Positive Arousal	Negative Dominance	Positive Dominance	Mean
003	0.27	0.18	0.20	0.26
006	0.03	0.10	0.10	0.10
007	0.37	0.01	0.43	0.25
008	0.50	0.21	0.44	0.32
009	0.08	0.30	0.24	0.16
011	0.12	0.12	0.39	0.29
012	0.31	0.16	0.36	0.28
013	0.36	0.44	0.43	0.39
014	0.32	0.45	0.50	0.42
016	0.33	0.20	0.31	0.22
017	0.08	0.25	0.18	0.20
018	0.26	0.29	0.19	0.23
019	0.21	0.12	0.08	0.14
020	0.01	0.36	0.43	0.21

Appendix H-4: Baseline GSR vs 6 Emotion groups GSR

Table 33: GSR results between participants within emotion groups; baseline vs test-data

P-values

Participant	Negative Valence	Positive Valence	Negative Arousal	
003	0.29	0.27	0.28	
006	0.49	0.29	0.31	
007	0.49	0.45	0.31	
008	0.08	0.00	0.01	
009	0.48	0.09	0.17	
013	0.14	0.10	0.25	
Participant	Positive Arousal	Negative Dominance	Positive Dominance	Mean
003	0.24	0.36	0.33	0.29
006	0.47	0.47	0.31	0.39
007	0.20	0.34	0.46	0.38
008	0.00	0.20	0.00	0.05
009	0.44	0.47	0.13	0.30
013	0.22	0.12	0.09	0.15

Appendix H-5: Baseline FT vs 6 Emotion groups FT

Table 34: Finger temperature results between participants within emotion groups; baseline vs test-data

P-values

Participant	Negative Valence	Positive Valence	Negative Arousal	
003	0.00	0.00	0.00	
006	0.00	0.00	0.00	
007	0.00	0.00	0.00	
008	0.00	0.01	0.00	
009	0.20	0.00	0.00	
011	0.17	0.79	0.30	
012	0.00	0.00	0.00	
013	0.53	0.03	0.75	
014	0.00	0.00	0.00	
016	0.00	0.00	0.00	
017	0.00	0.00	0.00	
018	0.00	0.02	0.00	
019	0.29	0.07	0.07	
020	0.00	0.00	0.00	
Participant	Positive Arousal	Negative Dominance	Positive Dominance	Mean
003	0.00	0.00	0.00	0.00
006	0.00	0.00	0.00	0.00
007	0.00	0.00	0.00	0.00
008	0.20	0.00	0.01	0.04
009	0.05	0.05	0.00	0.05
011	0.60	0.34	0.49	0.45
012	0.00	0.00	0.00	0.00
013	0.21	0.90	0.12	0.42
014	0.00	0.00	0.00	0.00
016	0.00	0.00	0.00	0.00
017	0.00	0.00	0.00	0.00
018	0.01	0.00	0.03	0.01
019	0.16	0.15	0.11	0.14
020	0.00	0.00	0.00	0.00

Appendix H-6: Baseline PD vs 6 Emotion groups PD

Table 35: Pupil diameter results between participants within emotion groups; baseline vs test-data

P-values

Participant	Negative Valence	Positive Valence	Negative Arousal	
007	0.2550	0.2519	0.0129	
009	0.1483	0.0039	0.0064	
016	0.0000	0.0000	0.0000	
018	0.0065	0.0000	0.0005	
Participant	Positive Arousal	Negative Dominance	Positive Dominance	Mean
007	0.1030	0.0084	0.1143	0.12
009	0.1287	0.3539	0.0046	0.11
016	0.0000	0.0000	0.0000	0.00
018	0.0012	0.0107	0.0001	0.00

Appendix I: Statistically invalid results

Appendix I-1: Pupil Diameter Results

10.1.1 Included Data

The data that is included in the results shown are from 4 participants, 2 male and 2 female. The data that was excluded from the results are due to poor video quality and are described in detail in section 5, Methodology.

10.1.2 Results within each Emotion Group

Table 36 displays the results obtained after the pupil diameter was calculated for each of the emotion groups. The pupil diameter is expressed in pixels. The table shows the mean baseline and mean test-values for the pupil diameter calculations. A t-test conducted to compare the baseline and test-values yielded the p-values displayed. Since $p << 0.01$ for all the values obtained, a significant statistical difference is established between the baseline and test-data for all emotion groups in both the combined gender groups as well as the results for the male participants (Table 38). The female results (Table 37) only revealed a statistical significant difference for the positive dominance group between the baseline and test-values.

