Bachelor's Thesis

Measuring vMMN, P300 and AEPs with a mobile EEG system

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Abstract

Electroencephalography (EEG) is a commonly used method for recording potentials generated by the human brain. It allows us to gain insights into how the brain reacts to certain stimuli in a non-invasive way. For a long time, EEG could be measured only in laboratories because of the heavy equipment required and the artifacts movements would create in the data. To make recording outside of laboratories in natural environments possible, sometimes even with moving subjects, mobile EEG systems were developed.

The Traumschreiber is just such a mobile EEG system, developed at the University of Osnabrück. In contrast to standard EEG systems, it records with a low number of channels and is small and lightweight. These differences between the Traumschreiber and commonly used systems lead to the question whether the Traumschreiber can be used for typical EEG experiments instead of a standard system. This question was addressed in this bachelor's thesis.

For evaluating the Traumschreiber, two aspects were of importance: the general usability and the quality of the recorded data. To be able to analyze both aspects, the Traumschreiber was used in an EEG experiment with typical paradigms. The event-related potentials (ERPs) evoked by the paradigms analyzed for this thesis are visual mismatch negativity, P300 and auditory-evoked potentials. They were chosen because they are well studied and easy to elicit, and therefore should be detected by the Traumschreiber if it is able to record like a standard system.

Rereferencing, baseline correction and artifact removal was done on the recorded data, but no additional filters were applied. The preprocessed data were averaged for each subject and over all subjects to see whether the ERPs are visible.

The Traumschreiber was able to produce very good results (ERP visible for all subjects) for visual mismatch negativity, and good results (ERP visible for most subjects) for the other paradigms. It was not only able to record the potentials, but showed satisfactory usability as well, even though some improvements should still be made.

The obtained results led to the conclusion that the Traumschreiber is able to record ERPs in general. Therefore it would be possible to conduct experiments in which EEG is used for ERP detection with the Traumschreiber in the place of more commonly used systems.

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List of Abbreviations

vMMN Visual Mismatch Negativity

SSVEP Steady State Evoked Potential

AEP Auditory Evoked Potential

EEG Electroencephalography

ERP Event Related Potential

NBP Neurobiopsychology

MMN Mismatch Negativity

ABR Auditory Brainstem Response

LED Light Emitting Diode

HDMI High Definition Multimedia Interface

1. Introduction

We all know nowadays that we use our brain for thinking. But how does that work exactly? This question has been addressed by many scientists, who developed different methods, to gather better insights into the brain's work. One of these methods is electroencephalography. In today's research it is a common method because it allows to study the brain activity of living individuals non-invasively. Different systems, with different advantages and disadvantages can be found.

For this bachelor's thesis a study was conducted in order to test a mobile low cost electroencephalography system - the Traumschreiber - which was developed at the University of Osnabrück. To provide the background knowledge needed to understand the study and its results, the following sections will give a short overview over the important matters. After having explained electroencephalography and its neuronal background in general the focus will lie on mobile electroencephalography systems. After that the three potentials analyzed in the study will be elaborated further.

1.1. Electroencephalography

Electroencephalography (EEG) is a non-invasive method used for measuring brain activity. Brain activity can be found whenever neurons in the brain fire.

Neurons, also known as nerve cells, normally consist of dendrites, a cell body and an axon. The dendrites receive electrical or chemical signals from other neurons and propagate them to the cell body. In the cell body all received signals are summed up and if a certain threshold is reached an action potential is created at the axon hillock. The axon hillock is the connection between the cell body and the axon and therefore the action potential can propagate down the axon after its creation. The axon ends in synapses, which are connected to axons, cell bodies or dendrites of other neurons (Purves et al., 2008).

Two different electrical signals are produced while neurons fire. First, the action potential, which travels down the axon, and after that the post-synaptic potential, which is elicited in the dendrite after the synapse is passed. Often just the post-synaptic potential can be measured because synchronization in the same direction is needed for measuring action potentials (Luck, 2005).

If an electric potential is related to external or internal events, for example a specific stimulation, it is called an event-related potential (ERP) (Luck, 2012). ERPs can be distinguished by their components, which therefore play a central role in EEG analysis (Donchin, Ritter, McCallum, et al., 1978). Components differ in polarity, waveform and the relative time to the stimulation (Bressler and Ding, 2006). When measuring EEG it is often the ERPs in which scientists are interested (Delorme et al., 2015).

To be able to record them, electrodes are placed on the head. By using special electrode gels, alcohol, abrasion or other methods the conductance is enhanced. A good conductance lowers the impedances between the electrode and the scalp resulting in cleaner data. If the conductance between the scalp and electrode is bad, for example because of air, less of the real potentials and more noise is recorded, which is undesired.

If the conductance is good enough, the electrodes pick up the different charges produced by the neurons in the brain. The charges are measured directly when they arise, which leads to a good temporal resolution. The spatial resolution however is quite bad because every measured potential could originate from different sums of underlying neuronal potentials. The problem of computing the origins of a potential from just the measured potentials is known as the *inverse problem* (Jackson and Bolger, 2014). The complexity of the inverse problem is a reason why EEG is not easily used to localize the origins of potentials, but rather for looking how the brain reacts to certain stimulus types.

The raw EEG data themselves are not easy to interpret, as many different neuronal processes are recorded at the same time. To get meaningful results from the data, ERPs and their components are important (Luck, 2014). To identify components in the EEG data, it is often necessary to average over many trials or subjects, to make them visible (Duncan et al., 2009). Normally an amplifier is used when EEG is recorded. The amplifier multiplies the data input with a certain gain, to increase the visibility as well. Not only brain activity, but also movements like eye movements or blinks will be picked up by the EEG system. This leads to noise and creates artifacts in the data (Corby and Kopell, 1972). Therefore it is often important to reduce movements and avoid anything else that can lead to noisy EEG data (e.g. electronic devices) while recording. But sometimes movements are wanted during the recording, for example when reactions in natural environments are tested. In that case mobile EEG systems can be used.

1.1.1. Mobile EEG systems

During the last years the number of mobile and low-cost EEG systems has increased (Melnik et al., 2017, Debener et al., 2012, Lin et al., 2008). Mobile EEG systems face the difficulty mentioned above: recording clean data, even though the subject is moving. In order to not disturb the subject "[d]edicated mobile EEG systems should therefore be small, lightweight, and fully headmounted" (Debener et al., 2012). An advantage of mobile EEG systems isthat it is possible to record EEG data in different surroundings and not just in laboratories (De Vos et al., 2014).

Debener et al. (2012) looked at P300 data obtained in a "natural" environment versus P300 data recorded indoors in a quiet office room. Their results show that the data obtained inside are better, but the other data still performed well in a classification task. In a later study De Vos et al. (2014) looked at the differences in data recorded with an amplifier used in EEG laboratories in comparison to data recorded with an amplifier used for mobile EEG systems. All other conditions stayed the same during the experiment. The study suggests, just like the one before that small and mobile EEG systems can give results not significantly different form those obtained with standard EEG systems.

The advantages of mobile EEG systems make them usable in situations where it was previously impossible to record EEG with the bigger and heavier standard systems.

1.1.2. The Traumschreiber

One mobile and low cost EEG system is the Traumschreiber (see figure 1). The Traumschreiber was developed at the University of Osnabrück by Kristoffer Appel and Johannes Leugering of the Neuroinformatics Department under supervision of Prof. Dr. Gordon Pipa, originally for recording polysomnic data (Appel, 2017).

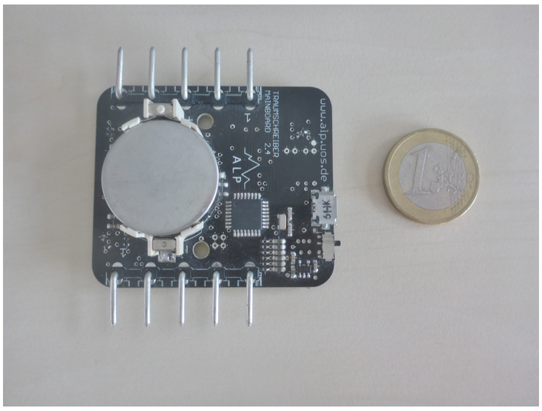

Figure 1: The Traumschreiber.

It can not only measure EEG data, but also electrooculography (EOG), electromyography (EMG) and electrocardiography (ECG). The Traumschreiber can additionally be used to stimulate the user with LEDs or sound (*The Traumschreiber Project* 2017). For his dissertation Appel (2017) computed the total cost for building one Traumschreiber. For the Traumschreiber itself without electrodes or the sleep mask the cost is around 93 EUR when ordering twenty at a time.

The idea behind the Traumschreiber is to offer an affordable device for measuring polysomnic data during sleep. An advantage of the Traumschreiber system is that it can be used at home and not only in a laboratory. This was tested in a field study by Mandt (2017). The field study showed that it was indeed possible for the participants to conduct the experiment at home, but it also showed that the data quality could be improved. For the field study two EEG channels (four electrodes) were recorded, while a previous experiment in the sleep laboratory used only one channel (two electrodes) (Appel, 2017). In these experiments the focus was on recording with different methods, leaving the question whether or not the Traumschreiber could be used as a mobile EEG system open. Besides these experiments there were no previous experiments for just analyzing the quality of EEG data obtained with the Traumschreiber system.

1.2. Event-related potentials

In the following sections the ERPs which were analyzed in this study will be described and explained.

1.2.1. Visual mismatch negativity

One ERP component, which occurs after seeing a deviant stimulus in a sequence of standard stimuli, is visual mismatch negativity (vMMN) (Stagg et al., 2004). If the standard and deviant stimulus differ in color a negative potential can be observed 120-200 ms after the deviant stimulus in posterior regions (Kimura, Katayama, and Murohashi, 2006). Other possible distinctions between the stimuli are shape, motion direction, brightness, spatial frequency, spatial location, orientation and size (Kimura, Katayama, Ohira, et al., 2009). Just physically different stimuli representations, without different occurrence probabilities, do not evoke a similar response (Stagg et al., 2004). This finding excludes the possible explanation that vMMN is just a pure confound in the experiments on vMMN because of different stimuli.

Czigler, Weisz, and Winkler (2006) argue in their paper on deviance detection for ERPs that it is not necessary to change the physical properties of the stimulus to elicit vMMN, but that a violation of sequential regularity also works. This observation is comparable to the observations made about auditory MMN (Czigler, 2007). It suggests furthermore that visual MMN can be seen as “evidence for the existence of unintentional prediction about the next state of a visual object in the immediate future on the basis of its temporal context” (Kimura, Schröger, and Czigler, 2011).

1.2.2. P300

The P300 component is, as the name suggests, an ERP with a positive amplitude, which peaks about 300 ms after the presentation of the stimulus (Ilardi et al., 2007). It is also known as the P3 component and consists of two sub parts, which are called P3a and P3b (Luck, 2014). P3a and P3b are both elicited when a less frequent deviant stimulus is presented between standard stimuli. For eliciting a P3b the stimulus has to be task relevant, whereas P3a is also seen for non-relevant stimuli (Snyder and Hillyard, 1976). P3a is stronger in the frontal and central regions of the scalp, while P3b can be found in parietal regions (Polich, 2012). When one talks about P300 or P3, P3b is often what is meant. This will also be the case for the analysis of the P300 component in this thesis.

A classical paradigm for P3a and P3b is the three-stimulus oddball paradigm, where a standard stimulus, a deviant stimulus and a distractor are presented (Polich, 2007). The deviant stimulus elicits a P3b wave when attended, whereas the ignored distractor leads to a P3a wave (Snyder and Hillyard, 1976). Different factors, such as the subjective probability and meaningfulness of the stimulus can influence the amplitude of P300 (Johnson, 1993). Subjective probability describes not just the general probability with which the oddball occurs, but how likely the subject assumes it to be (Duncan-Johnson and Donchin, 1982). Meaningfulness of a stimulus is given, when the deviant stimulus is task relevant. If the subject is engaged in a cognitively demanding task, which does not include the oddballs, P300 is reduced or not elicited at all. But if the oddballs are relevant for the task, for example if the subject is counting them, or reacting by pressing a button, a larger P300 can be measured (Donchin and Coles, 1988). Subjective probability and meaningfulness are two of three components of the triarchic model, which tries to make the P300 amplitude predictable by just using the two mentioned components and the stimulus information, which is received by the subject (Donchin and Coles, 1988). Other factors which can influence the P300 wave are age, sex and the sensory modality of the presented stimulus (Fabiani et al., 1987). Visual stimuli are known to elicit bigger amplitudes than auditory stimuli, therefore often a visual oddball task is used to study P300. Regardless of the sensory modality, depression is known for causing an attenuated P300 component (Ilardi et al., 2007).

P300 is a relatively well studied component, but the reason why it is elicited is not known. A theory by Donchin and Coles (1988) is that P300 is a sign of context updating. Whenever a distractor is presented or a task is changed, context updating becomes active. The former representation of the context in the brain is adjusted according to the received stimulus (Lenartowicz, Escobedo-Quiroz, and Cohen, 2010).

1.2.3. Auditory-evoked potentials

There are three different responses to auditory stimulation. The first part of auditory-evoked potentials (AEPs) is the auditory brainstem response (ABR), which is followed by the midlatency response, and lastly the long-latency response (Luck, 2014).

The ABR can be seen in the first 10 ms and derives from the brainstem and cochlea (Picton, 1990). It has a short latency of about 1-2 ms, which can lead to shifts while averaging, when the peaks are not always exactly at the same time (Luck, 2014). Midlatency responses follow from 10 ms to 80 ms after the stimulus (Liegeois-Chauvel et al., 1994). Long-latency responses normally begin with the components P1, N1 and P2 after the midlatency response. The mid- and long-latency responses are both dependent on the inter-stimulus interval; a longer inter-stimulus interval leads to a smaller amplitude of the response potential (Luck, 2014).

1.3. Aim of the study

The study aims at evaluating the performance of the Traumschreiber as an EEG system. Therefore the data quality which is delivered by the Traumschreiber was important. For the evaluation the Traumschreiber was used to record EEG data during an EEG experiment with typical paradigms. The experiment had six different paradigms of which three (see section 1.2) were used for the evaluation. The other three, steady state evoked potentials, N240 and motor responses (see section 2.3), were used for classification tasks, done by Ann-Kathrin Schalkamp (Schalkamp, 2018). The data obtained in the three parts of the experiment relevant for this thesis, were preprocessed and then analyzed in regard to the visibility of the components and general quality.

A closer look was also taken at the usability of the Traumschreiber. Therefore not only the results of the experiment are important, but also the execution of it with the Traumschreiber.

2. Materials and Methods

As previously mentioned, an experiment was conducted to examine the data quality and usability of the Traumschreiber system. Some classical paradigms for EEG recordings were used in this experiment. The experimental design was influenced by the study conducted by Melnik et al. (2017). The paradigm for the N170 component (faces-versus-cars) was substituted by an oddball paradigm for measuring P300. Since P300 is a quite large component it can be easily detected by using EEG. Therefore it would be still possible to detect P300 with the Traumschreiber's EEG, if the Traumschreiber would fail to detect smaller components. The N170 paradigm was ruled out because it failed to be replicated by another group at the University of Osnabrück. If the experiment for that paradigm had failed with the Traumschreiber as well, it would not have been possible to ascribe that failure to the Traumschreiber, as a normal EEG system had previously failed.

2.1. Participants

For the study a total of nine native German speakers (seven female, aged 19 to 28, mean age: 21.5) were recruited as participants. The subjects were recruited via e-mail to the cognitive science mailing list and mouth to mouth advertisement. All subjects were neurologically healthy and had neither dreadlocks nor a bald head. They were asked to come with washed hair. Every subject signed a consent form (see Appendix 18) prior to the experiment and was informed about the right to exit the experiment at any point without naming reasons. The subjects, who where students of the institute of cognitive science, were able to receive subject hours as compensation, according to the time they spend in the laboratory.

2.2. Material

The recordings took place in the laboratory of the neurobiopsychology (NBP) group. The laboratory consists of a larger room, which is used for the preparation of the participants before the experiment and is occupied by the experimenter during the experiments.

Another smaller room is intended to be used for the participant during the experiment. The smaller room has two monitors, which are connected to computers in the bigger room, and two comfortable chairs. Next to the left monitor, which was used for the Traumschreiber EEG experiments, a small speaker was placed for auditory stimulation.

The EEG cap which is used for the Traumschreiber is an EASYCAP [1], with Ag/AgCl ring electrodes. In total eight channels were recorded from ten electrodes. For doing that the difference in voltage between two electrodes was taken (bipolar referencing method). The electrodes were connected directly to the Traumschreiber via male plugs.

[1] `https://www.easycap.de`

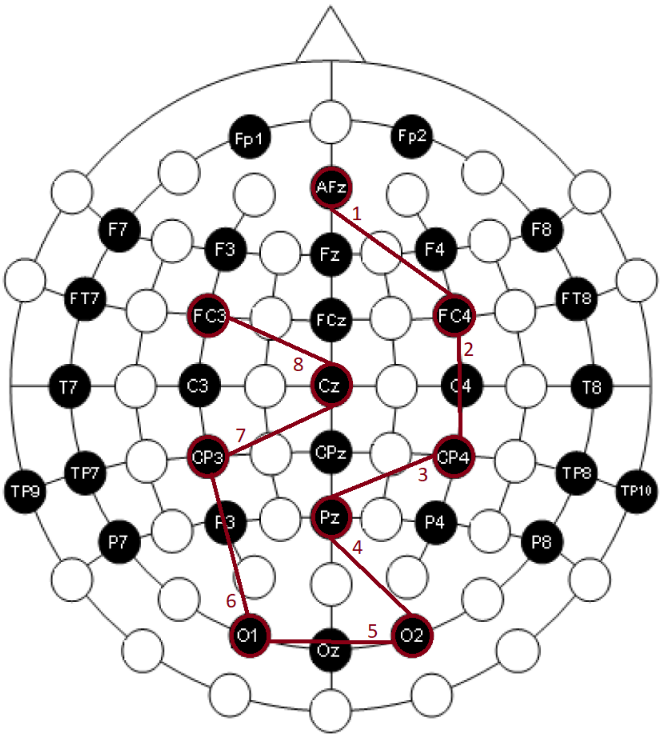

Figure 2: The red circles indicate the used electrodes and the numbers the number of the channel. A channel is always between two electrodes (bipolar referencing). Adapted from: `http://www.fieldtriptoolbox.org/template/layout`

The placements of the electrodes were chosen in regard to the location of the potentials to be measured.

The channels were between AFz and FC4 (channel 1), FC4 and CP4 (channel 2), CP4 and Pz (channel 3), Pz and O2 (channel 4), O2 and O1 (channel 5), O1 and CP3 (channel 6), CP3 and Cz (channel 7), and Cz and FC3 (channel 8). An electrode placed at TP10 was recorded as a ground electrode.

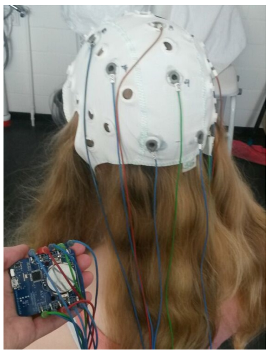

Figure 3: A cap with electrodes.

For subject 3 the electrodes were connected in a wrong order (AFz - FC3 - CP3 - Pz - O1 - O2 - CP4 - Cz - FC4) because the used cap was mislabeled, leading to a different rereferencing in the analysis (see section 2.4), to make the data comparable.

To know if the connections between electrodes and the scalp were sufficiently good a live plot (see figure 9) was used. The connections were improved to get the signal as clean as possible, with a time limit of about half an hour. To establish a good connection the scalp was cleaned below the electrodes with alcohol to remove oils and then a conductive electrode gel was used for connecting the electrode with the skin.

The Traumschreiber was placed behind the back of the participant's chair in a small cotton bag. The participant was placed in front of the left monitor. The door of the smaller room was closed during the experiment to avoid disturbances.

The Traumschreiber's gain for the recordings was set to one, even though the Traumschreiber would be able to work with a gain up to 64.

Signals sent from the Traumschreiber via bluetooth were recorded with a bluetooth capable laptop (Lenovo IdeaPad U330 Touch with Ubuntu 18.04.1 LTS). This laptop was also used to start the experiment from the bigger room, while the participant was in the smaller room.

2.3. Design

The whole experiment consisted of six different paradigms which were used several times for each participant in a random order. The order was determined beforehand by random shuffling. In the middle of the experiment, there was a break in which the room was vented. Before each paradigm, the subjects could choose to wait before starting the next one. The whole experiment took about an hour without preparation of the subjects.

The code for running experiments and recording with the Traumschreiber was provided by Johannes Leugering. The paradigms for the experiment were programmed by Ann-Kathrin Schalkamp (steady state evoked potentials, motor response and N240) and Merle Reimann (auditory evoked potentials, visual mismatch negativity and P300). The experiment was run together by Ann-Kathrin Schalkamp and Merle Reimann, with an equal amount of workload.

2.3.1. Paradigm: Auditory evoked potentials

For AEPs a tone with a length of 200 ms was presented, followed by at least 400 ms of silence. In total the tone was presented 125 times. After that, noise was played 125 times for 400 ms, followed by at least 200 ms of silence. Each block, consisting of a total of 250 stimuli, was presented four times per subject. The screen was turned black during the task and the subjects were instructed to keep their eyes closed. For this paradigm a problem occurred because the Traumschreiber works with pygame[2], which was not able to time the stimuli and pauses exactly. This led to an irregular presentation of the stimuli during the experiments.

2.3.2. Paradigm: Steady state evoked potentials

The paradigm for steady state evoked potentials (SSVEPs) consisted of a chessboard, which alternated the black and white fields in a 12Hz frequency, in front of a gray background. In the middle of the chessboard was a gray cross, which the subjects should keep in their focus. Each block had a total number of 300 alternations and the block was run four times in total.

[2]https://www.pygame.org

2.3.3. Paradigm: Motor response

For the motor response task the subjects were asked to press the arrow down key in a one second rhythm for 90 times (1.5 minutes, if done correctly), while keeping their eyes closed. In the beginning the subjects heard ten beeps in the one second rhythm. They could use them as orientation for the rhythm of their key presses. But even if the subjects started pressing along with the beeps the recording just started after the beeps stopped. In total three blocks were recorded for the motor response.

2.3.4. Paradigm: Visual mismatch negativity

Visual mismatch negativity was measured by using an oddball paradigm consisting of 150 stimuli. A red circle was the "normal" stimulus, while a yellow circle functioned as the oddball. Each stimulus was shown for 250 ms in front of a gray background, followed by a pause of random length (620 ms to 820 ms). The circles were presented in a rate of 4:1 and between each oddball was a minimum of one standard stimulus and a maximum of eight standard stimuli. The subjects did not need to react to the stimuli, but were told to stay focused. The paradigm for vMMN was used four times per participant.

2.3.5. Paradigm: N240

To evoke an N240 potential four different German color words were shown to the subject for 280 ms. There were *Rot* (red), *Gelb* (yellow), *Grün* (green) and *Blau* (blue), written in black letters on gray background. The pause between the stimuli was programmed to be one second, but irregularities occurred here as well. The participants were asked to press the arrow down key whenever *Rot* appeared. The color words appeared in a random order but each stimulus showed exactly 30 times, which lead to a total of 120 stimuli per block. For each participant there were four blocks.

2.3.6. Paradigm: P300

The paradigm for P300 was also an oddball paradigm, but with X and O as stimuli. Both were presented in black font in front of a white background and X was used as the oddball. The ratio between the standard stimulus O and the deviant X was 9:1 and between two deviant stimuli a minimum of one and a maximum of eighteen standard stimuli was shown. The stimuli should show for 280 ms with a 720 ms pause, but because of the same irregularities mentioned for AEPs the time of the pause varied. In total there were three blocks per participant with 150 stimuli each.

2.4. Analysis

For the analysis of P300, vMMN and AEPs the data were epoched and the relevant time windows were selected. For P300 a window from 0 ms to 800 ms, for vMMN from 0 ms to 400 ms and for AEPs from 0 ms to 250 ms after the stimulus onset was selected.

All trials of the selected data were rereferenced. For P300 and vMMN electrode O2 was chosen as a reference electrode (see figure 4), for AEPs electrode Pz. The reference electrodes were chosen because the channels between those reference electrodes and the other electrodes cover most of the areas where the potential, evoked by the paradigm, is originating. This choice leads to the highest number of channels which show the component of interest. Normally, electrodes not lying near the origin are chosen as references (Luck, 2014).

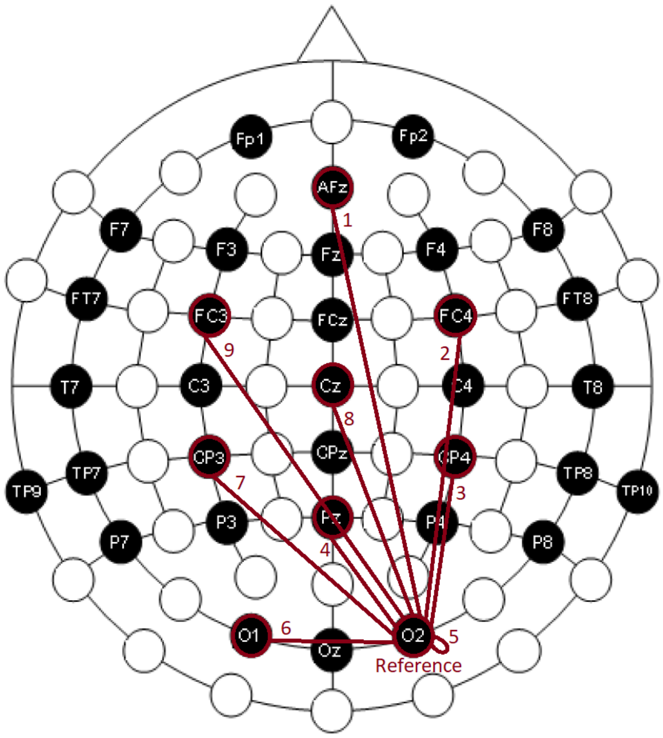

Figure 4: The channels after rereferencing with O2 as a reference, as it was for P300 and vMMN. Adapted from: `http://www.fieldtriptoolbox.org/template/layout`

But the Traumschreiber has only eight channels, far less than most EEG systems, and therefore it is important that the component is visible in most of the channels. If the other EEG systems show the component in half of the channels it is still more often, than if the Traumschreiber shows it in all of its available channels. Another negative aspect of reference electrodes further away is that the noise is added up between the electrodes. Subject 3 needed to be rereferenced separately because the electrodes were connected in a different order (AFz - FC3 - CP3 - Pz - O1 - O2 - CP4 - Cz - FC4). After the rereferencing step the channels were the same for subject 3 and the other subjects.

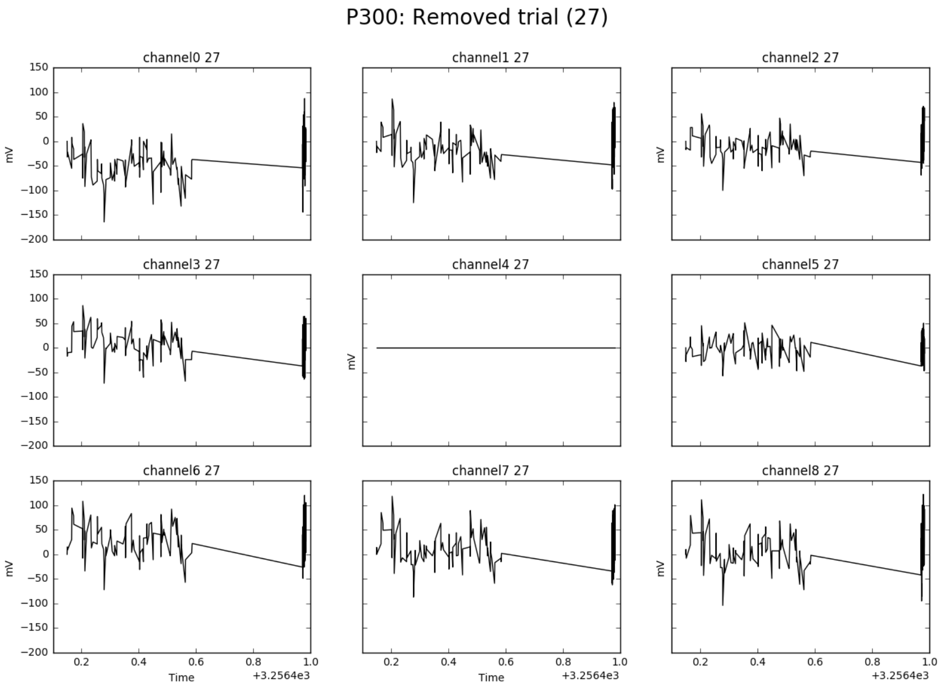

Figure 5: Example of a removed artifact.

Baseline correction was done on the rereferenced data. By doing baseline correction, each chunk starts with a voltage of zero and therefore averaging is not influenced by different offsets. This is done by subtracting the first value of an epoch form all other values.

Artifacts were removed by hand after inspection of the rereferenced and baseline corrected data. The most commonly found artifacts in the relevant intervals were drifts or flat lines, induced by irregular timestamps set by the Traumschreiber (see figure 5).

After these preprocessing steps the different ERPs were obtained by averaging over each subject and once over all subjects. The ERPs were then plotted for each channel.

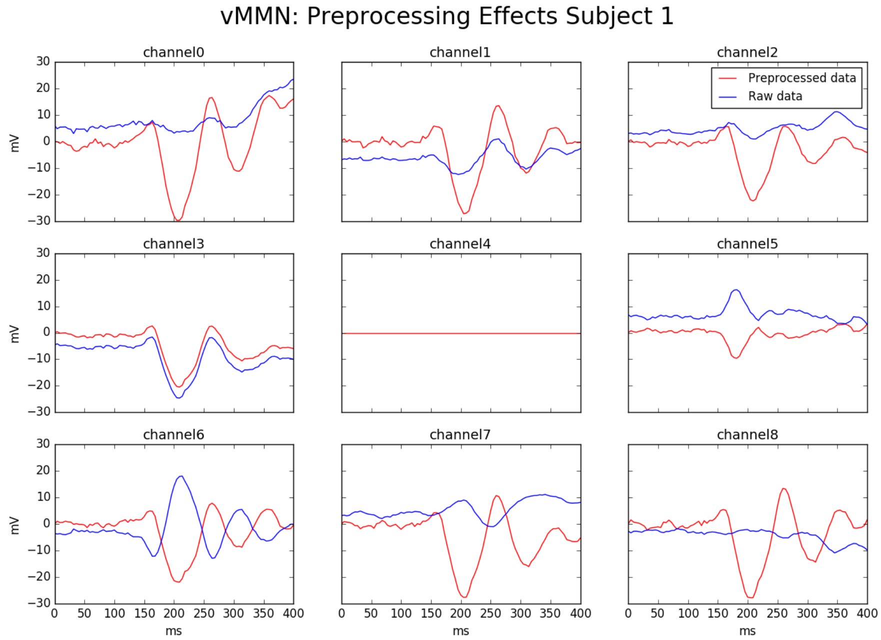

Figure 6: The average of preprocessed vMMN data (red line) in comparison to the average of raw vMMN data (blue line) for each of the eight channels.

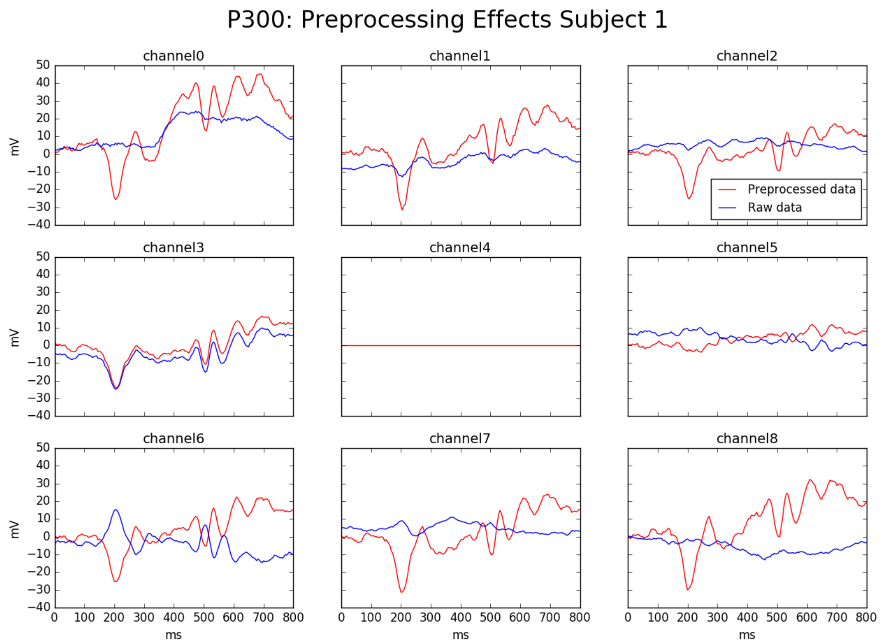

Figure 7: The average of preprocessed P300 data (red line) in comparison to the average of raw P300 data (blue line) for each of the eight channels.

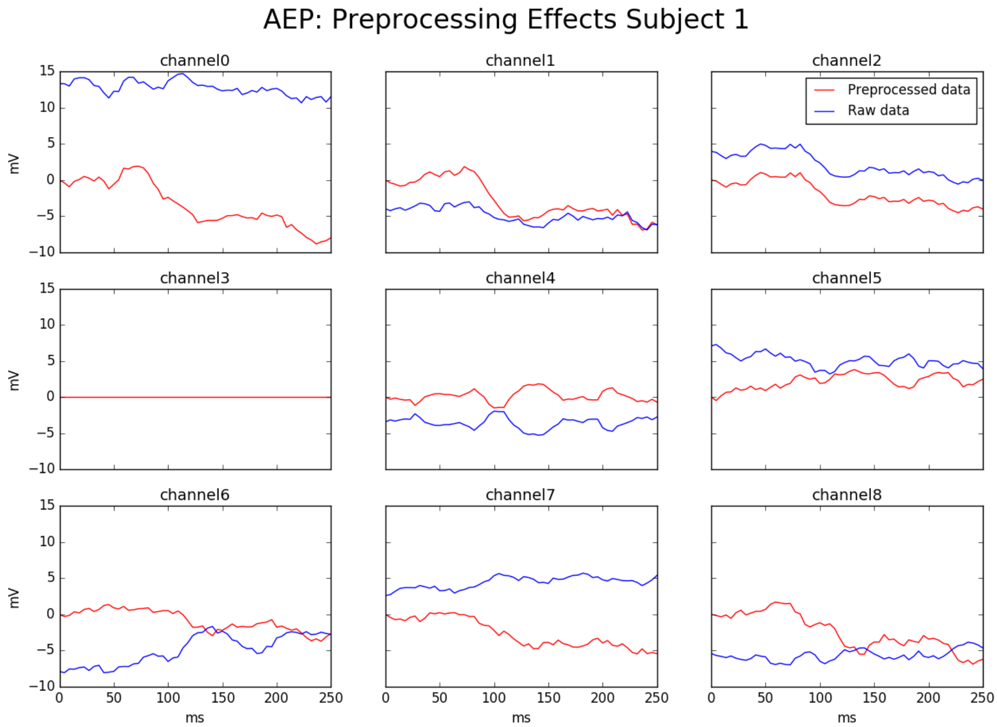

Figure 8: The average of preprocessed AEP data (red line) in comparison to the average of raw AEP data (blue line) for each of the eight channels.

There was no need for filters or further preprocessing steps to make the ERPs easier detectable. The effects of preprocessing can be seen in the plots 6, 7 and 8 for the three paradigms. For vMMN and P300 the preprocessing had more impact on the data than for AEPs. Rereferencing made the components of P300 and vMMN more visible (see figure 6 and figure 7). For AEPs the biggest difference between the raw data and the preprocessed data was induced by the baseline correction (see figure 8).

3. Results

There were two different aspects the EEG study with the Traumschreiber should reveal. On one hand the obtained data quality should be analyzed, to see if the Traumschreiber is able to measure ERPs. On the other hand the usability of the Traumschreiber played a role in the evaluation of the study. A closer look will be taken at both aspects in the following sections.

3.1. Recording with the Traumschreiber

Recording with the Traumschreiber is not complicated. The Traumschreiber itself is lightweight and because of its size easy to handle. It works with just eight channels, and always uses the neighbor electrode as a reference. Therefore a total number of nine electrodes needs to be connected to the participant, plus one additional ground electrode. This makes the preparation process faster and easier than for EEG systems with more channels.

For this experiment an EASYCAP was used. It would also be possible to do the experiments with other caps, if they had the right connectors for the electrodes. The electrodes were connected directly to the EASYCAP and the Traumschreiber. The cap had the problem that it was not always at all points close to the head. Especially for O1 and O2 it was hard to establish a good connection for some participants. Another problem that occurred with the cap was that it shifted backwards while applying the gel. Because of that, the placement of the cap was controlled several times during the preparation phase, so that it could be corrected before shifting too far. In general this could have been a problem, if electrodes had shifted to the former place of another electrode. In that case, gel bridges would have been established. Gel bridges have the effect that the data measured from two electrodes (connected by the bridge) are exactly the same. But for this study the electrodes were placed quite far away from each other, reducing the chance of gel bridges.

Another problem while preparing the subject was that there was no possibility to check the impedances directly, as it is done with standard EEG systems. Instead, a live plot was used (see figure 9), which plotted the voltage of each channel. The connections were improved until the noise, which could be seen in the plot, was reduced to a minimal level. Another test was seeing whether alpha waves were visible when the subjects closed their eyes. Alpha waves appear when the subject is really relaxed or tired. For subject 6 the latter test failed, but the subject reported to be not tired at all and therefore was admitted as well.

During the recording the Traumschreiber was placed at the back of the participant's chair and did not distract or impair the subjects during the recording.

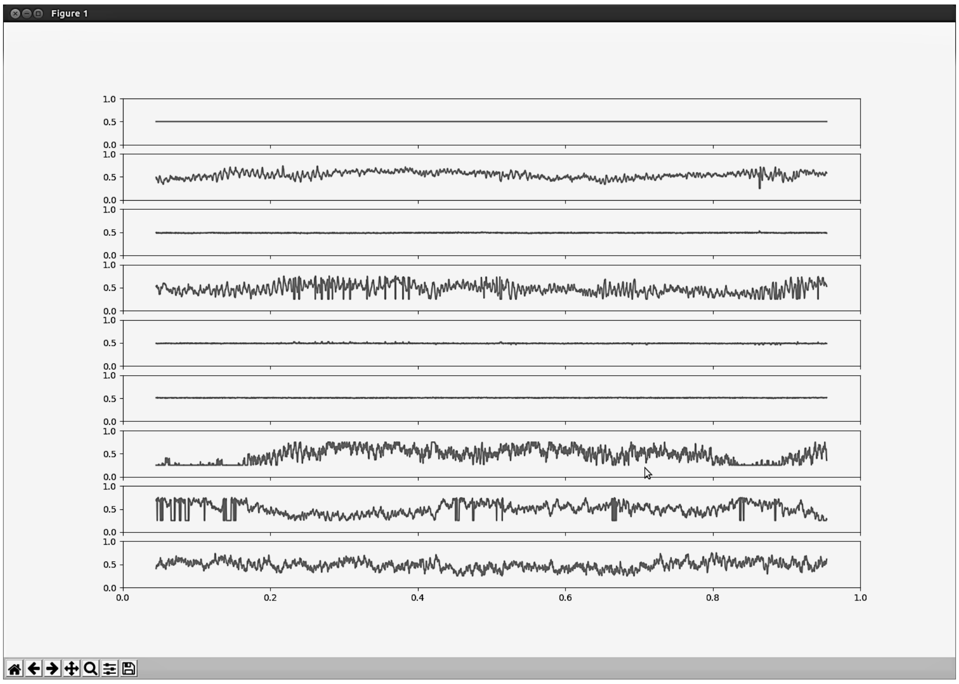

Figure 9: An excerpt from a live plot during the preparation phase. The channels looking like flat lines need to be improved by lowering the impedances.

No subject complained about anything regarding the Traumschreiber, but some criticized the brightness of the screen during the P300 task.

During the experiments a warning ("Warning: Root exception cursor not defined") occurred for subject 3 (third time N240), subject 4 (third time N240), subject 7 (third time N240) and subject 8 (second time P300). For the second P300 block of subject 6 there were, for some unknown reason, fewer timestamps between the stimuli. The trials with less than 177 data points between the events were removed during the analysis of P300because these were needed to see the whole component.

The timestamps lead to some problems in general. In theory, the Traumschreiber should sample at a rate of 250 data points per second, but in reality it is about 220 data points. The data points were recorded irregularly and sent in blocks of different sizes due to bluetooth buffering. This problem occurred for all three analyzed paradigms. Examples from the three paradigms can be seen in figure 10, figure 38 and figure 57. When having a look at the sampling rate, it became obvious that there were big differences. One time the sampling rate dropped down to seventeen data points per second. Therefore trials with a too low sampling rate were excluded.

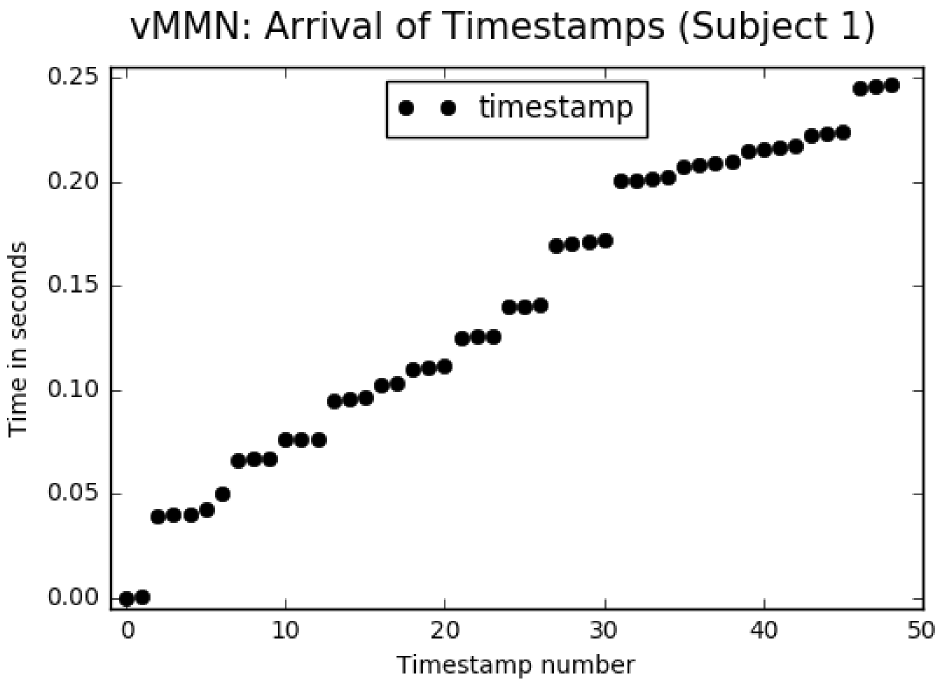

Figure 10: Example of irregularly arriving timestamps during the vMMN task. Here taken from the first trial of subject 1.

For the analysis it was required to work with the data as if the timestamps arrived regularly, to be able to average over several trials. This method of dealing with the irregular timestamps can increase inaccuracies. Especially for components with a short latency, it can easily happen that the component gets averaged out, when they do not align for the new timestamps.

Establishing a connection between the laptop and the Traumschreiber took some time. Together with the time needed for starting the next block, it resulted in a waiting period of some seconds for the participants. A positive aspect was that the Traumschreiber was able to keep the connection, even though it was in a different room as the laptop.

After recording subject 9 it was recognized that the on-off-switch had fallen off during the experiment. This problem occurred also in previous studies (Appel, 2017). Testing the Traumschreiber after the experiment revealed that the Traumschreiber was still turned on but had some problems recording data. The data recorded for subject 9 look quite normal, which could be a sign that the switch fell off at the end of the experiment, while removing the Traumschreiber from the cotton bag.

The Traumschreiber works with a battery, which needs to be charged after conducting an experiment. A problem with this was that the Traumschreiber does not indicate when a battery is fully charged. Because of this uncertainty, the battery was changed for each participant after adjusting the impedances with the live plot to a charged one. By doing this, an empty battery during the experiment could be avoided.

A summary of the advantages and disadvantages of working with the Traumschreiber system can be found in table 1.

Advantages of the Traumschreiber	Disadvantages of the Traumschreiber
low-cost	no impedance check
mobile	irregular timestamps
easy to work with	switch falls off easily
connection via bluetooth (no cables needed)	no information about battery charge
easy preparation (just ten electrodes)	needs some time to find connection
works even with a low gain	sometimes loses the connection
does not disturb the subject	cap for the Traumschreiber is bad
capable of more than just EEG	differing sampling rates

Table 1: Advantages and disadvantages of the Traumschreiber

3.2. EEG data quality

	vMMN	**P300**	**AEP**
Subj 1	clearly visible	clearly visible (+ vMMN)	slightly visible (for tone trials)
Subj 2	clearly visible	small positive deflection (noisy, + vMMN)	visible (best for channel 2)
Subj 3	visible (+ begin of P300)	clearly visible (also for standard trials)	clearly visible (better for tones)
Subj 4	clearly visible	visible (noisy, small latency, + vMMN)	clearly visible
Subj 5	clearly visible (greater for standard trials)	not visible (noisy, + vMMN)	clearly visible
Subj 6	visible (greater for standard trials)	clearly visible (+ vMMN)	slightly visible (for channel 8)
Subj 7	clearly visible	visible (channel 1, 6, 7 & 8, + vMMN)	slightly visible (for noise trials, strong alpha waves)
Subj 8	clearly visible (230 ms after stimulus) +	slightly visible (noisy, + vMMN)	clearly visible (for tone & noise)
Subj 9	clearly visible	not visible (noisy, + vMMN)	not visible (some alpha waves)

Table 2: Visibility of the components for each subject

A good EEG system has to be able to provide results of high quality. The data should not contain much noise, and evoked ERPs should be visible.