Table 36: Pupil diameter results within each emotion group; baseline vs test-data

	Mean Baseline-value	*Mean Test-value*	*P-value*
Positive valence group	18.7266	18.0365	0.0007
Negative valence group	18.7856	17.8632	0.0001
Positive arousal group	18.8282	18.0752	0.0012
Negative arousal group	18.6540	17.8640	0.0001
Positive dominance group	18.6820	18.0562	0.0017
Negative dominance group	18.8885	17.8060	0.0000

Table 37: Pupil diameter results within each emotion group for female participants; baseline vs test-data

	Mean Baseline-value	*Mean Test-value*	*p-value*
Positive valence group	17.9984	18.4296	0.0923
Negative valence group	18.2775	18.0816	0.9150
Positive arousal group	18.0206	18.4670	0.1302
Negative arousal group	18.1147	18.1069	0.6874
Positive dominance group	17.9413	18.4712	0.0317
Negative dominance group	18.3951	17.9134	0.1632

Table 38: Pupil diameter results within each emotion group for male participants; baseline vs test-data

	Mean Baseline-value	*Mean Test-value*	*p-value*
Positive valence group	19.2834	17.6549	0.0000
Negative valence group	19.0845	17.6580	0.0000
Positive arousal group	19.4143	17.7150	0.0000
Negative arousal group	19.0041	17.6210	0.0000
Positive dominance group	19.2518	17.6518	0.0000
Negative dominance group	19.1533	17.7067	0.0000

10.1.3 Results between Participants within Emotion Groups

After the results of the pupil diameter calculations have been compared within the emotion groups, a t-test was conducted between the participants. The values depicted in Table 35 (Appendix H-6) reveals the statistical difference between the baseline and test-data for each participant. Each emotion group's p-values are showed, as well as the mean p-value for each participant. As $p << 0.01$ for participants 016 and 018 it can be confirmed that a statistical significant difference exists between the baseline and test-data for these participants.

10.1.4 Pupil diameter results between the emotion groups

Table 39 depicted a statistical significant difference for all the comparisons between the emotion groups with the exception of the comparison between the positive valence and negative dominance groups. These results are from the t-test that compared the pupil diameter results of each emotion group amongst themselves.

Table 39: Pupil diameter results between emotion groups; baseline vs test-data

	Positive Valence	*Negative Valence*	*Positive Arousal*	*Negative Arousal*	*Positive Dominance*
Negative Valence	0.03				
Positive Arousal	0.02	0.00			
Negative Arousal	0.00	0.00	0.00		
Positive Dominance	0.00	0.05	0.00	0.01	
Negative Dominance	0.06	0.00	0.00	0.00	0.00

10.1.5 Results compared to EEG-results

The results obtained from the pupil diameter calculations was compared to the results of the PSD-calculations done on the EEG-results in three different statistical tests. The results of the Pearson correlation test between the data of pupil diameter and EEG, are shown in Table 40. The r-values obtained shows the relationship between the pupil diameter and calculated PSD-values. The r-values showed a weak linear relationship for all the emotion groups.

The results of a two-way ANOVA with replication between the test-data of pupil diameter and EEG, are shown in Table 41. The p-values obtained shows that the difference in participant influenced the data significantly ($p << 0.01$), and the stimuli and interaction between stimuli and participants contributed to approximately 90% of the change in measurements ($p = \pm 0.1$).

The results of a two-way ANOVA with replication of the percentage difference between baseline and test-data for pupil diameter and EEG, are shown in Table 42. The p-values obtained displays that the variance in participant made a significant difference ($p << 0.01$) in the results recorded, and the stimuli and interaction between stimuli and participant made an 89% difference ($p = \pm 0.11$) in the alpha frequency band.