Therefore the Traumschreiber needs to provide good data quality in addition to ease of use to compete with other EEG systems. Most plots of the Traumschreiber's data look smooth, even though everything was recorded with a gain of one. There is some noise, but in the majority of cases the ERP could be seen without problems. Table 2 was created after visual inspection and displays how good each component could be seen for each subject. The corresponding plots for each entry can be found in the appendix (section B, C, D). In general it is possible to record data with the Traumschreiber clean enough to see the components of different ERPs.

3.2.1. Results: vMMN

Visual mismatch negativity can be seen after the occurrence of an unlikely stimulus. In this study red and yellow circles were presented to the subject with different probabilities. The yellow circle worked as the oddball, which should be followed by a vMMN response. To see if there was a response, the average of the oddball trials in a 400 ms interval after the stimulus was plotted against the standard trial intervals. In figure 11, the typical negative deflection between 120-200 ms after the stimulus can be seen in the Traumschreiber's EEG data.

But the deflection cannot only be seen in the data oddball trial plot, but also in the standard trial plot. This could bebecause the paradigm for vMMN had different pause lengths between the stimuli. Irregular presentation of one stimulus (in this case the standard stimulus) can also lead to a vMMN response (Czigler, Winkler, et al., 2006).

When plotting the grand average of the preprocessed vMMN data (see figure 12) a negative deflection, which peaks around 200 ms after the stimulus onset, can be seen clearly. This suggests that the Traumschreiber is able to record vMMN.

A confound in the data can be found around 250 ms in the interval. At this time the stimulus was offset, leading to a positive peak, which then influenced the amplitude and latency of the ERP in the plot.

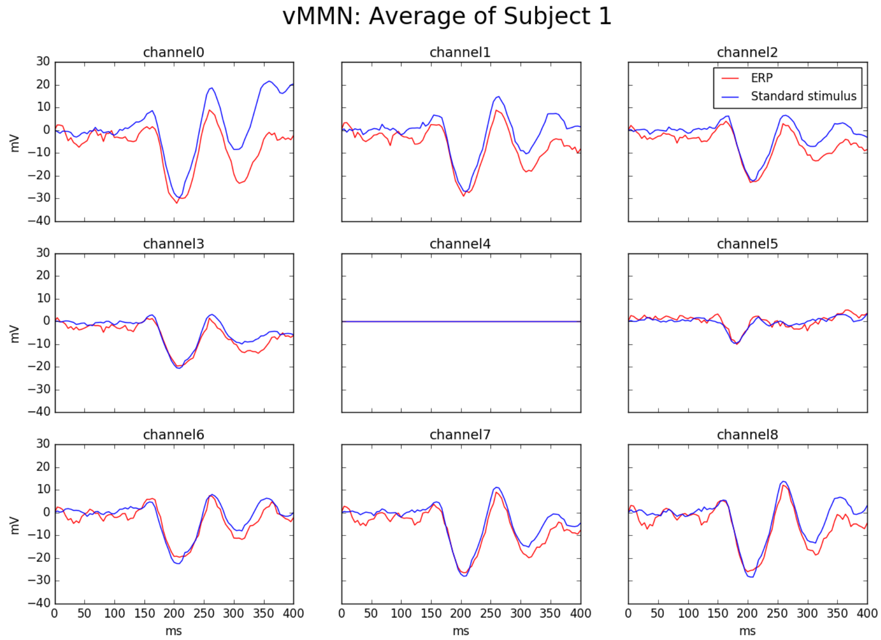

Figure 11: Comparison between the reaction to oddball trials (red line) and to standard trials (blue line) of the vMMN experiment for subject 1 for each channel.

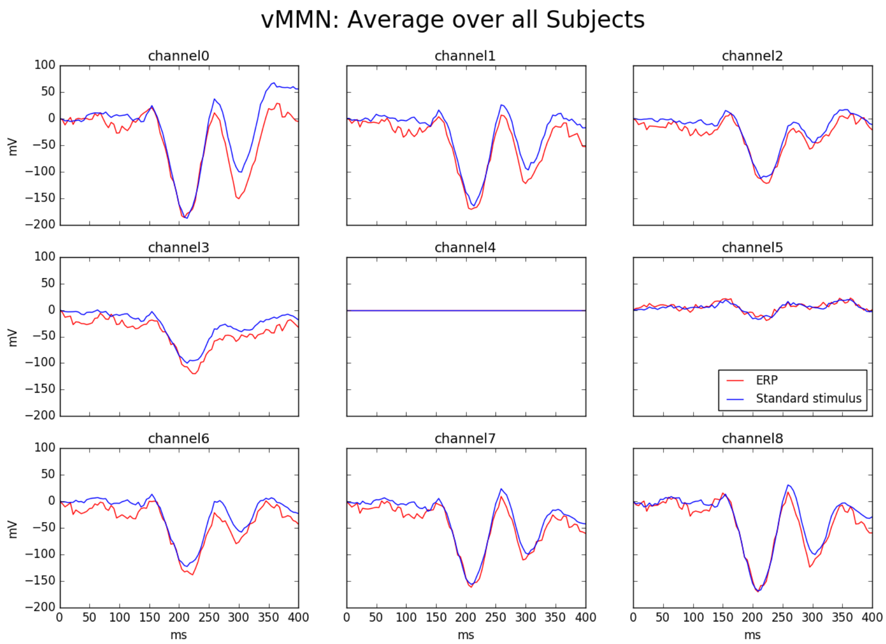

Figure 12: Comparison between the reaction to oddball trials (red line) and to standard trials (blue line) of the vMMN experiment averaged over all subjects.

3.2.2. Results: P300

P300 also occurs after an unlikely stimulus, but only if the stimulus is attended to. In this case the subjects needed to press a button when the oddball (a black X) was shown. For the standard stimulus (a black O) no reaction was required.

The different stimuli themselves or the motor response could be thought to lead to a confound. But in the case of P300 it was found that motor responses and different stimuli do not influence the ERP directly (Luck, 2014). But a confound that can actually be seen is the stimulus offset for the individual subjects (see figure 13) and in the grand average (see figure 14). The stimulus offset is 280 ms after the stimulus onset, which is at 0 ms. As the plot shows, the offset of the stimulus leads to a peak with a relatively short latency and small amplitude around 280-300 ms after the onset.

The P300 component can be seen after 300 ms, with a maximum peak of 80 mV after 700 ms. For subject 1 (figure 13) the difference between the standard stimulus trials and the oddball trials is clearly visible. In the grand average the difference is barely noticeable. The same problem as the one which occurred for vMMN, could be made accountable for the missing difference.

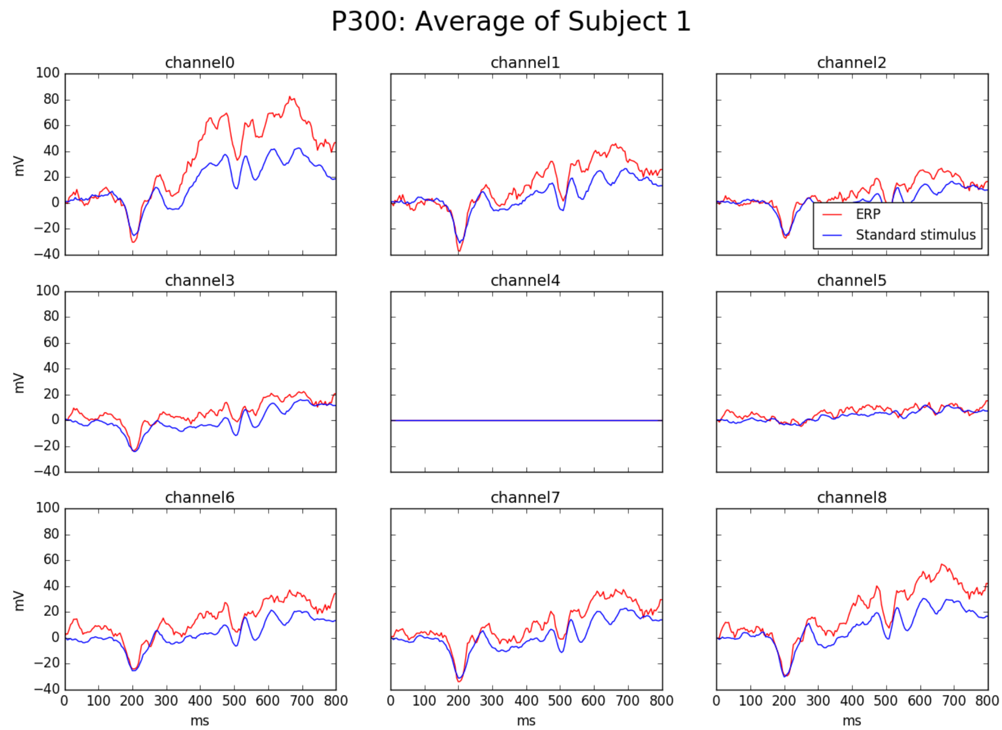

Figure 13: Comparison between the reaction to oddball trials (red line) of the P300 experiment and the reaction to standard trials (blue line) of the P300 experiment for subject 1 for each channel.

The plots made from the data of P300 do not only show P300, but also vMMN. The negative deflection can be seen shortly before 200 ms are reached. This result is quite expectablebecause both ERPs are evoked by an oddball paradigm. For the oddball paradigm of P300, it becomes visible that the negative deflection of vMMN is stronger for deviant, than for standard stimuli. That this result could be accomplished by the paradigm for P300 and not to this extent by the vMMN paradigm, can have its reason in the probabilities of the oddballs. In the vMMN paradigm, on average every fifth stimulus was an oddball, while it was only every tenth stimulus for P300. Therefore this result is not surprising.

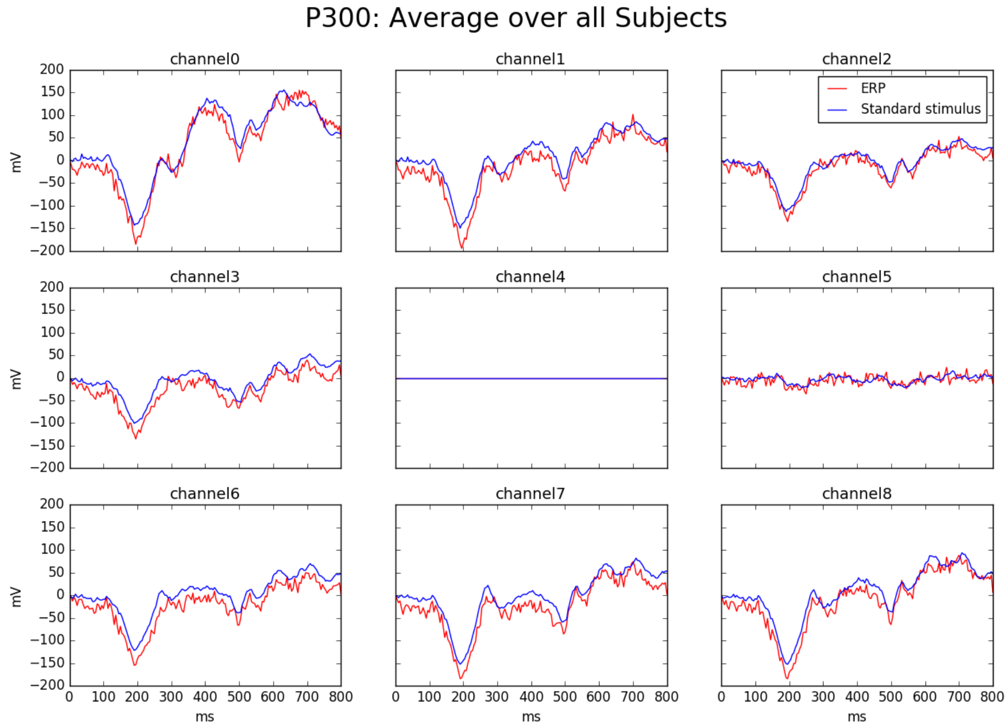

Figure 14: Comparison between the reaction to oddball trials (red line) of the P300 experiment and the reaction to standard trials (blue line) of the P300 experiment averaged over all subjects for each channel.

3.2.3. Results: AEP

AEPs consist of three parts, the early ABR, the mid- and the long-latency response. In the experiment, which served as an orientation, “[e]arly auditory components of the ERP [...] were smoothed, however, the most prominent components N1 and P2 have nearly identical forms [compared to the literature]” (Melnik et al., 2017). Because of this the focus in this study will be on the latter components as well.

For some of the subjects the EEG data were not goodbecause it showed mostly alpha waves (see figure 15). A reason for the occurrence of alpha waves for this paradigm could be that the subjects kept their eyes closed during the experiment and that they did not need to react. These factors could have led to too much relaxation of the subjects.

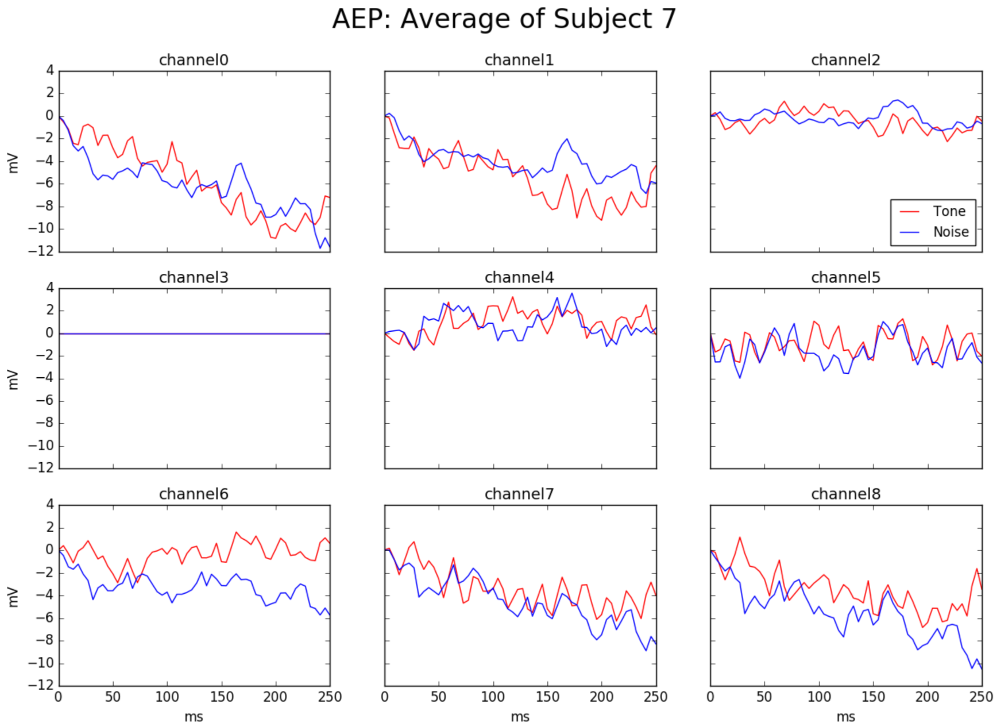

Figure 15: Clearly visible alpha waves during the tone stimulation (red line) for each channel.

But even with some of the data looking strange, the N1 and P2 component were still visible for some of the subjects (see figure 16). N1 is a negative deflection around 100 ms after the stimulus onset, while P2 is a positive deflection after about 200 ms. Both components can be clearly seen in the data of subject 1 as a reaction to the auditory stimulation with a tone.

In the average over all subjects (see figure 17) the components are much smaller. This is due to the data of the subjects where the components were not visible (see table 2) which was also used for the average. But when taking a closer look, the deflections can still be seen for some channels, even though the amplitudes are reduced.

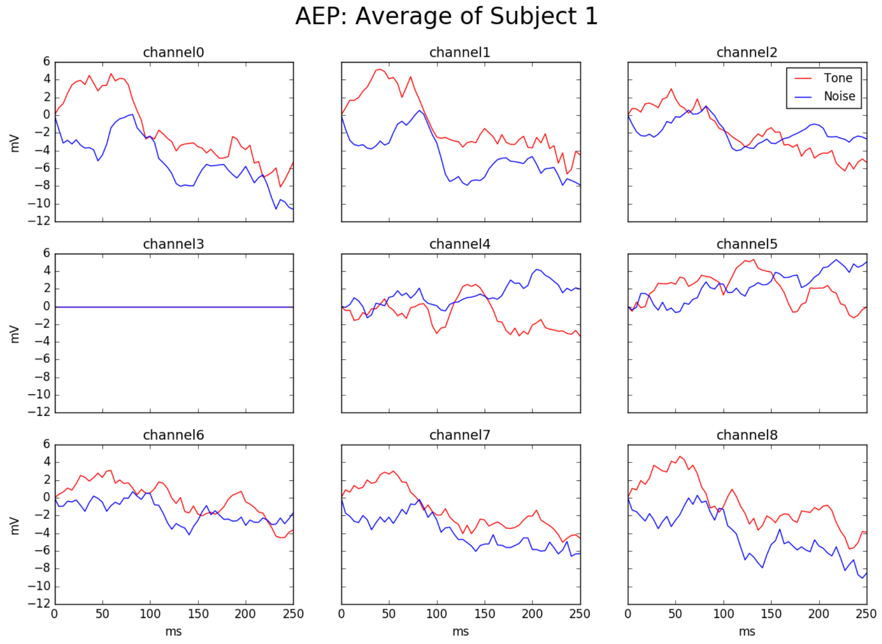

Figure 16: Comparison between the reaction to tone (red line) and to noise trials (blue line) of the AEP experiment for subject 1 for each channel.

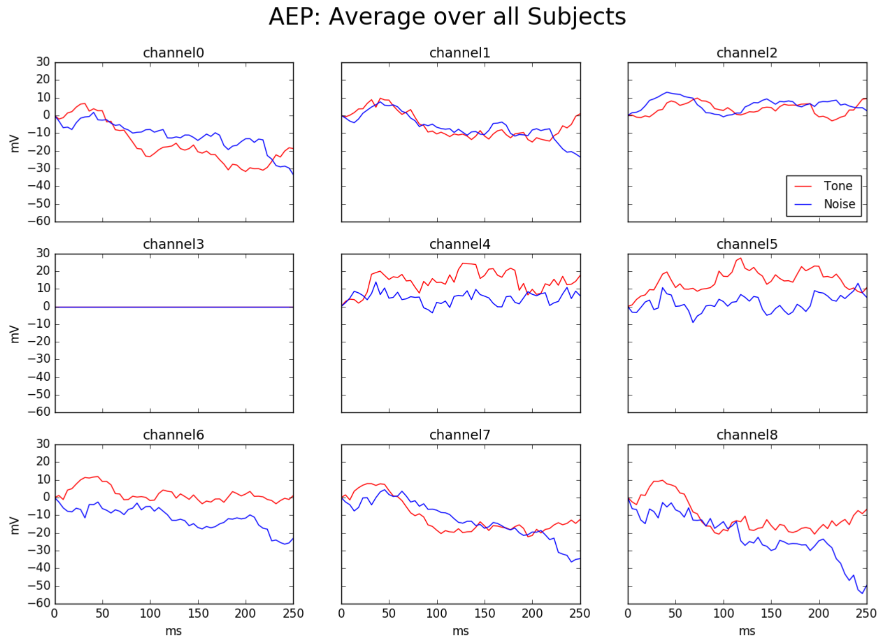

Figure 17: Comparison between the reaction to tone (red line) and to noise trials (blue line) of the AEP experiment averaged over all subjects for each channel.

4. Discussion

The whole study aimed at finding out, whether the Traumschreiber can not only be used for polysomnic, but also for pure EEG experiments (see section 1.3). Therefore the experiment was conducted, as if it was already known to work, so that the results would be directly comparable to other EEG studies. The results were presented in the section above (section 3). Now a closer look shall be taken at the meaning of the outcome. The general usage as an EEG system will be considered as well as possible improvements which are still needed.

4.1. The Traumschreiber as an EEG system

The Traumschreiber has all the advantages a mobile EEG system should have: it is small, lightweight and portable. In its current state it still needs some improvements (see section 4.2), however it already works quite good.

For EEG studies it is often recommended to measure as many channels as possible (Luck, 2014). The reasoning behind this approach is that it is not as problematic as it would be with less channels, if one channel fails to record correctly. Hence it leads to a greater amount of usable data, which is desirable. Now the Traumschreiber is measuring just eight channels, which is compared to systems with 128 channels not much. But as it can be seen in the study conducted for this thesis, eight channels suffice for making components in EEG data visible. But this only works for well-studied components because the origin needs to be known. It does not seem necessary to have a high number of channels, if the data of standard EEG experiments are analyzed for extracting single components. The recognition of components is one of the main things done with EEG data meaning that the Traumschreiber could be used for most EEG experiments, as long as no localization is aspired.

It can be useful to apply filters to the EEG data, to get rid of artifacts. This is especially useful if the data are not averaged. During this study a look was only taken at averaged data to identify components. Therefore it was decided against using special filters for ruling out high or low frequencies. Even though this approach was chosen, the Traumschreiber's results were good, showing that the Traumschreiber's recordings do not depend on filters to work properly.

4.2. Further improvements

Even though it generally worked to record EEG data with the Traumschreiber there are still some improvements needed. The improvements do not only concern the Traumschreiber, but also the experiment and the code written for it. This section is aimed at suggesting improvements for the Traumschreiber, and differences in design for an experiment building up on this work.

The Traumschreiber itself is currently in development, and one of the needed improvements is an improvement of the design. For example a cover would prevent accidental damage to the Traumschreiber under normal use. The Traumschreiber would also greatly benefit from improvements of the electrode connections. Right now, one has to fear that they will fall off if the Traumschreiber is not held upright. Another important point when talking about the design of the Traumschreiber is the switch. It was already known that the switch can fall off (Appel, 2017) and it happened once more in this experiment. After the switch had fallen off the Traumschreiber did not work properly, even if it was still switched on. Therefore it would be necessary for it to have a switch which is not susceptible to falling off, if the Traumschreiber should be used for research.

Another thing impairing the analysis is the sampling rate of the Traumschreiber. Originally the Traumschreiber should have a sampling rate of 250, but in reality it is closer to 220. This is inconvenient, but not really problematic. The problem with the sampling rate becomes visible, when one looks at the gaps between each timestamp. The gaps differ between all timestamps, meaning that the Traumschreiber samples irregularly (see figure 10). Irregularities in the distance of the timestamps makes the analysis much more complicated. They demand to find a solution on how to average over several trials, if these trials have completely different timestamp intervals. It sounds like a good solution to just average over short time intervals of each trial so that all trials have the same time intervals afterwards. But this is not possiblebecause the intervals would need to have a length of over 50 ms if each interval should contain at least one timestamps. Interval lengths of 50 ms would mean that for AEPs the average over many trials would contain just five averaged data points which is simply insufficient. Another solution, which was used for the analysis of this experiment, is that the timestamps are assumed to arrive regularly, even though they do not. This solution is prone to inaccuracies, due to the fact that components with a short latency are likely to get averaged out and bigger components will appear with a longer latency but lower amplitude. Even though it bears some disadvantages this solution was the best among the given alternatives. But for future experiments it would be necessary to have a regular sampling rate to ensure high quality data.

The experiment itself could have been better in some aspects. First of all, the used equipment was not optimal. The electrodes were old and oxidized, even though they were cleaned before being used. In advance to the experiments all electrodes which did not work were sorted out, leaving just sixteen working ones remaining. For this study the number of electrodes was sufficientbecause the Traumschreiber can only measure ten electrodes. Switching the electrodes to other, newer ones was not possible since the Traumschreiber only works with electrodes which have male plugs and the used electrodes were the only ones available in the laboratory to meet this requirement.

The cap had some problems as well (see section 3.1). It was used neverthelessbecause it was the only cap in the laboratory fitting together with the electrodes.

Everything of the experiment was run on a laptop and then transmitted to the displays in the room via a HDMI-cable. Normally experiments in the NBP laboratory are run on the computers which are available in the bigger room. But these computers use an old version of Python (2.7) which is not compatible with the Traumschreiber's code, which was written in Python 3.6.

The code which was used to run the experiment in general had some problems with the timing. A function called "blocking_sleep" should time the pauses exactly. It uses another thread and does therefore in theory not interfere with the recording. In the recorded data, artifacts which were flat lines (see figure 5) could be found. This type of artifacts only occurred for the paradigms were “blocking_sleep” was used, suggesting that it sometimes did not work the way it was intended. Hence it would be good to find another possibility for exact timing, which does not influence the data quality. For another problem with the code no explanation could be found. Namely that for some, but not all, blocks of N240 and P300 there was a warning (“Warning: Root exception cursor not defined”), but as no big impact on the recorded data could be seen, the warning was disregarded.

The paradigms of the experiment were tested in advance to get to know how long they could be without affecting the subjects concentration. Even though that was done in advance it was reported by some subjects that some of the paradigms seemed quite long and a bit boring. The effect of it can be seen for the auditory task, where alpha waves could be seen clearly for some subjects (for one example see figure 15). Some trials of subject 3 showed alpha waves for the vMMN task, but these were averaged out.

Another inconvenience was reported for the P300 paradigm. The stimuli were presented in black in front of a white background, which was perceived as too bright by some subjects.

The waiting time between the blocks was longer than it was wanted, but since it proved impossible to concatenate the blocks with the existing code base in such a manner that they do not need to be started separately it was unavoidable. The different problems with the code suggest that it is not the best solution to run experiments with the Traumschreiber using pygame. Therefore, a new code base for experiments with the Traumschreiber should be created independently of pygame, with exact timing mechanisms and the ability to create and concatenate different blocks.

5. Conclusion

The aim of the study was to investigate, whether the Traumschreiber can measure EEG sufficiently good. This was done by conducting an EEG study with some standard paradigms and then comparing the results to what was expected. The paradigms which were analyzed as part of this thesis evoke vMMN, P300 and AEPs. The expected components could be seen best for vMMN, where the negative deflection could be seen for both oddball paradigms (vMMN and P300). The data for P300 had some flat line artifacts, but showed the expected component for most of the subjects. The auditory task produced the worst results because some subjects had a lot of alpha waves and even the larger components were not visible for all subjects. In general the results which were obtained were quite good, even though the data was not filtered and the recording was done with a gain of one. The low number of channels used for the experiment turned out to be sufficiently good as well. All these factors lead to the conclusion that the Traumschreiber can indeed be used as an EEG system, even though improvements are desirable.

In the future, the development and improvement of such mobile and low-cost systems means that EEG research would not be bound to laboratories, but could be done in nearly any environment without great inconvenience.

References

Appel, Kristoffer (2017). “The Traumschreiber System: Enabling Crowd-based, Automated, Complex, Polysomnographic Sleep and Dream Experiments”. PhD thesis. University of Osnabrueck.

Bressler, Steven L and Mingzhou Ding (2006). “Event-Related Potentials”. In: *Wiley encyclopedia of biomedical engineering*.

Corby, James C. and Bert S. Kopell (1972). “Differential Contributions of Blinks and Vertical Eye Movements as Artifacts in EEG Recording”. In: *Psychophysiology* 9.6, pp. 640–644.

Czigler, István (2007). “Visual mismatch negativity: violation of nonattended environmental regularities”. In: *Journal of Psychophysiology* 21.3-4, pp. 224–230.

Czigler, István, Júlia Weisz, and István Winkler (2006). “ERPs and deviance detection: visual mismatch negativity to repeated visual stimuli”. In: *Neuroscience letters* 401.1-2, pp. 178–182.

Czigler, István, István Winkler, et al. (2006). “Visual temporal window of integration as revealed by the visual mismatch negativity event-related potential to stimulus omissions”. In: *Brain research* 1104.1, pp. 129–140.

De Vos, Maarten et al. (2014). “P300 speller BCI with a mobile EEG system: comparison to a traditional amplifier”. In: *Journal of neural engineering* 11.3, p. 036008.

Debener, Stefan et al. (2012). “How about taking a low-cost, small, and wireless EEG for a walk?” In: *Psychophysiology* 49.11, pp. 1617–1621.

Delorme, Arnaud et al. (2015). “Grand average ERP-image plotting and statistics: A method for comparing variability in event-related single-trial EEG activities across subjects and conditions”. In: *Journal of neuroscience methods* 250, pp. 3–6.

Donchin, Emanuel and Michael GH Coles (1988). “Is the P300 component a manifestation of context updating?” In: *Behavioral and brain sciences* 11.3, pp. 357–374.

Donchin, Emanuel, Walter Ritter, W CHEYNE McCallum, et al. (1978). “Cognitive psychophysiology: The endogenous components of the ERP”. In: *Event-related brain potentials in man*, pp. 349–411.

Duncan-Johnson, Connie C and Emanuel Donchin (1982). “The P300 component of the event-related brain potential as an index of information processing”. In: *Biological psychology* 14.1-2, pp. 1–52.

Duncan, Connie C et al. (2009). “Event-related potentials in clinical research: guidelines for eliciting, recording, and quantifying mismatch negativity, P300, and N400”. In: *Clinical Neurophysiology* 120.11, pp. 1883–1908.

Fabiani, Monica et al. (1987). “Definition, identification, and reliability of measurement of the P300 component of the event-related brain potential”. In: *Advances in psychophysiology* 2.S 1, p. 78.

Ilardi, Stephen S et al. (2007). "Disentangling attentional biases and attentional deficits in depression: An event-related potential P300 analysis". In: *Cognitive Therapy and Research* 31.2, pp. 175–187.

Jackson, Alice F and Donald J Bolger (2014). "The neurophysiological bases of EEG and EEG measurement: A review for the rest of us". In: *Psychophysiology* 51.11, pp. 1061–1071.

Johnson, Ray (1993). "On the neural generators of the P300 component of the event-related potential". In: *Psychophysiology* 30.1, pp. 90–97.

Kimura, Motohiro, Jun'ichi Katayama, and Harumitsu Murohashi (2006). "Probability-independent and-dependent ERPs reflecting visual change detection". In: *Psychophysiology* 43.2, pp. 180–189.

Kimura, Motohiro, Jun'ichi Katayama, Hideki Ohira, et al. (2009). "Visual mismatch negativity: new evidence from the equiprobable paradigm". In: *Psychophysiology* 46.2, pp. 402–409.

Kimura, Motohiro, Erich Schröger, and István Czigler (2011). "Visual mismatch negativity and its importance in visual cognitive sciences". In: *Neuroreport* 22.14, pp. 669–673.

Lenartowicz, Agatha, Rafael Escobedo-Quiroz, and Jonathan D Cohen (2010). "Updating of context in working memory: an event-related potential study". In: *Cognitive, Affective, & Behavioral Neuroscience* 10.2, pp. 298–315.

Liegeois-Chauvel, C et al. (1994). "Evoked potentials recorded from the auditory cortex in man: evaluation and topography of the middle latency components". In: *Electroencephalography and Clinical Neurophysiology/Evoked Potentials Section* 92.3, pp. 204–214.

Lin, C et al. (2008). "Noninvasive neural prostheses using mobile and wireless EEG". In: *PROCEEDINGS-IEEE* 96.7, p. 1167.

Luck, Steven J (2005). "An introduction to the event-related potential technique. 2005". In: *Massachusetts: The MIT Press Google Scholar*.

– (2012). "Event-related potentials". In: *APA handbook of research methods in psychology* 1, pp. 523–546.

– (2014). *An introduction to the event-related potential technique*. MIT press.

Mandt, Laura Sophie (2017). "Conducting a Polysomnographic, Automated Auditory Stimulation Sleep Experiment Using a Portable High-Tech Sleep Mask." unpublished bachelor's thesis. University of Osnabrueck.

Melnik, Andrew et al. (2017). "Systems, subjects, sessions: to what extent do these factors influence EEG data?" In: *Frontiers in human neuroscience* 11, p. 150.

Picton, TERENCE W (1990). "Auditory evoked potentials". In: *Current practice of clinical electroencephalography*, pp. 625–678.

Polich, John (2007). "Updating P300: an integrative theory of P3a and P3b". In: *Clinical neurophysiology* 118.10, pp. 2128–2148.

Polich, John (2012). “Neuropsychology of P300”. In: *Oxford handbook of event-related potential components*, pp. 159–188.

Purves, Dale et al. (2008). *Cognitive Neuroscience*. Sunderland: Sinauer Associates, Inc.

Schalkamp, Ann-Kathrin (2018). “Analyzing event-related potentials in 8-channel EEG data using machine learning methods”. unpublished bachelor’s thesis. University of Osnabrueck.

Snyder, Elaine and Steven A Hillyard (1976). “Long-latency evoked potentials to irrelevant, deviant stimuli”. In: *Behavioral Biology* 16.3, pp. 319–331.

Stagg, Charlotte et al. (2004). “Visual mismatch negativity: the detection of stimulus change”. In: *Neuroreport* 15.4, pp. 659–663.

The Traumschreiber Project (2017). URL: `https://www.traumschreiber.uos.de/index.html` (visited on 06/08/2018).

List of Appendices

A. Consentform

Teilnahme an der Studie: Traumschreiber als EEG-System

Hiermit bestätige ich, ___________________________ geboren am ______________________, dass ich dieses Dokument vollständig gelesen und verstanden habe. Mir ist bewusst, dass die Teilnahme an der Studie freiwillig ist und jederzeit ohne nachteilige Auswirkungen, oder Nennung von Gründen abgebrochen werden kann. Mir ist bewusst, dass die Speicherung der gemessenen Daten in anonymisierter Form erfolgt und bei möglichen Veröffentlichungen keine Rückschlüsse auf meine Person möglich sind. Ich wurde informiert, dass ich jederzeit meine Einwilligung zur Speicherung und Nutzung meiner Daten entziehen kann. In diesem Fall werden die Daten unverzüglich gelöscht.

Die gesammelten Daten werden folgenden Personen zur Verfügung gestellt: Merle Reimann, Ann-Kathrin Schalkamp und der Neuroinformatik-Gruppe der Universität Osnabrück.

Ich bin damit einverstanden, dass während des Experiments Messungen mit einem Elektroenzephalogramm (EEG) gemacht werden. Dabei werden vom Gehirn erzeugte Spannungen auf der Kopfoberfläche gemessen. Ich stimme zu, dass hierzu der Traumschreiber verwendet werden darf. Der Traumschreiber wurde von Johannes Leugering und Kristoffer Appel zur Erhebung von Daten während des Schlafs entwickelt. Diese Studie soll dazu dienen herauszufinden, ob der Traumschreiber auch als mobiles EEG-System verwendet werden kann.

Ich bestätige, dass ich keine neurologischen Erkrankungen habe.

Ich bestätige, dass ich die obige Erklärung vollständig gelesen und verstanden habe und ihr zustimme. Alle eventuellen Fragen wurden von den Versuchsleiterinnen beantwortet.

Datum, Unterschrift

aschalkamp@uos.de
mereimann@uos.de

Figure 18: The form of consent for the experiment. Every subject needed to read the form and sign it to take part in the experiment, if they agreed.

B. vMMN plots

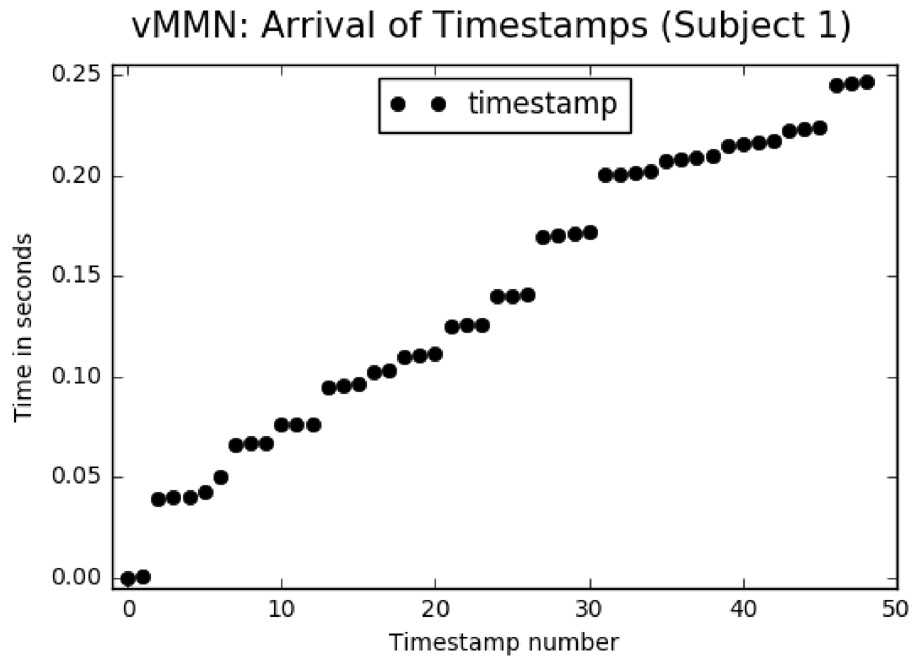

Figure 19: Example of irregularly arriving timestamps during the vMMN task. Here taken from the first trial of subject 1.