Table 40: Pearson Correlation between pupil diameter and EEG-results; test-data vs test-data

Positive Valence		*Positive Arousal*		*Positive Dominance*	
r-value		r-value		r-value	
delta	-0.02	delta	-0.06	delta	-0.04
theta	-0.03	theta	-0.07	theta	-0.06
alpha	-0.05	alpha	-0.09	alpha	-0.08
beta	-0.06	beta	-0.04	beta	-0.08
Negative Valence		*Negative Arousal*		*Negative Dominance*	
r-value		r-value		r-value	
delta	0.04	delta	0.06	delta	0.11
theta	0.03	theta	0.06	theta	0.11
alpha	0.00	alpha	0.03	alpha	0.10
beta	-0.04	beta	-0.06	beta	0.04

Table 41: Results of two-way ANOVA-test with replication between pupil diameter and EEG; test-data vs test-data

delta frequency band

Source of Variation	*F*	*P-value*	*F crit*
Participant	55372.2348	0	3.8674
Stimuli	1.2767	0.0947	1.3586
Interaction	1.2467	0.1178	1.3586

theta frequency band

Source of Variation	*F*	*P-value*	*F crit*
Participant	55362.8076	0	3.8674
Stimuli	1.2722	0.0980	1.3586
Interaction	1.2513	0.1141	1.3586

alpha frequency band

Source of Variation	*F*	*P-value*	*F crit*
Participant	55906.0034	0	3.8674
Stimuli	1.2639	0.1041	1.3586
Interaction	1.2625	0.1052	1.3586

beta frequency band

Source of Variation	*F*	*P-value*	*F crit*
Participant	56002.8608	0	3.8674
Stimuli	1.2633	0.1046	1.3586
Interaction	1.2633	0.1046	1.3586

Table 42: Results of two-way ANOVA-test with replication between the percentage difference of change from baseline to test-data for pupil diameter vs EEG

delta frequency band

Source of Variation	F	P-value	F crit
Participant	103.5787	0.0000	3.8674
Stimuli	0.8981	0.6863	1.3586
Interaction	0.8985	0.6855	1.3586

theta frequency band

Source of Variation	F	P-value	F crit
Participant	125.4573	0.0000	3.8674
Stimuli	1.0191	0.4431	1.3586
Interaction	1.0197	0.4421	1.3586

alpha frequency band

Source of Variation	F	P-value	F crit
Participant	128.2808	0.0000	3.8674
Stimuli	1.2511	0.1143	1.3586
Interaction	1.2517	0.1138	1.3586

beta frequency band

Source of Variation	F	P-value	F crit
Participant	48.0762	0.0000	3.8674
Stimuli	0.9174	0.6485	1.3586
Interaction	0.9166	0.6500	1.3586

Appendix I-2: Galvanic Skin Response Results

10.1.6 Included Data

The data that is included in the results shown are from 6 participants, 3 male and 3 female. The data that was excluded from the results are due to mechanical difficulties, including hardware malfunctions and human error.

10.1.7 Results within each Emotion Group

Table 43 depicts the results obtained after the mean GSR values was calculated for each of the emotion groups. The table shows the mean baseline and mean test-values for GSR. A t-test conducted to compare the baseline and test-values yielded the p-values displayed. Since $p > 0.05$ for all the values obtained, no significant statistical difference could be established between the baseline and test-data. This conclusion is true for both the gender groups (Female results: Table 44 and Male results: Table 45) as well as the combined group.

Table 43: GSR results within each emotion group; baseline vs test-data

	Mean Baseline-value	*Mean Test-value*	*p-value*
Positive valence group	2.6947	2.6829	0.2339
Negative valence group	2.5406	2.5483	0.5075
Positive arousal group	2.6398	2.6338	0.6161
Negative arousal group	2.6302	2.6296	0.9496
Positive dominance group	2.6865	2.6749	0.1868
Negative dominance group	2.5204	2.5323	0.3956

Table 44: GSR results within each emotion group for female participants; baseline vs test-data

	Mean Baseline-value	*Mean Test-value*	*p-value*
Positive valence group	2.8115	2.8125	0.9280
Negative valence group	2.8178	2.8129	0.6541
Positive arousal group	2.7002	2.7058	0.6498
Negative arousal group	2.9134	2.9053	0.4083
Positive dominance group	2.8264	2.8262	0.9848
Negative dominance group	2.7930	2.7889	0.7398

Table 45: GSR results within each emotion group for male participants; baseline vs test-data

	Mean Baseline-value	*Mean Test-value*	*p-value*
Positive valence group	2.5779	2.5534	0.1339
Negative valence group	2.2598	2.2804	0.3221
Positive arousal group	2.5794	2.5617	0.3920
Negative arousal group	2.3408	2.3479	0.6582
Positive dominance group	2.5477	2.5248	0.1097
Negative dominance group	2.2391	2.2675	0.2659

10.1.8 Results between Participants within Emotion Groups

After the results of the GSR calculations have been compared within the emotion groups a t-test was conducted between the participants. The values in Table 33 (Appendix H-4) shows the statistical difference between the baseline and test-data for each participant. Each emotion group's p-values are showed, as well as the mean p-value for each participant. The p-values of participant 008 proved a statistical significant difference as p = 0.05 for the mean of the p-values.