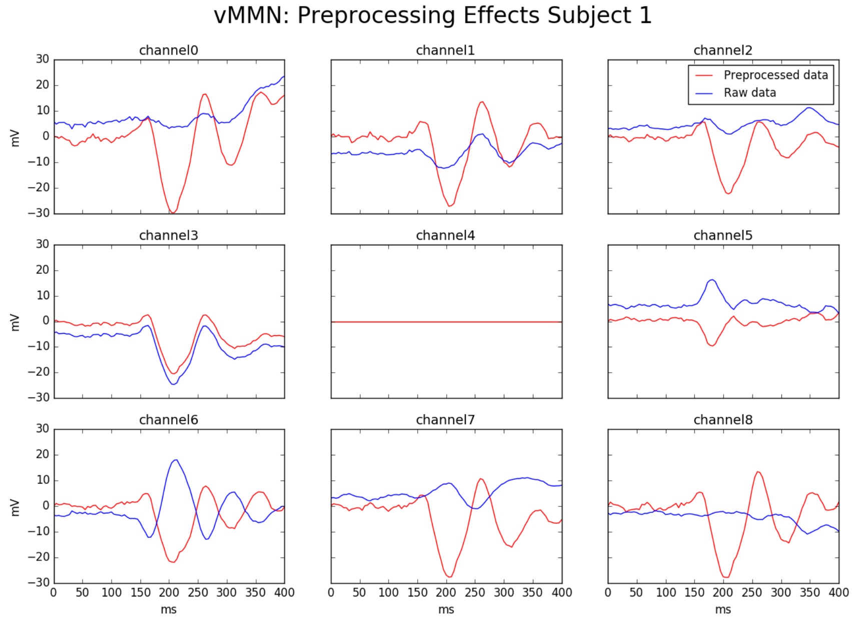

Figure 20: Effects of Preprocessing, vMMN, Subject 1

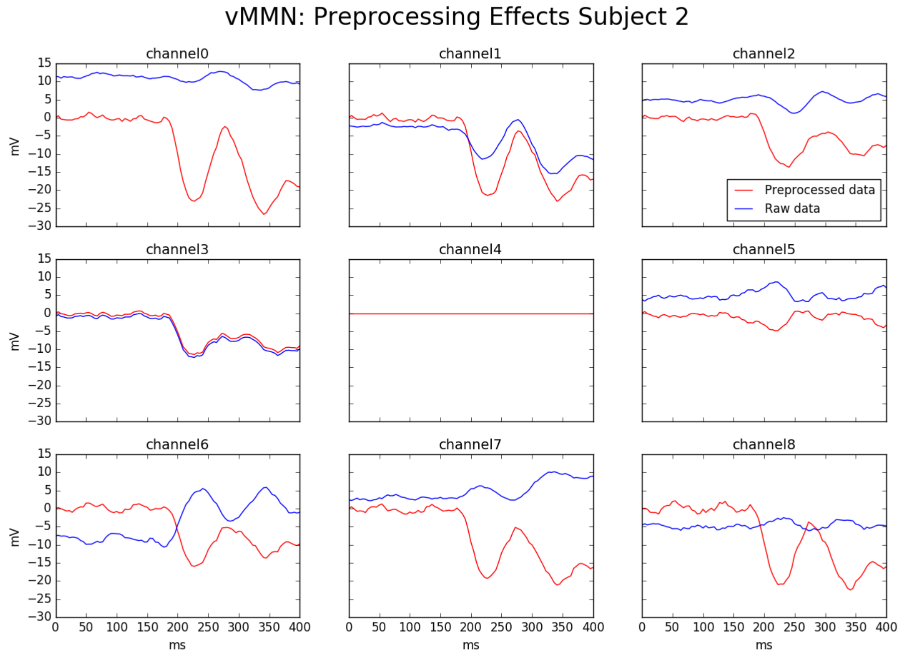

Figure 21: Effects of Preprocessing, vMMN, Subject 2

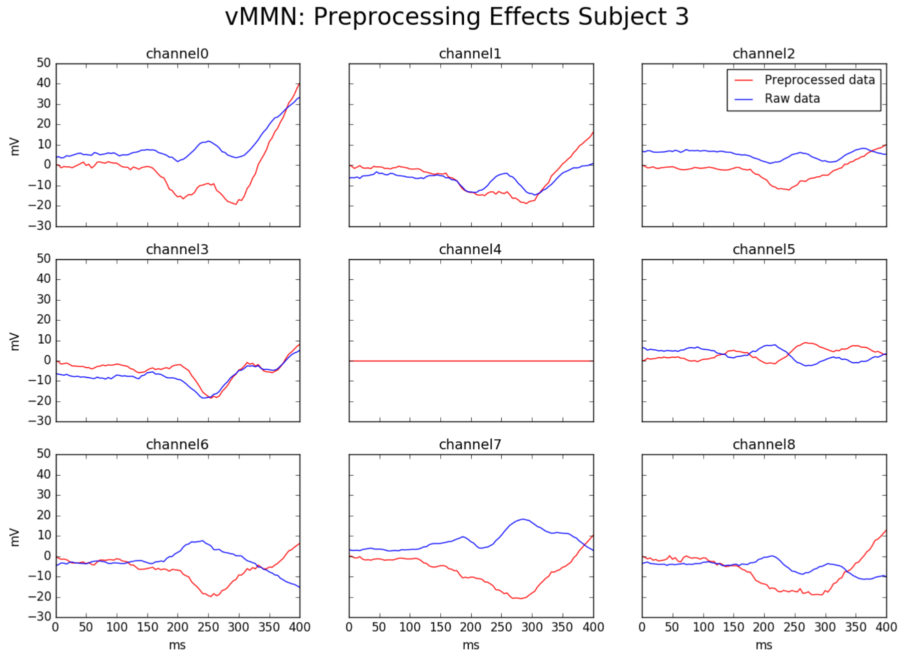

Figure 22: Effects of Preprocessing, vMMN, Subject 3

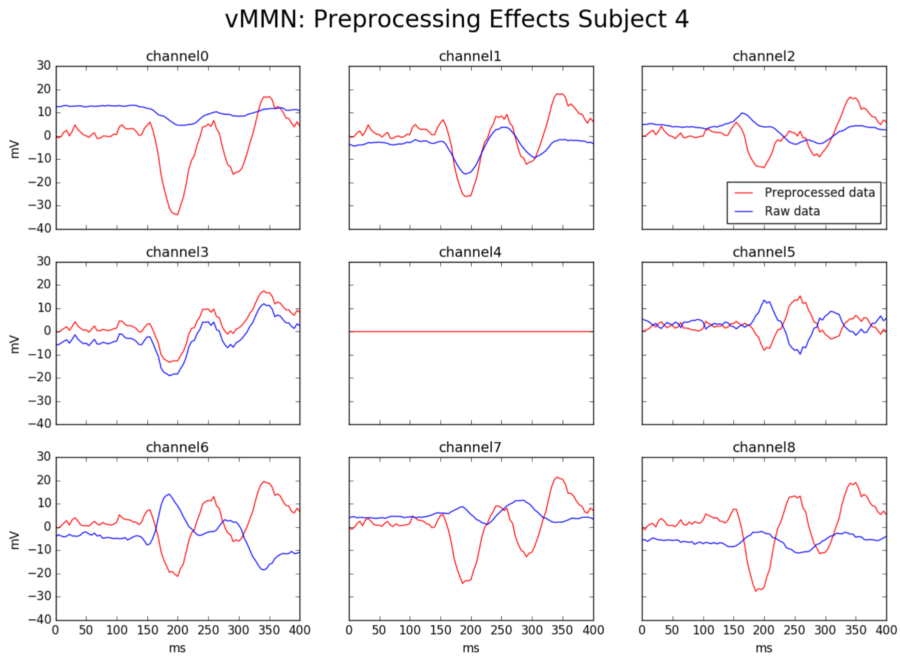

Figure 23: Effects of Preprocessing, vMMN, Subject 4

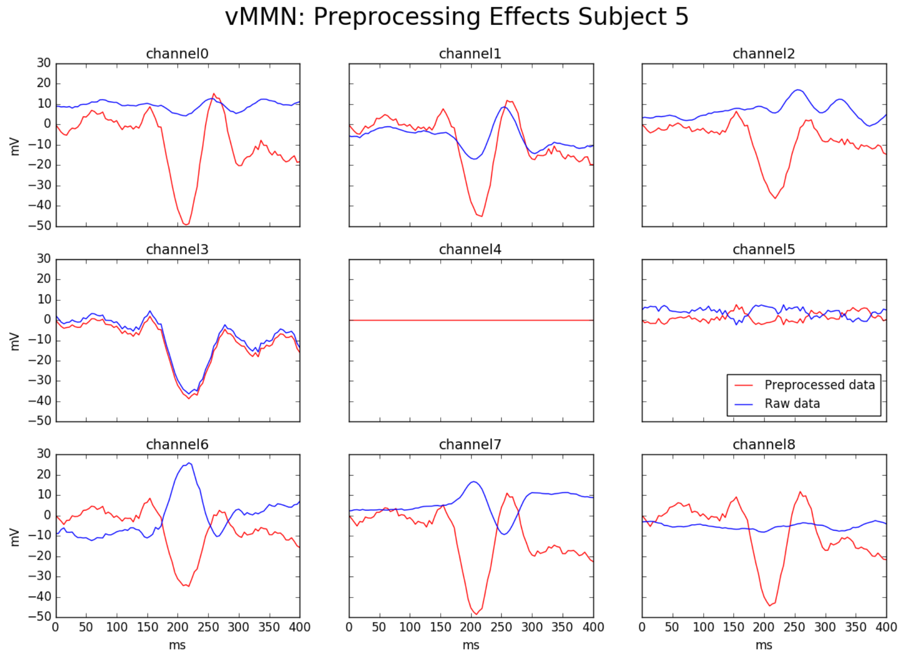

Figure 24: Effects of Preprocessing, vMMN, Subject 5

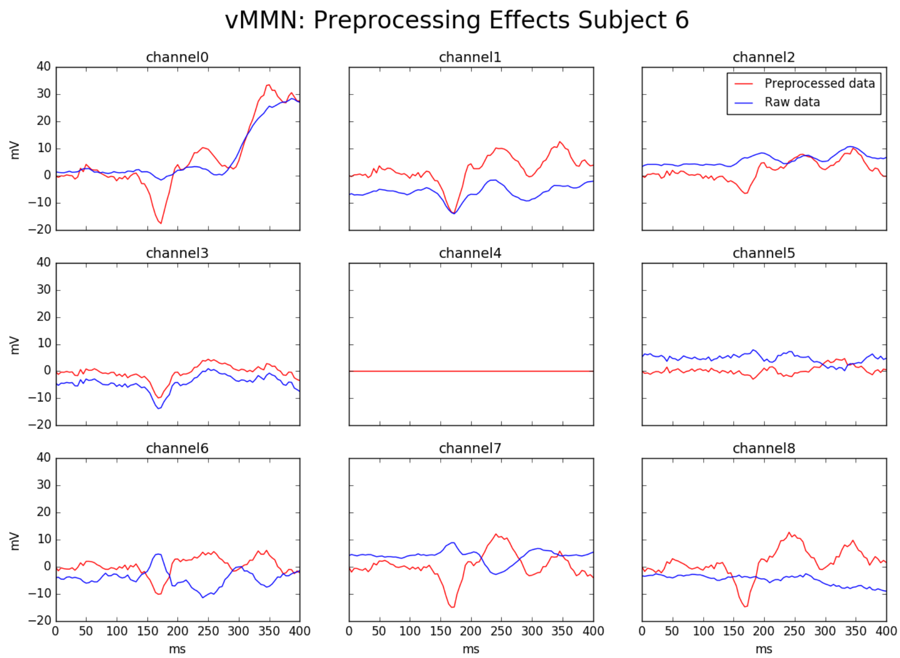

Figure 25: Effects of Preprocessing, vMMN, Subject 6

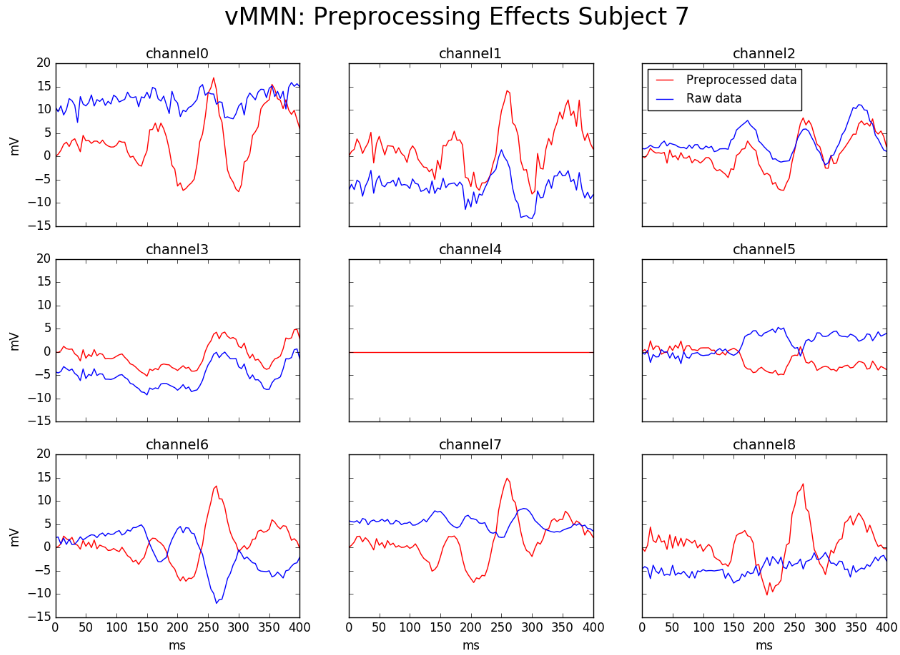

Figure 26: Effects of Preprocessing, vMMN, Subject 7

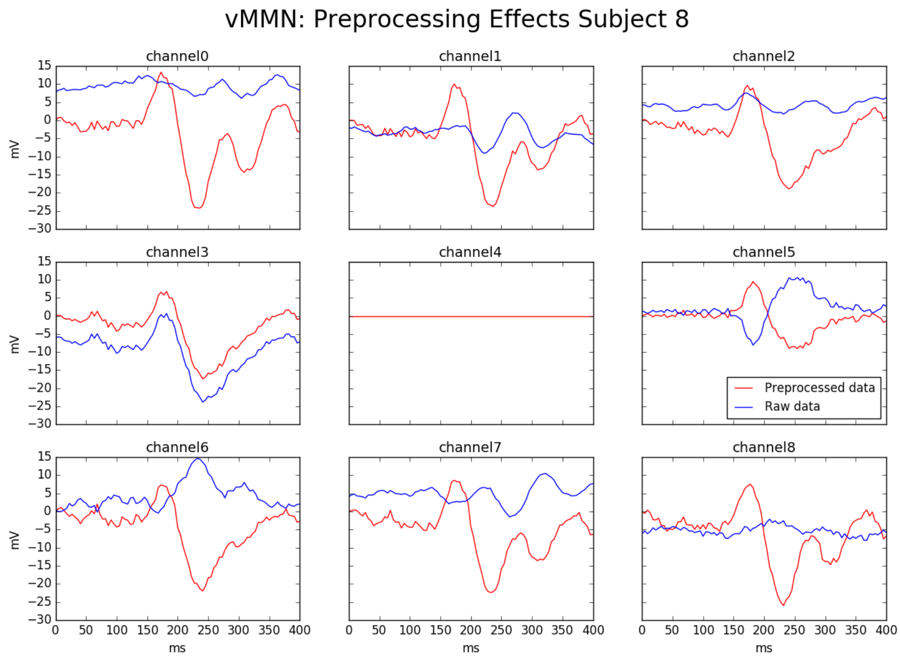

Figure 27: Effects of Preprocessing, vMMN, Subject 8

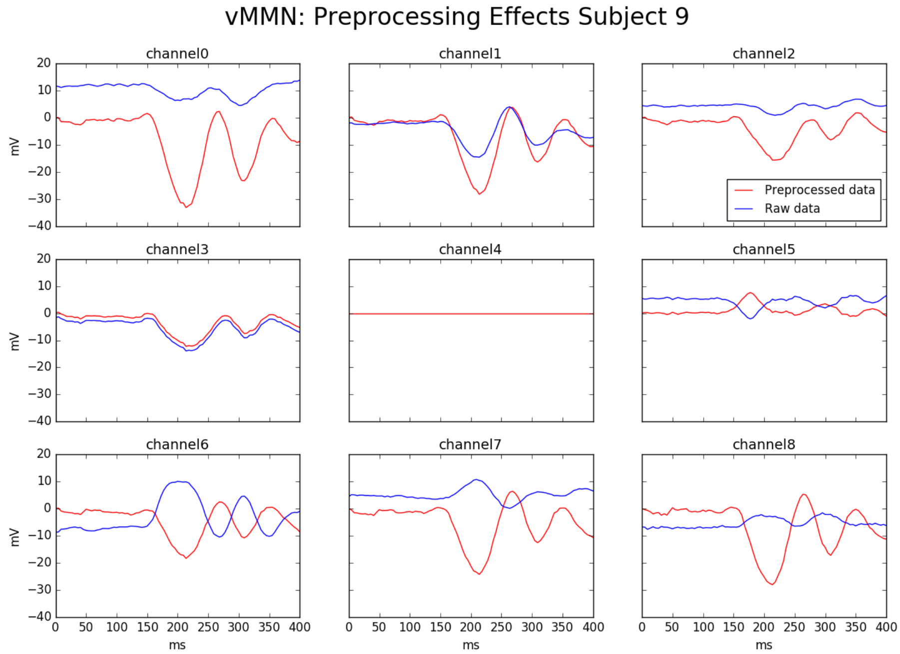

Figure 28: Effects of Preprocessing, vMMN, Subject 9

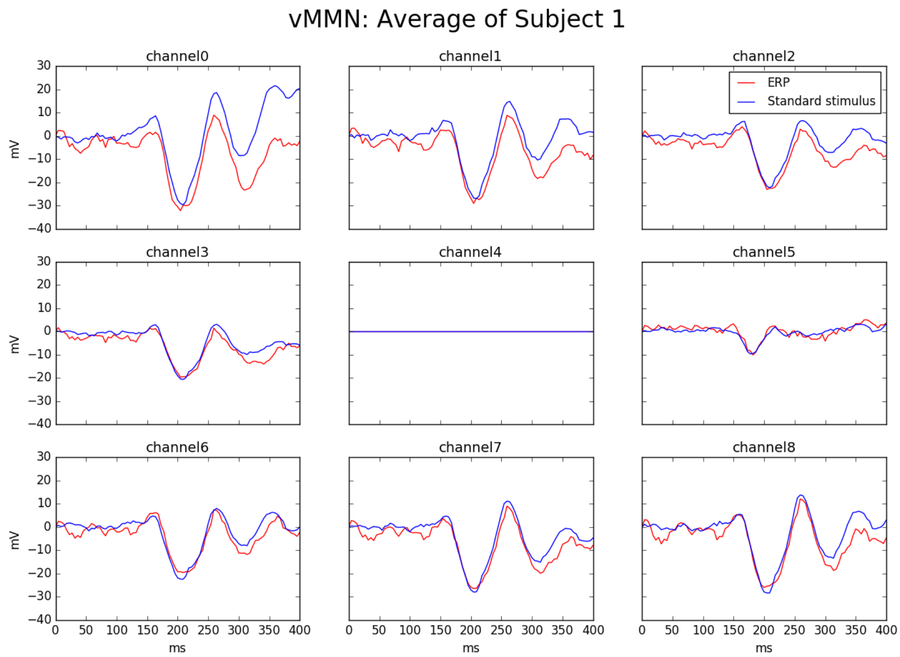

Figure 29: ERP, vMMN, Subject 1

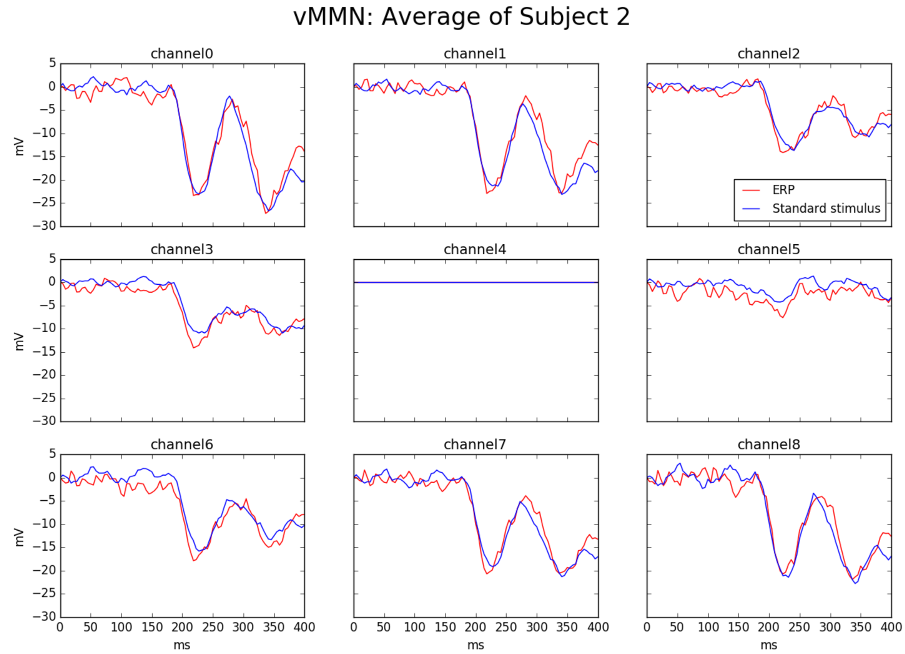

Figure 30: ERP, vMMN, Subject 2

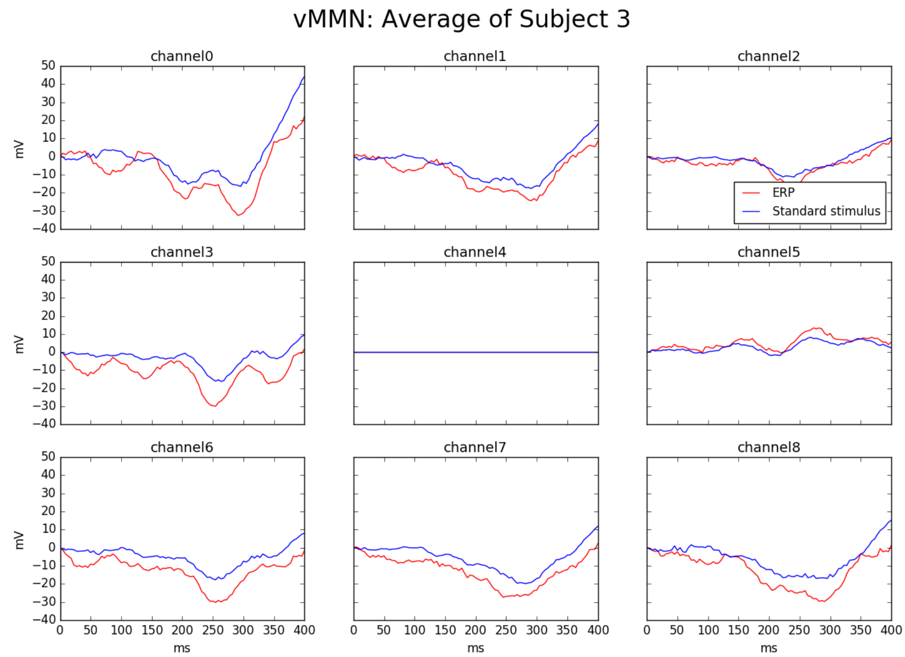

Figure 31: ERP, vMMN, Subject 3

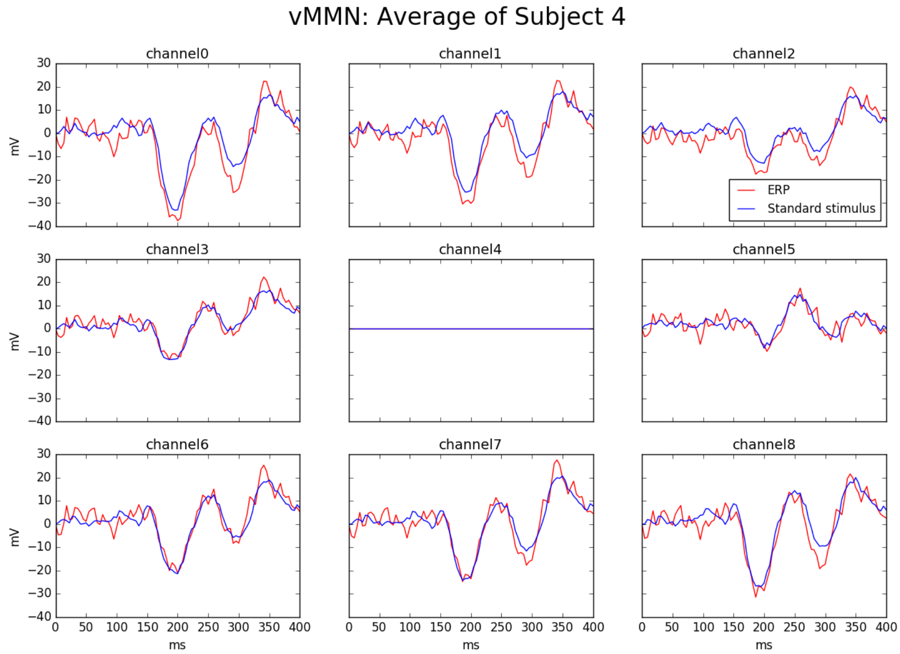

Figure 32: ERP, vMMN, Subject 4

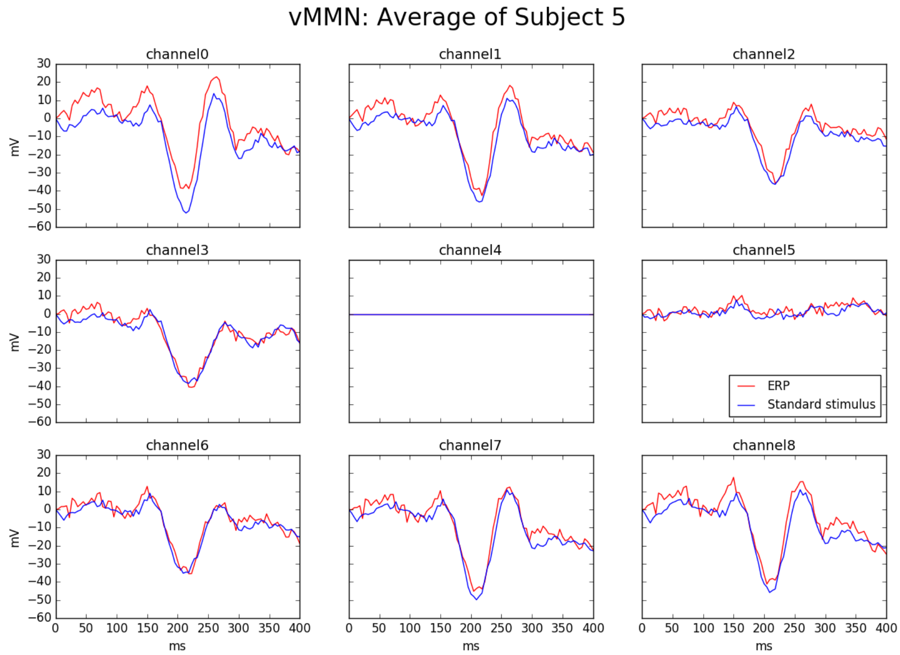

Figure 33: ERP, vMMN, Subject 5

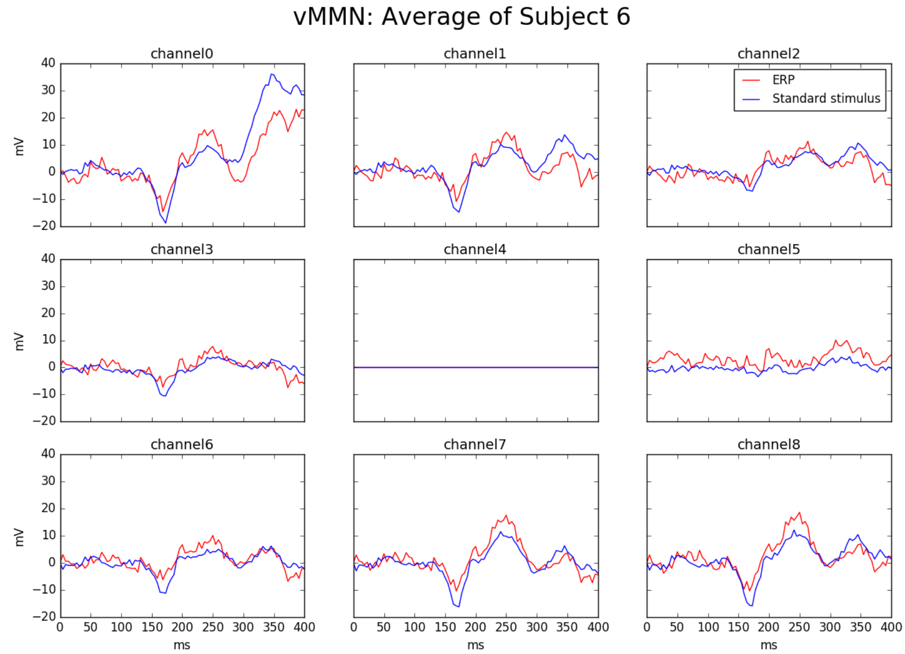

Figure 34: ERP, vMMN, Subject 6

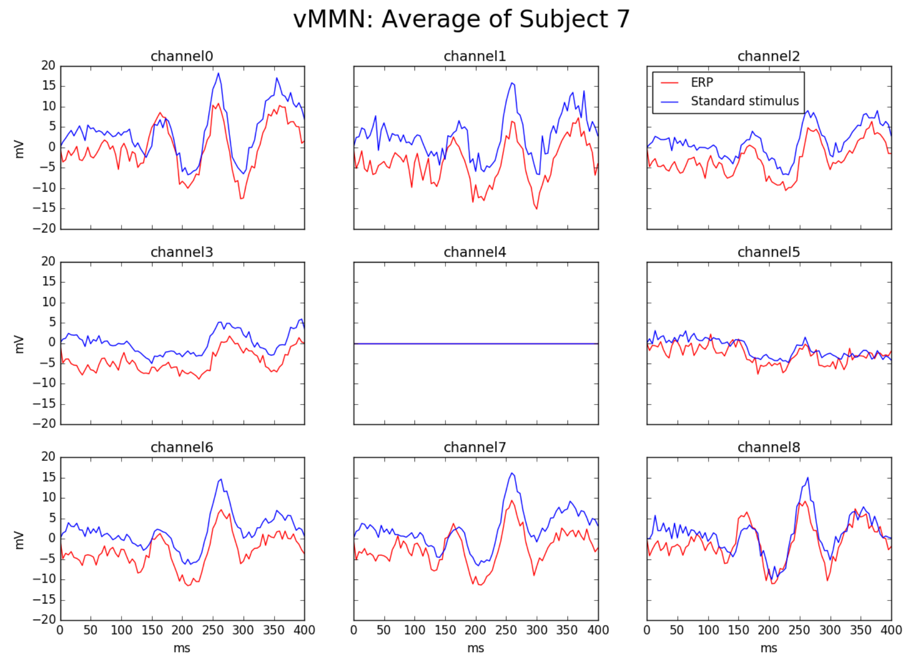

Figure 35: ERP, vMMN, Subject 7

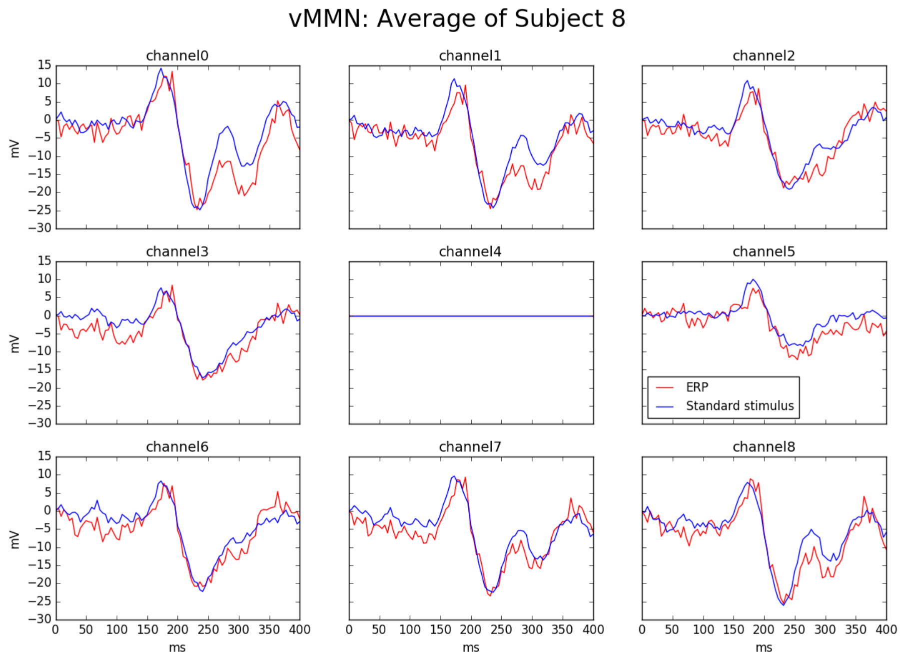

Figure 36: ERP, vMMN, Subject 8

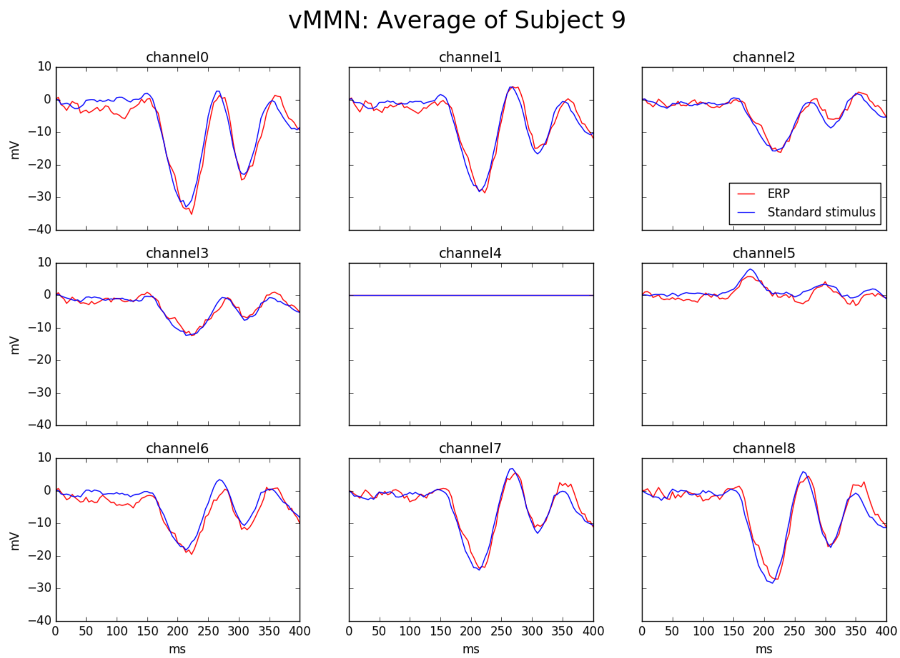

Figure 37: ERP, vMMN, Subject 9

C. P300 plots

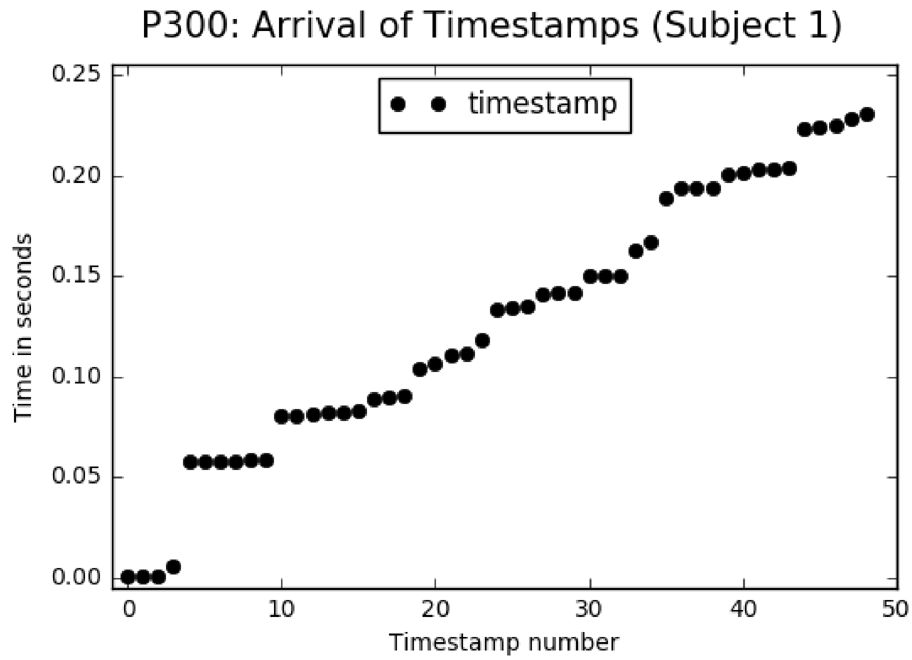

Figure 38: Example of irregularly arriving timestamps during the P300 task. Here taken from the first trial of subject 1.