10.1.9 GSR results between the emotion groups

Table 46 revealed the results of the t-test when comparing the GSR-data of each of the emotion groups to each other. These results reveal that there only exists a statistical significant difference between the negative dominance and positive arousal emotion group.

Table 46: GSR results between emotion groups; baseline vs test-data

	Positive Valence	*Negative Valence*	*Positive Arousal*	*Negative Arousal*	*Positive Dominance*
Negative Valence	0.25				
Positive Arousal	0.47	0.06			
Negative Arousal	0.43	0.34	0.23		
Positive Dominance	0.35	0.27	0.27	0.45	
Negative Dominance	0.06	0.45	0.01	0.35	0.23

10.1.10 Results compared to EEG-results

The results obtained from the GSR calculations was compared to the results of the PSD-calculations done on the EEG-results in three different statistical tests. The results of Pearson correlation test between the data of GSR and EEG, are shown in Table 47. The r-values obtained shows the relationship between the

GSR and calculated PSD-values. The r-values showed a weak linear relationship for all the emotion groups.

The results of a two-way ANOVA with replication between the test-data of GSR and EEG, are shown in Table 48. The p-values obtained shows that only the difference in participant influenced the results significantly ($p << 0.01$).

The results of a two-way ANOVA with replication of the percentage difference between baseline and test-data for GSR and EEG, are shown in Table 49. The p-values obtained displays that the difference in participant made a significant difference ($p << 0.01$) in the results recorded. The different stimuli and interaction between stimuli and participant also contributed to approximately 85% ($p = \pm 0.15$) of the change in results in the beta frequency band.

Table 47: Pearson Correlation between GSR and EEG-results; test-data vs test-data

Positive Valence		*Positive Arousal*		*Positive Dominance*	
r-value		r-value		r-value	
delta	0.07	delta	0.16	delta	0.10
theta	0.17	theta	0.13	theta	0.19
alpha	0.19	alpha	0.10	alpha	0.20
beta	0.26	beta	0.32	beta	0.36
Negative Valence		*Negative Arousal*		*Negative Dominance*	
r-value		r-value		r-value	
delta	0.17	delta	0.08	delta	0.13
theta	0.13	theta	0.16	theta	0.09
alpha	0.12	alpha	0.19	alpha	0.07
beta	0.32	beta	0.27	beta	0.15

Table 48: Results of two-way ANOVA test with replication between GSR and EEG; test data vs test data

delta frequency band			
Source of Variation	F	P-value	F crit
Participant	75.8384	0.0000	3.8570
Stimuli	0.9055	0.6751	1.3437
Interaction	0.9055	0.6751	1.3437
theta frequency band			
Source of Variation	F	P-value	F crit
Participant	97.6380	0.0000	3.8570
Stimuli	0.9874	0.5050	1.3437
Interaction	0.9874	0.5051	1.3437
alpha frequency band			

Source of Variation	F	P-value	F crit
Participant	166.2609	0.0000	3.8570
Stimuli	0.9223	0.6410	1.3437
Interaction	0.9223	0.6410	1.3437
	beta frequency band		
Source of Variation	F	P-value	F crit
Participant	54.8336	0.0000	3.8570
Stimuli	1.1942	0.1602	1.3437
Interaction	1.2019	0.1517	1.3437

Table 49: Results of two-way ANOVA-test with replication between the percentage difference of change from baseline to test-data for GSR vs EEG

	delta frequency band		
Source of Variation	F	P-value	F crit
Participant	75.8384	0.0000	3.8570
Stimuli	0.9055	0.6751	1.3437
Interaction	0.9055	0.6751	1.3437
	theta frequency band		
Source of Variation	F	P-value	F crit
Participant	97.6380	0.0000	3.8570
Stimuli	0.9874	0.5050	1.3437
Interaction	0.9874	0.5051	1.3437
	alpha frequency band		
Source of Variation	F	P-value	F crit
Participant	166.2609	0.0000	3.8570
Stimuli	0.9223	0.6410	1.3437
Interaction	0.9223	0.6410	1.3437
	beta frequency band		
Source of Variation	F	P-value	F crit
Participant	54.8336	0.0000	3.8570
Stimuli	1.1942	0.1602	1.3437
Interaction	1.2019	0.1517	1.3437