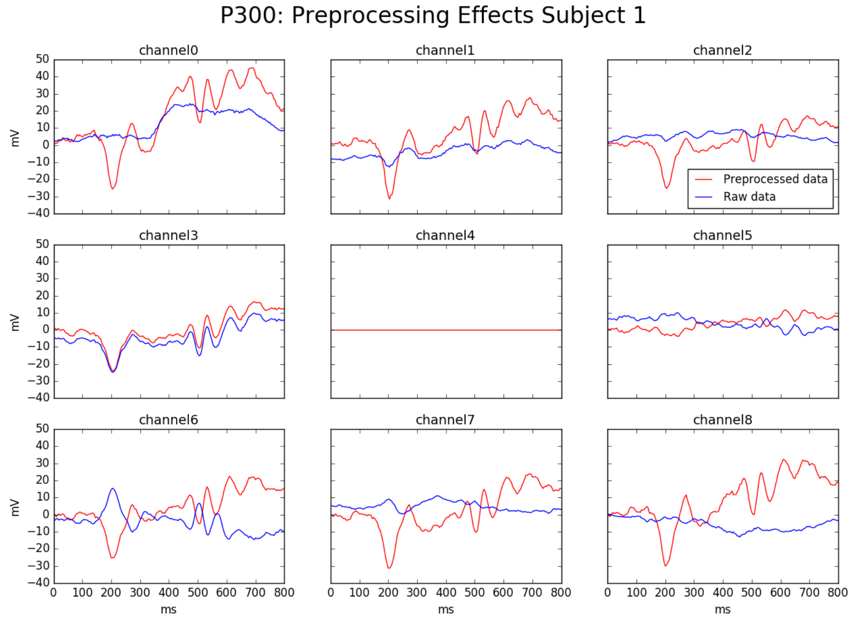

Figure 39: Effects of preprocessing, P300, Subject 1

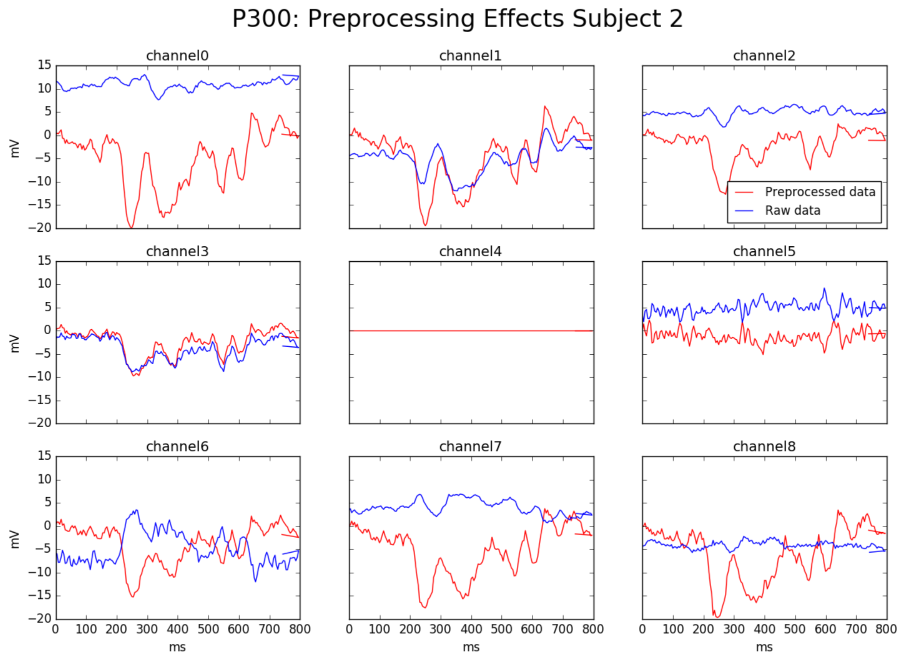

Figure 40: Effects of preprocessing, P300, Subject 2

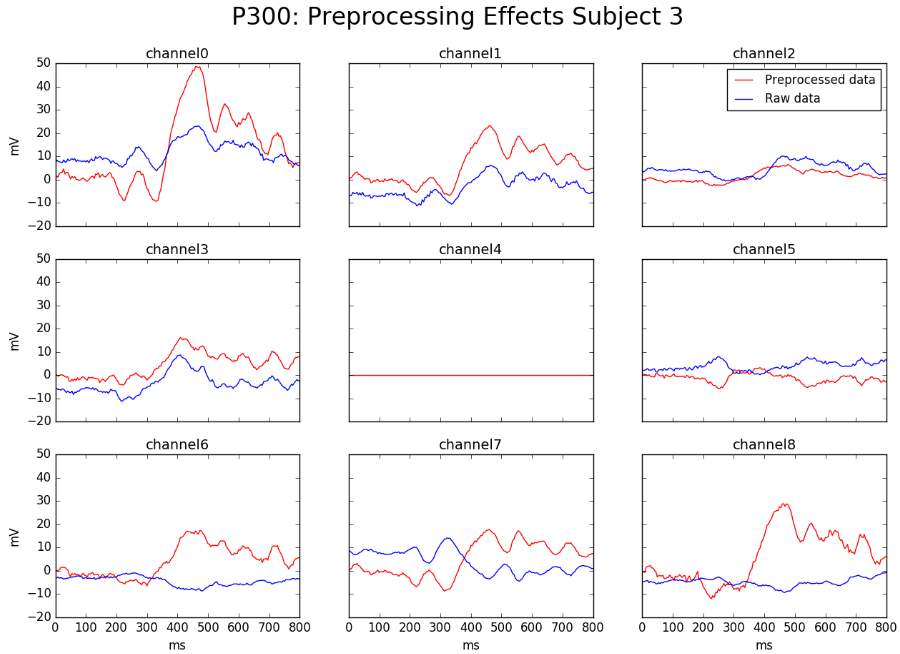

Figure 41: Effects of preprocessing, P300, Subject 3

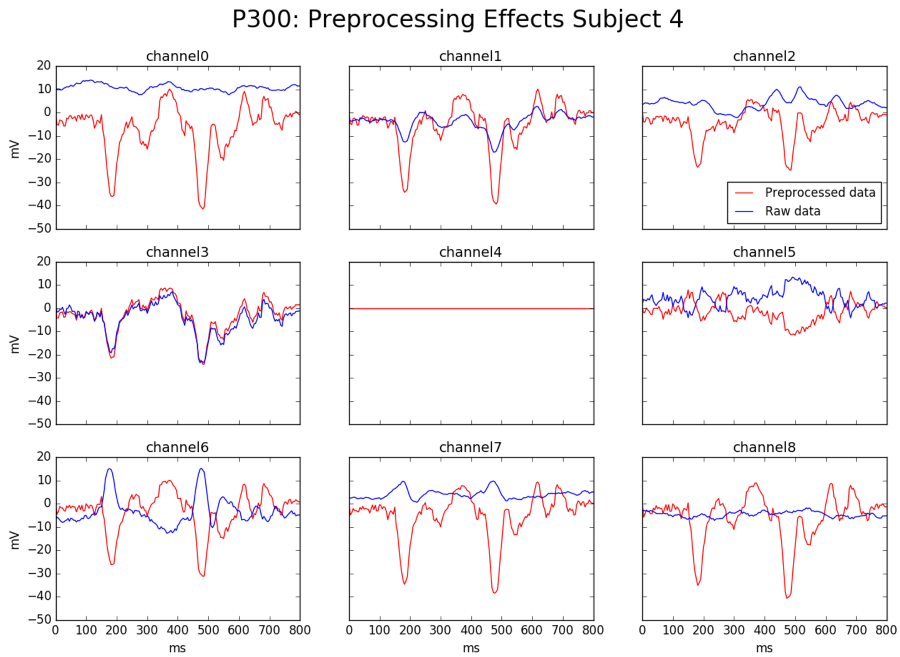

Figure 42: Effects of preprocessing, P300, Subject 4

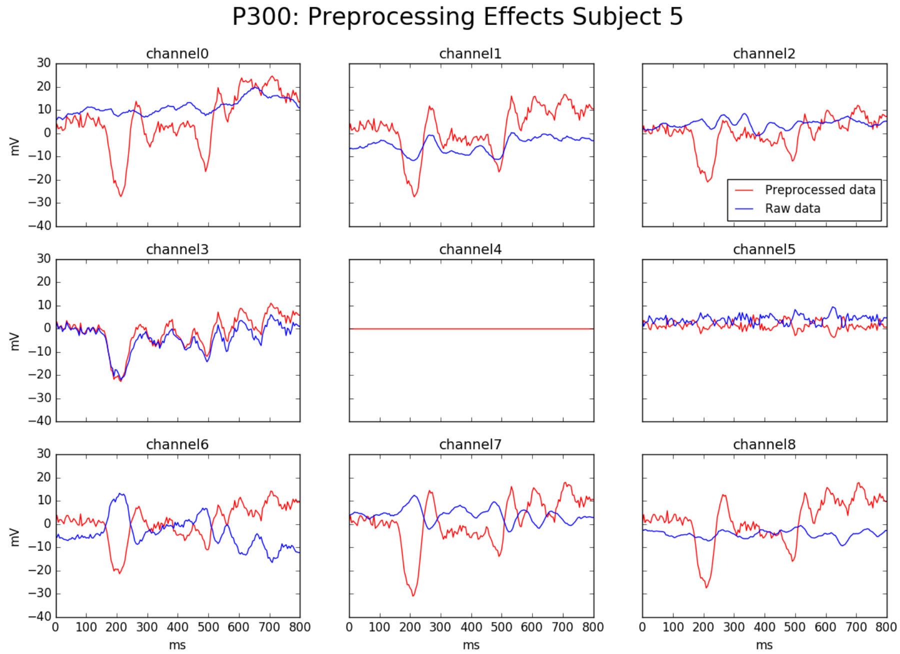

Figure 43: Effects of preprocessing, P300, Subject 5

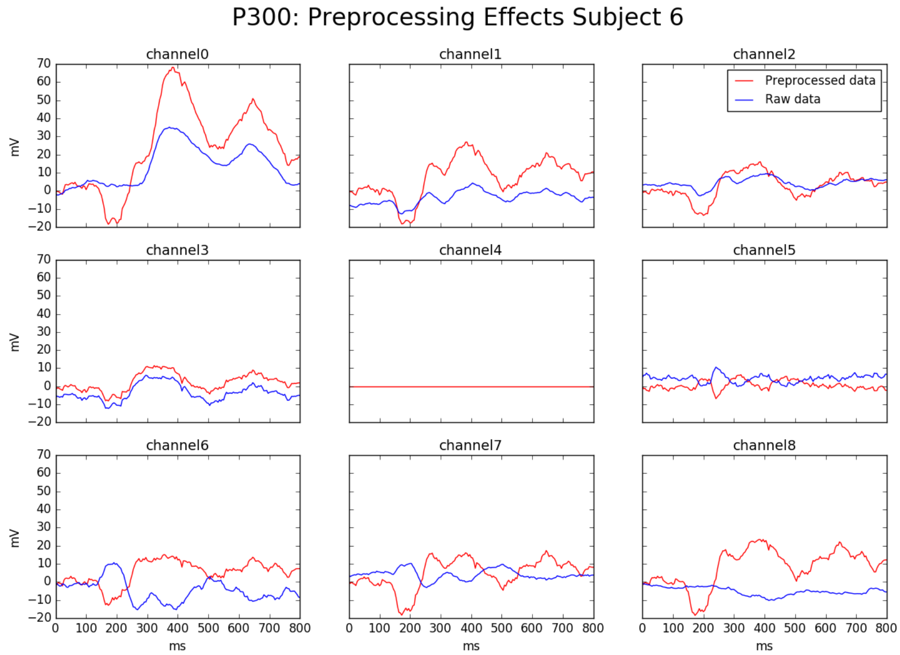

Figure 44: Effects of preprocessing, P300, Subject 6

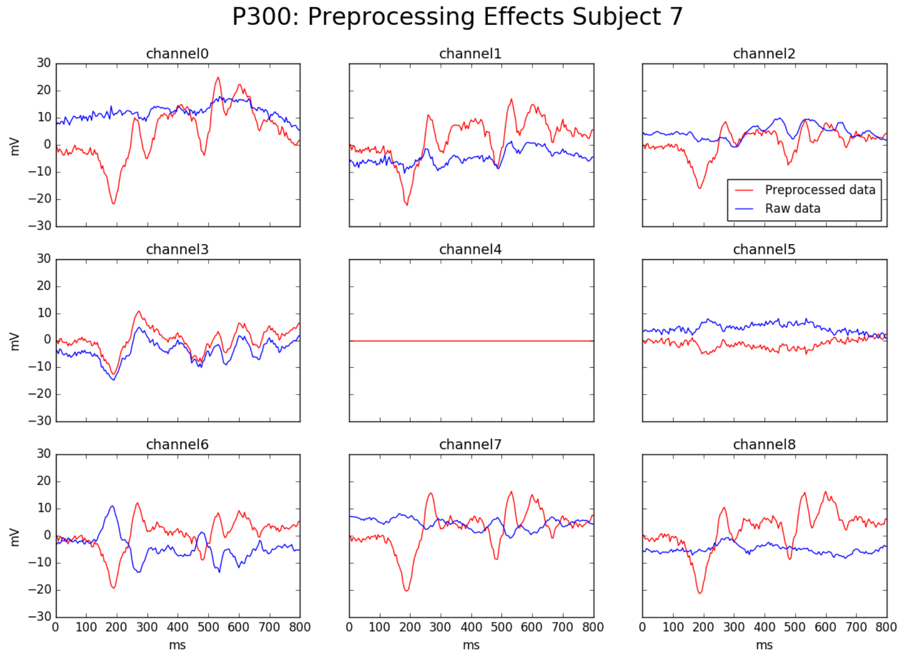

Figure 45: Effects of preprocessing, P300, Subject 7

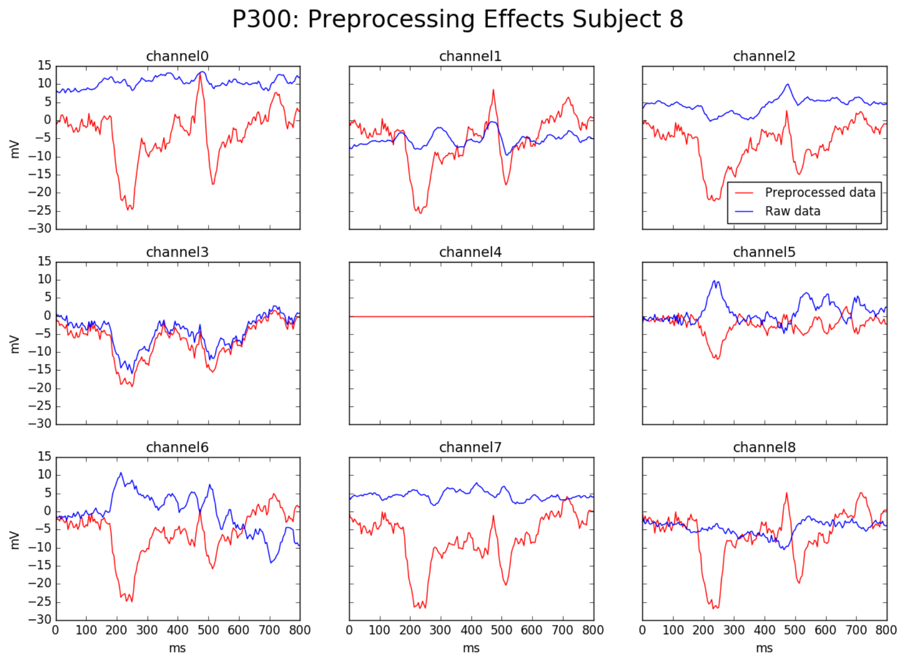

Figure 46: Effects of preprocessing, P300, Subject 8

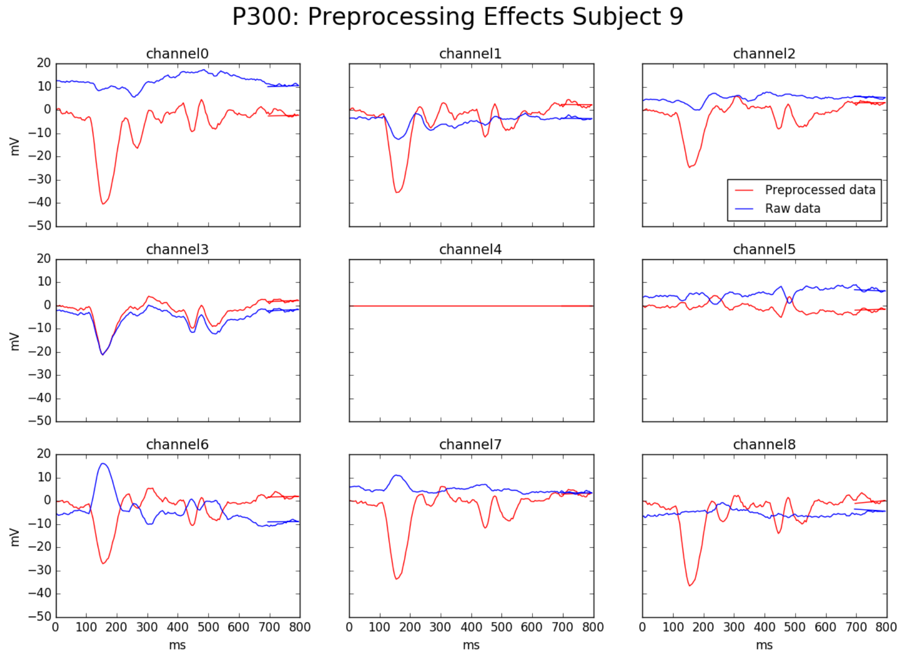

Figure 47: Effects of preprocessing, P300, Subject 9

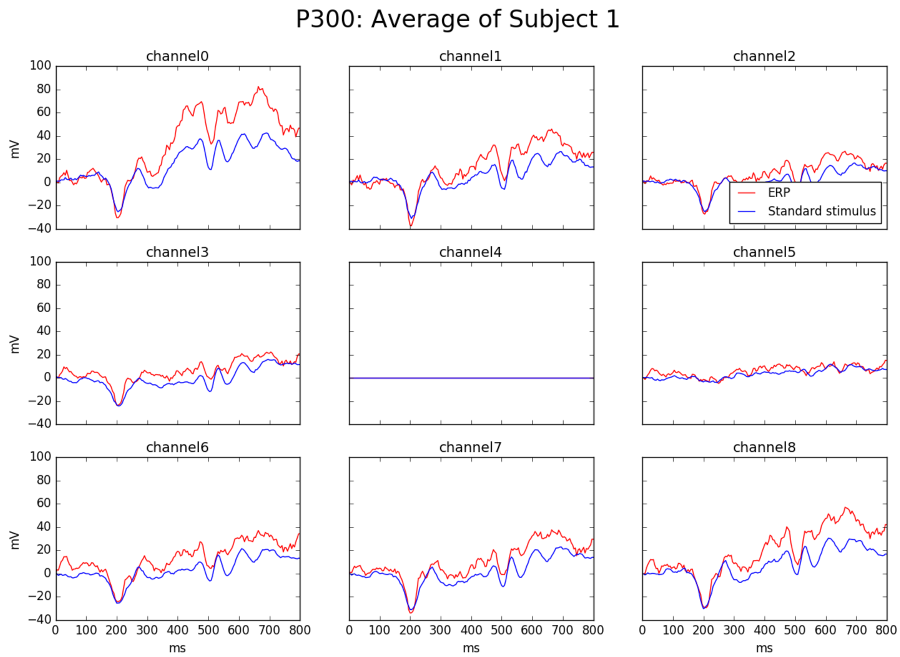

Figure 48: ERP, P300, Subject 1

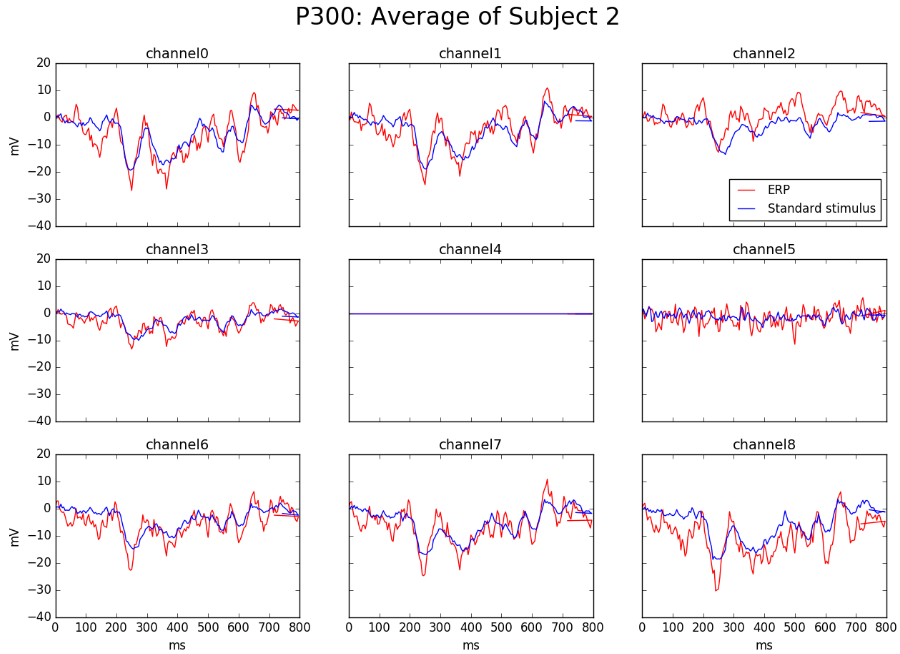

Figure 49: ERP, P300, Subject 2

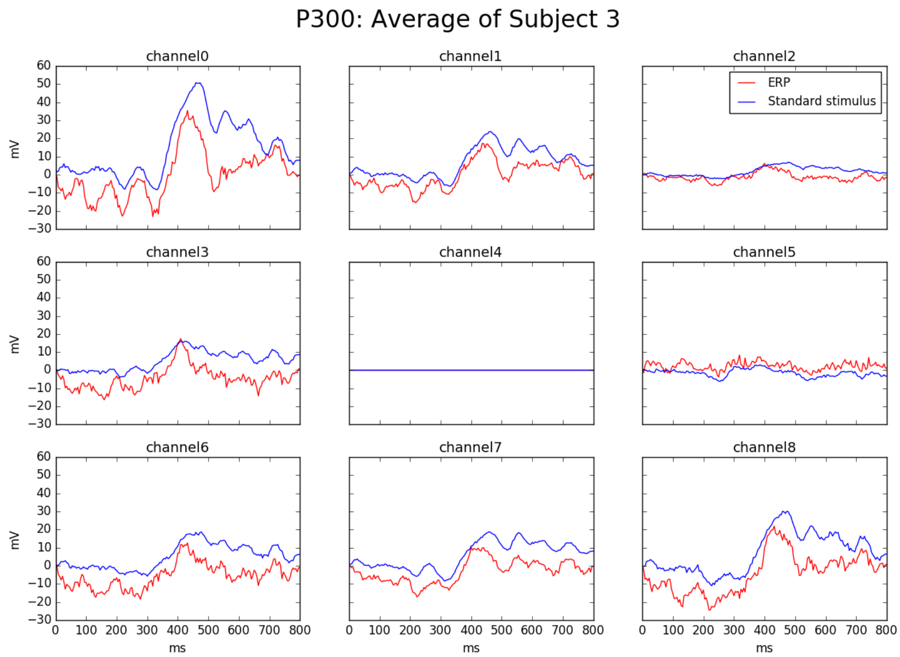

Figure 50: ERP, P300, Subject 3

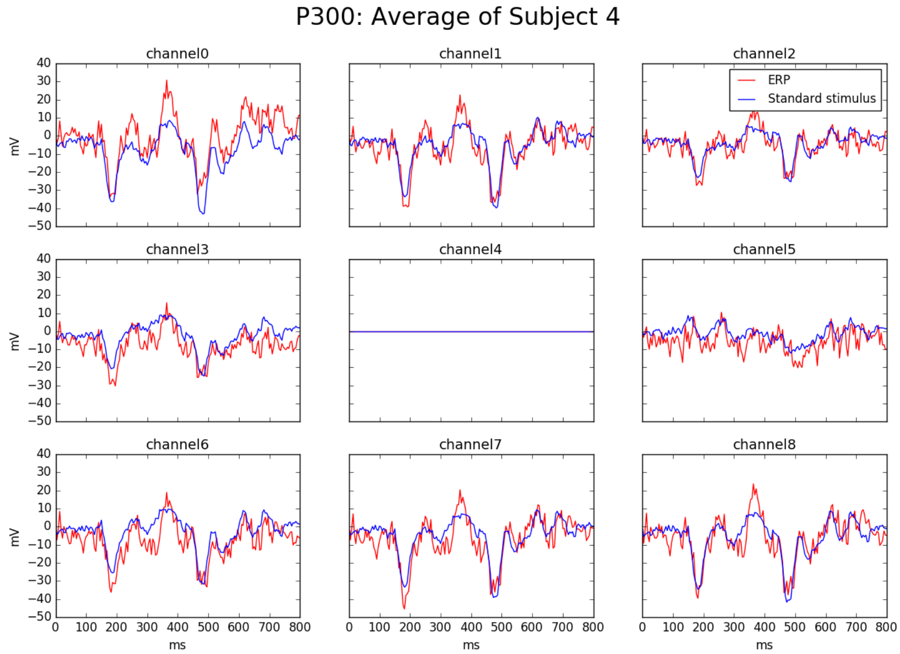

Figure 51: ERP, P300, Subject 4

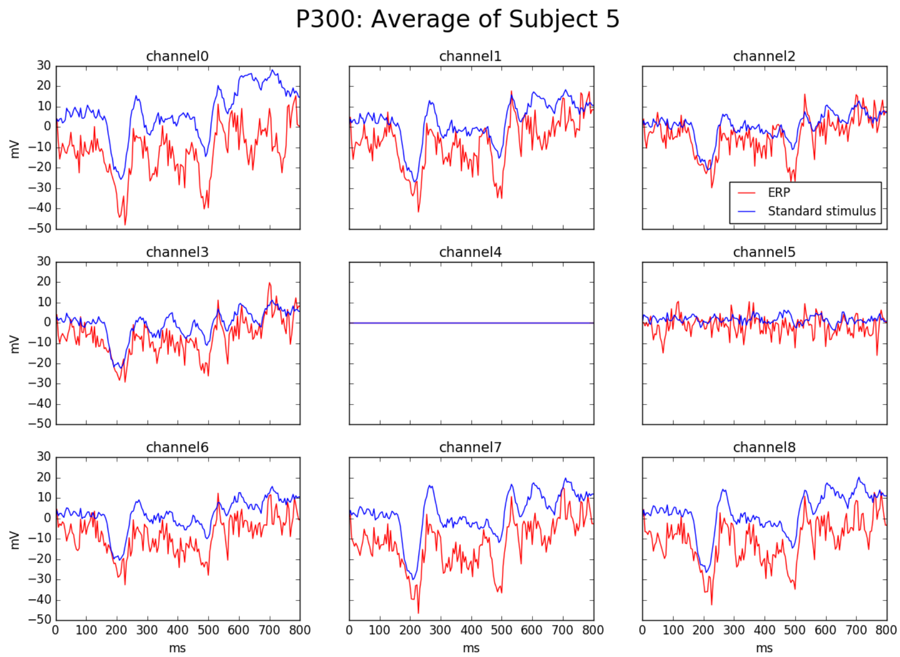

Figure 52: ERP, P300, Subject 5

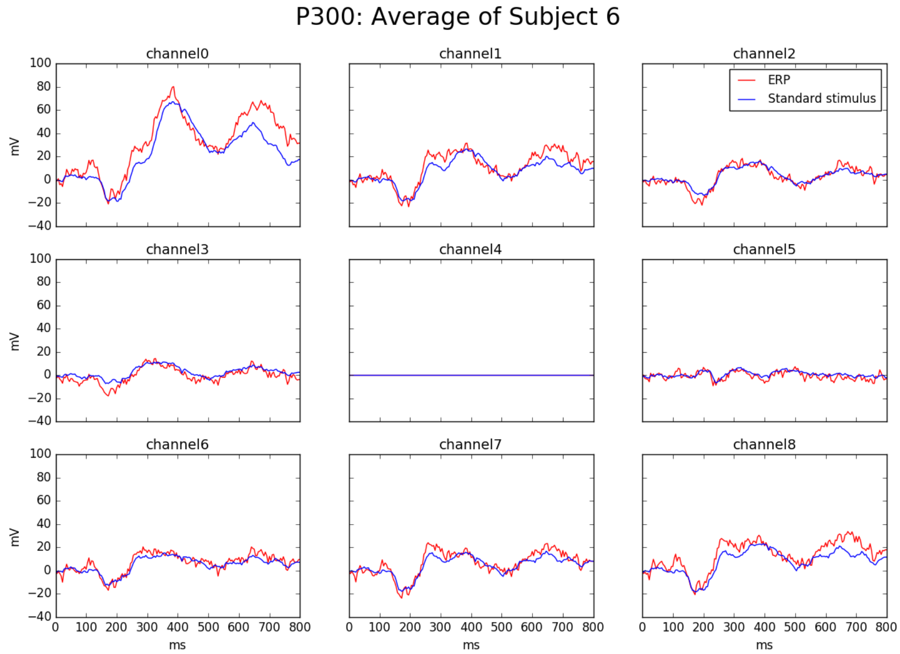

Figure 53: ERP, P300, Subject 6

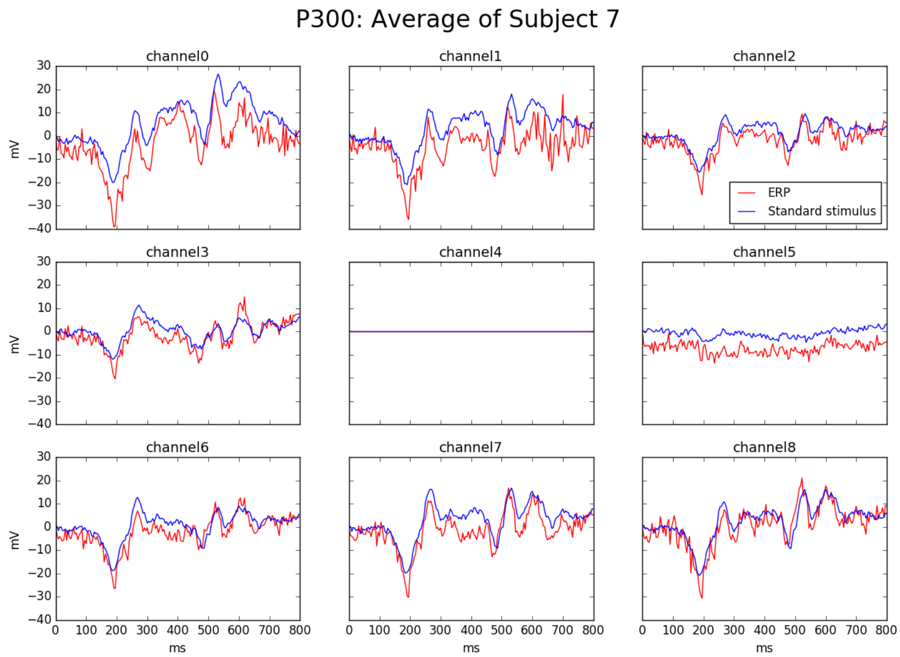

Figure 54: ERP, P300, Subject 7

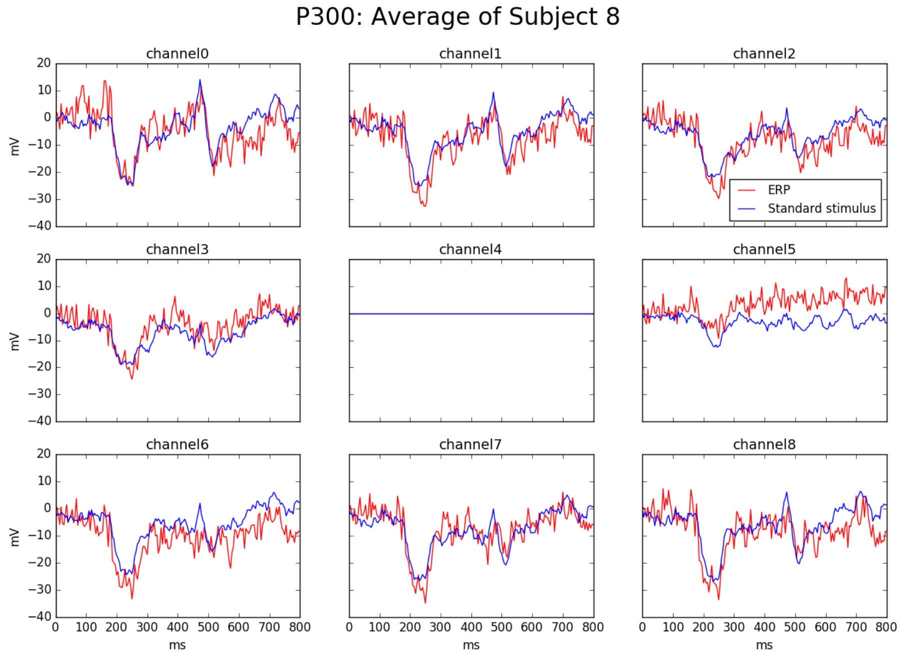

Figure 55: ERP, P300, Subject 8

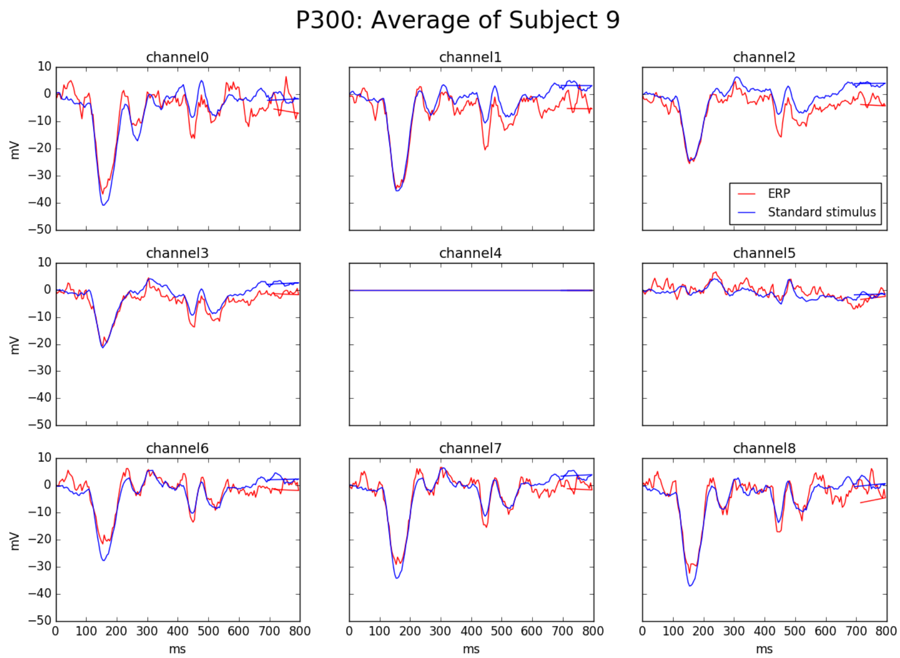

Figure 56: ERP, P300, Subject 9

D. AEPs plots

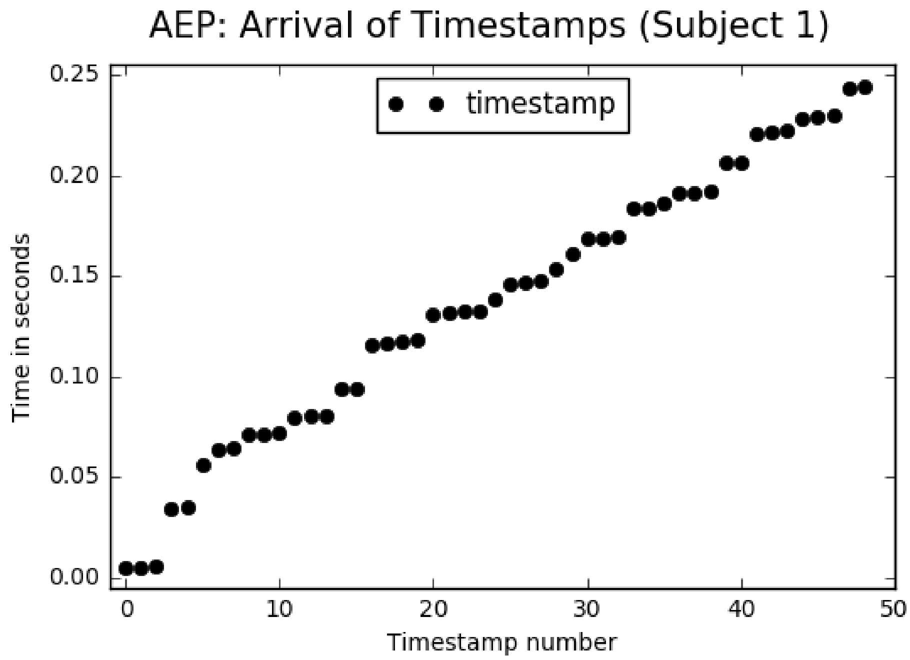

Figure 57: Example of irregularly arriving timestamps during the auditory task. Here taken from the first trial of subject 1.

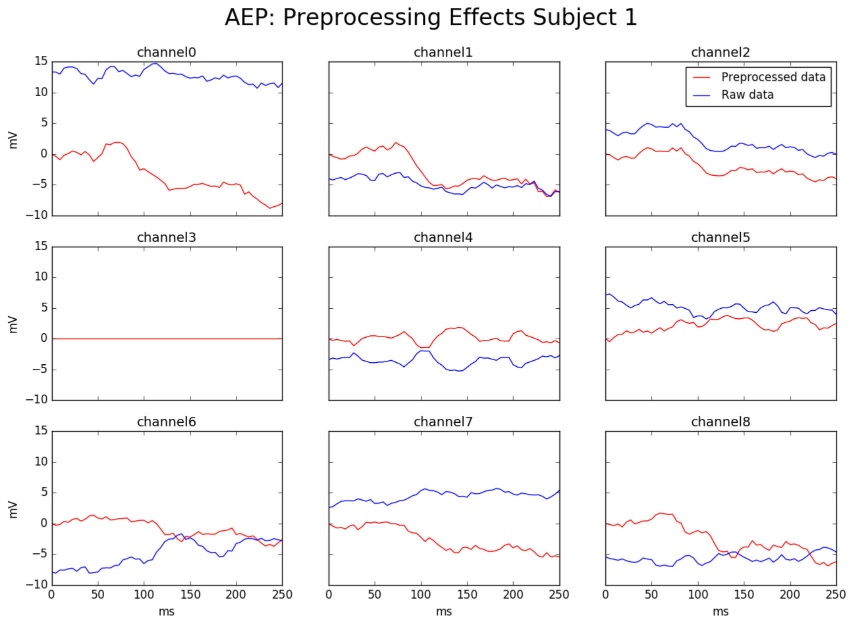

Figure 58: Effects of Preprocessing, AEP, Subject 1

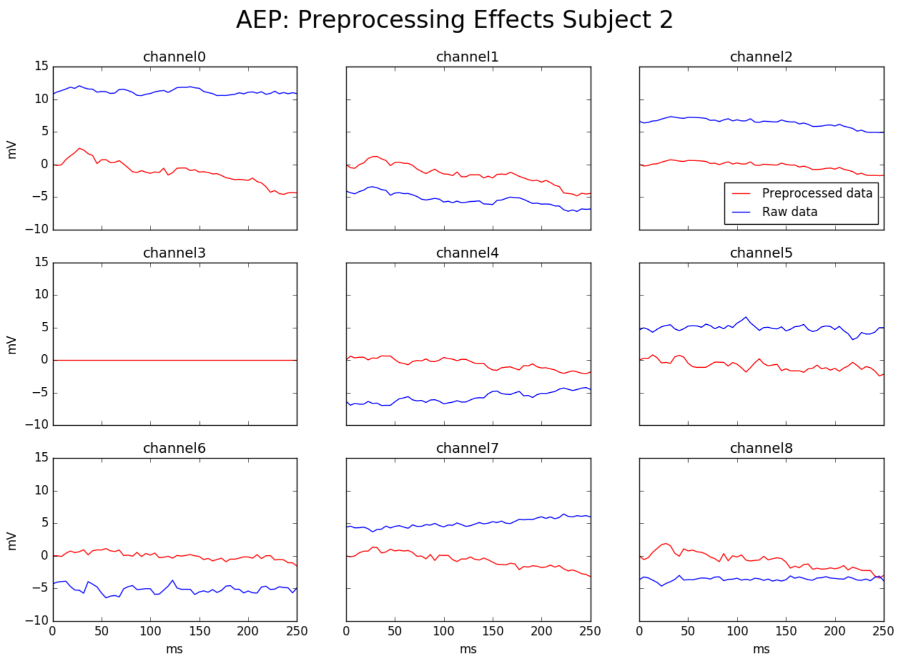

Figure 59: Effects of Preprocessing, AEP, Subject 2

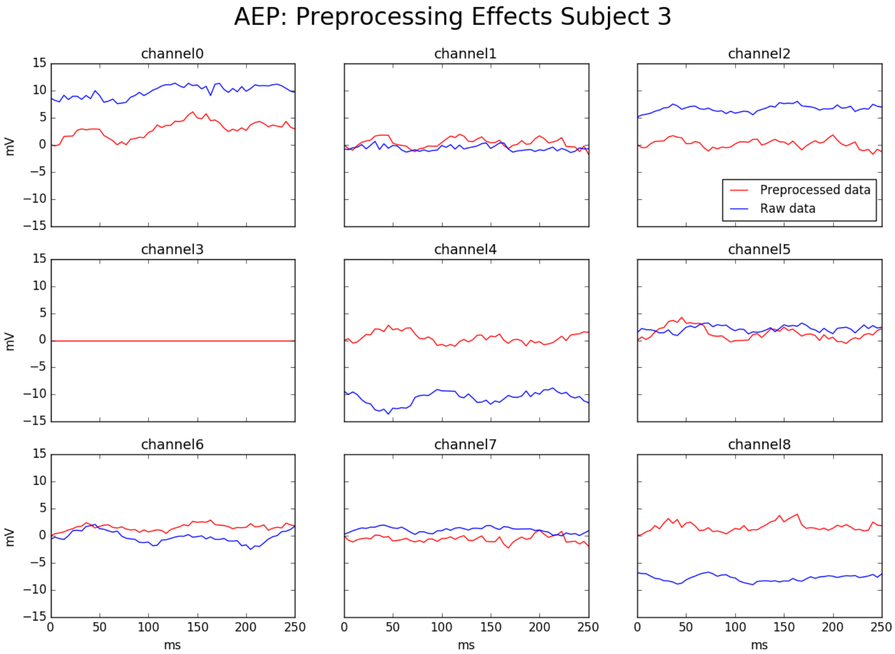

Figure 60: Effects of Preprocessing, AEP, Subject 3

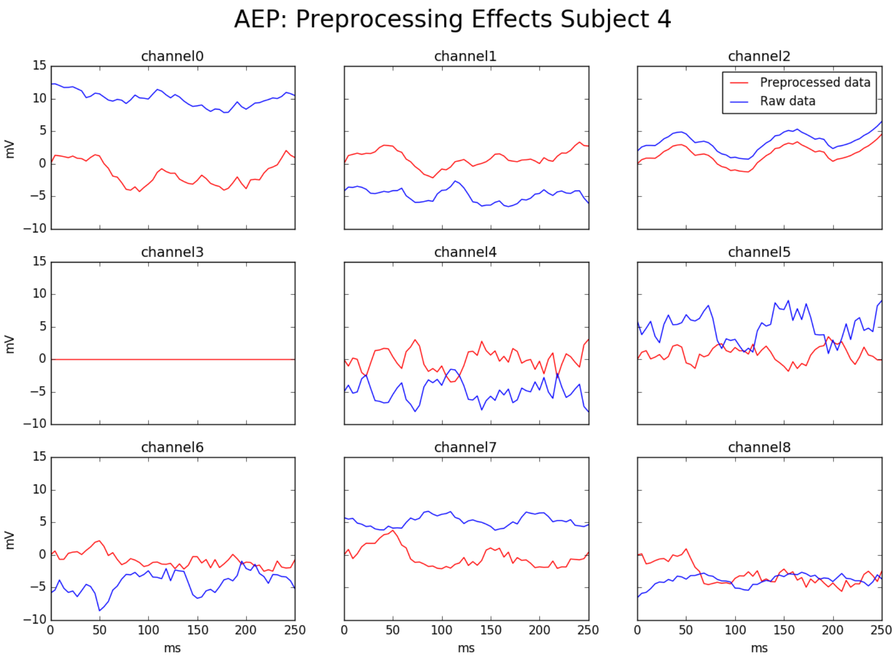

Figure 61: Effects of Preprocessing, AEP, Subject 4

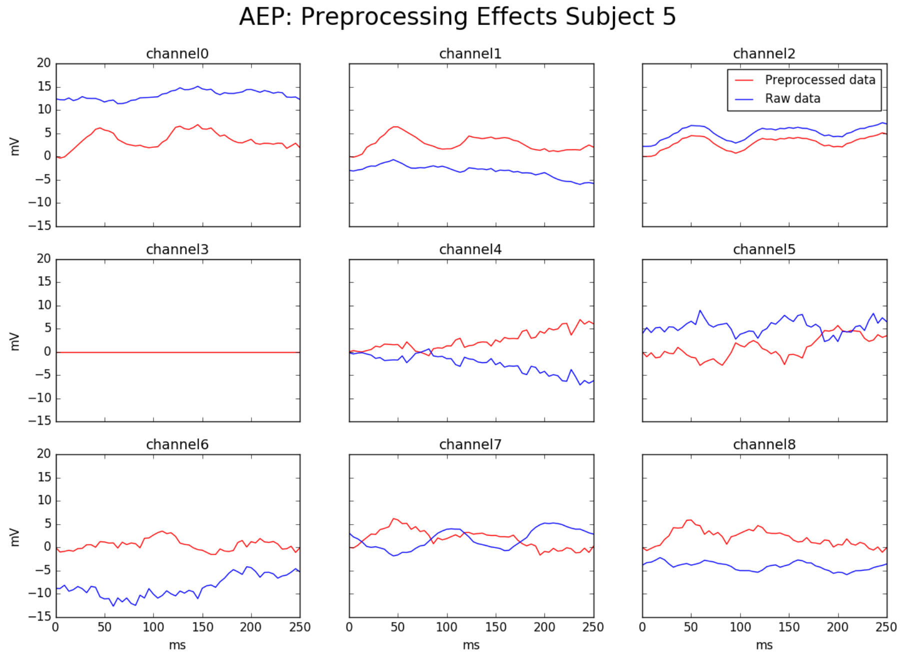

Figure 62: Effects of Preprocessing, AEP, Subject 5

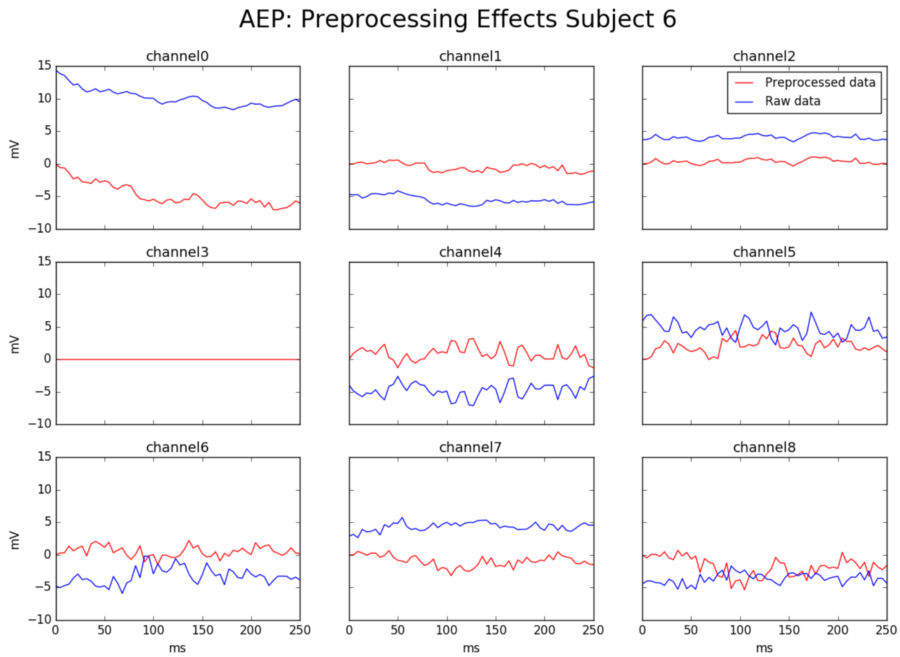

Figure 63: Effects of Preprocessing, AEP, Subject 6

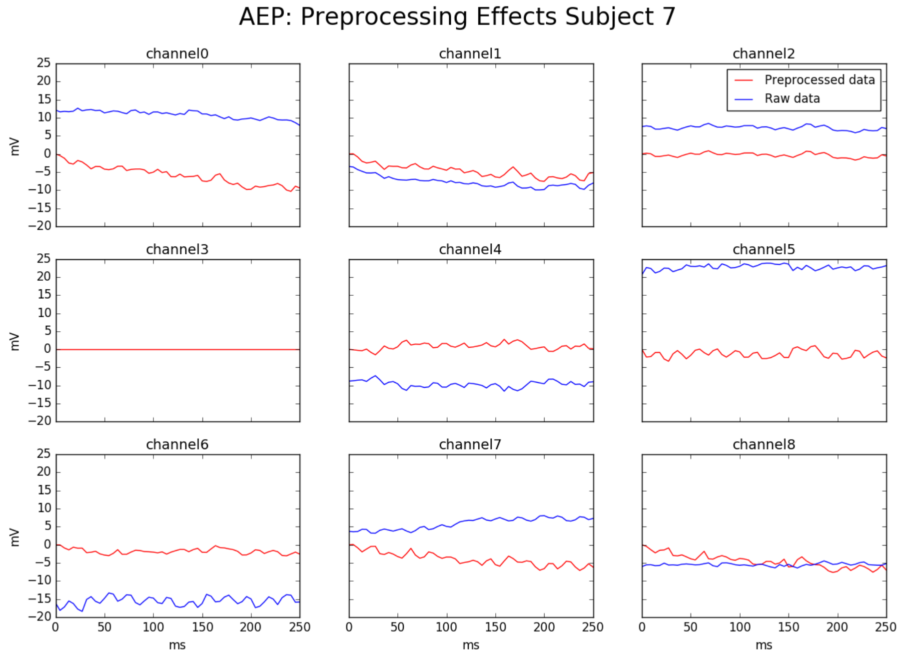

Figure 64: Effects of Preprocessing, AEP, Subject 7

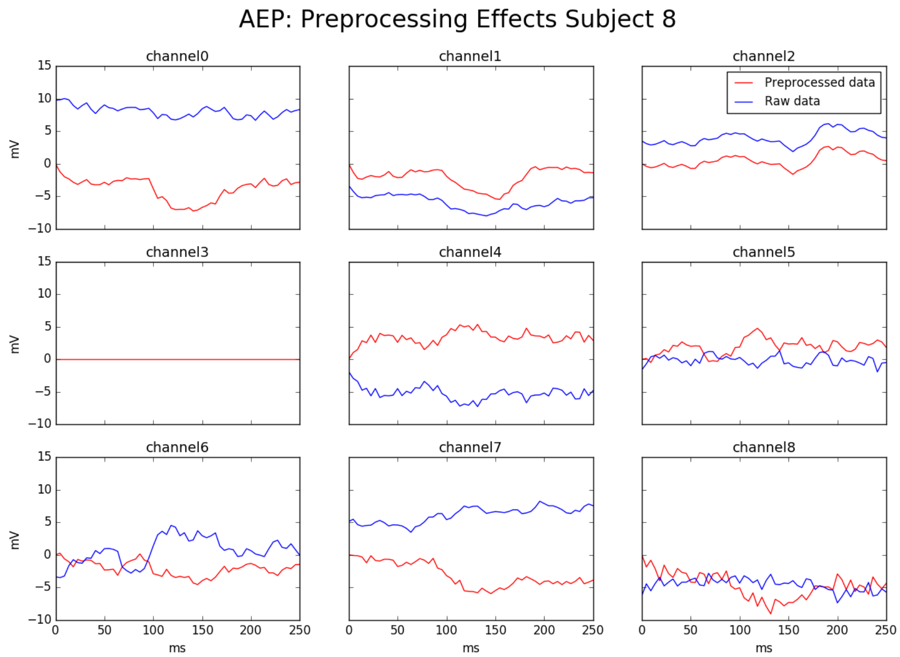

Figure 65: Effects of Preprocessing, AEP, Subject 8

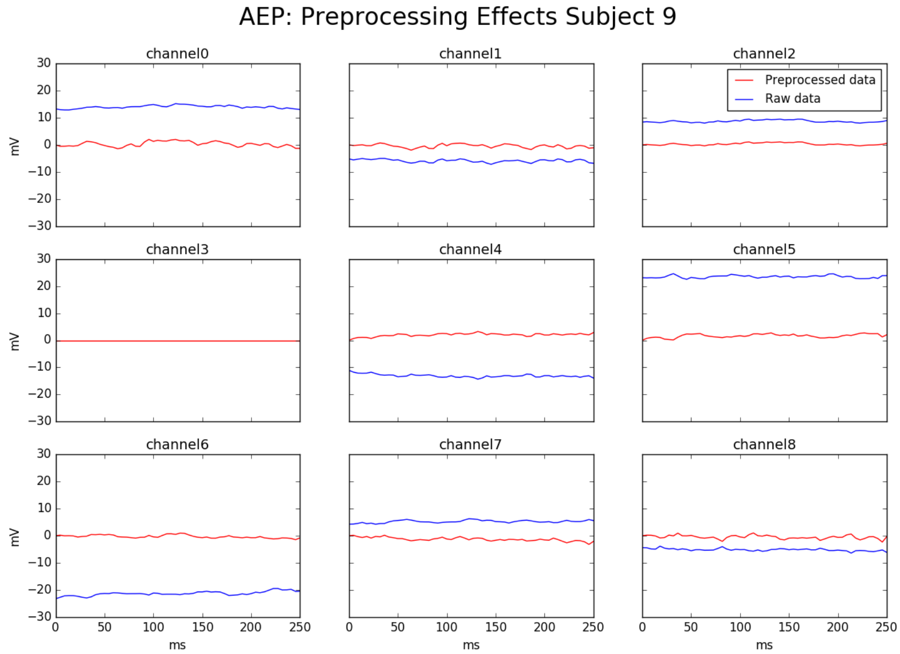

Figure 66: Effects of Preprocessing, AEP, Subject 9

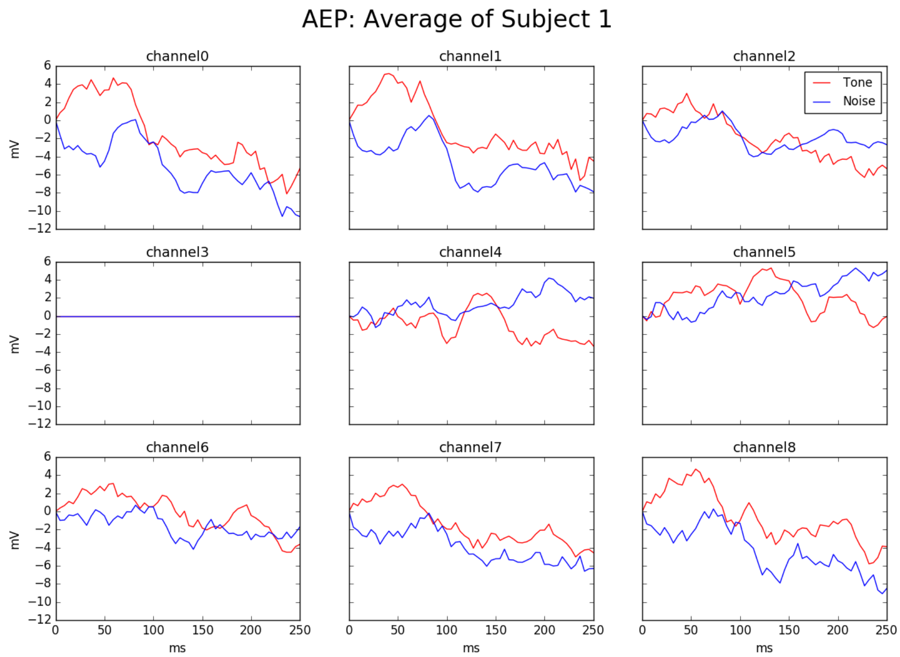

Figure 67: ERP, AEP, Subject 1

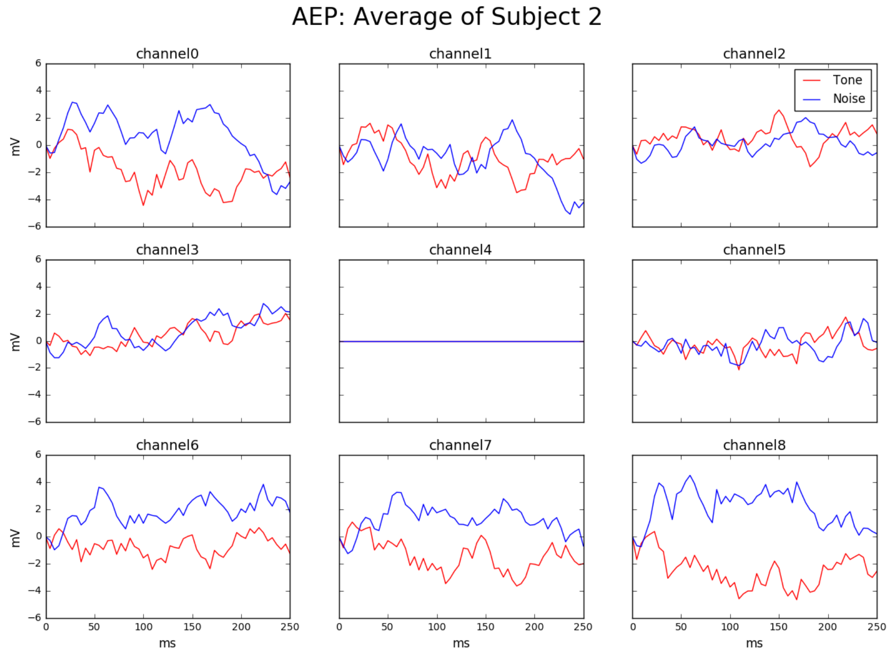

Figure 68: ERP, AEP, Subject 2

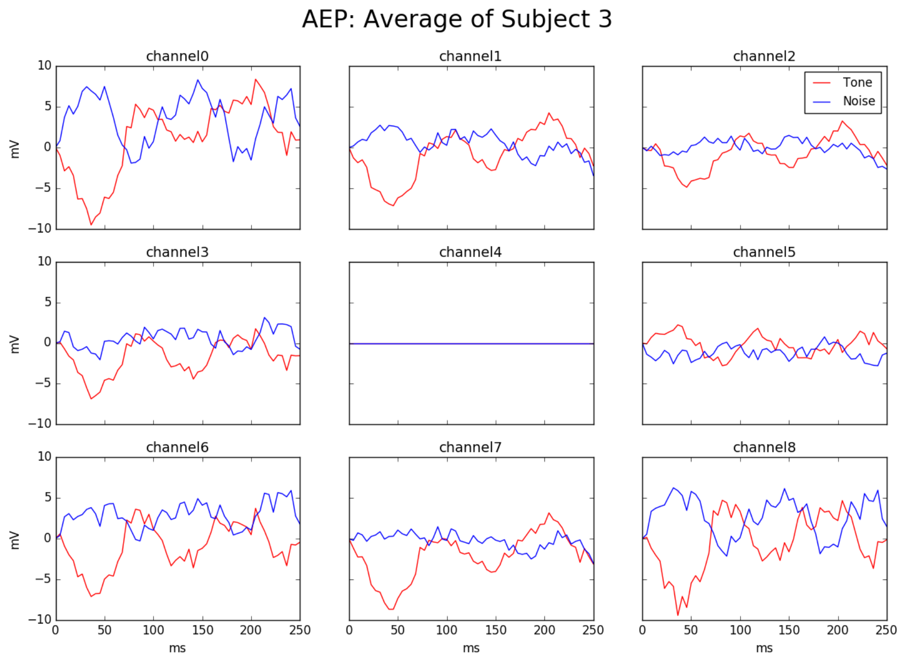

Figure 69: ERP, AEP, Subject 3

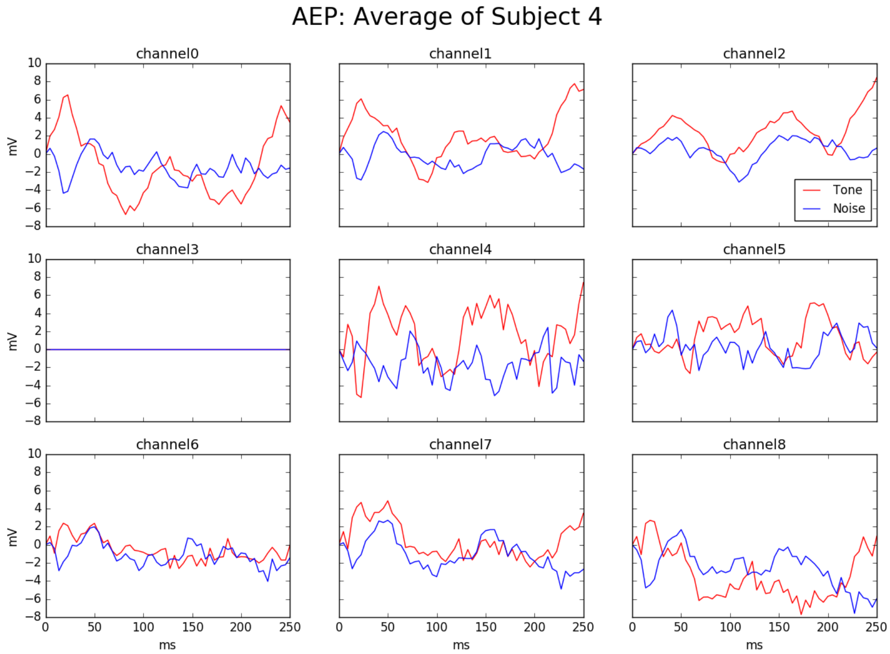

Figure 70: ERP, AEP, Subject 4

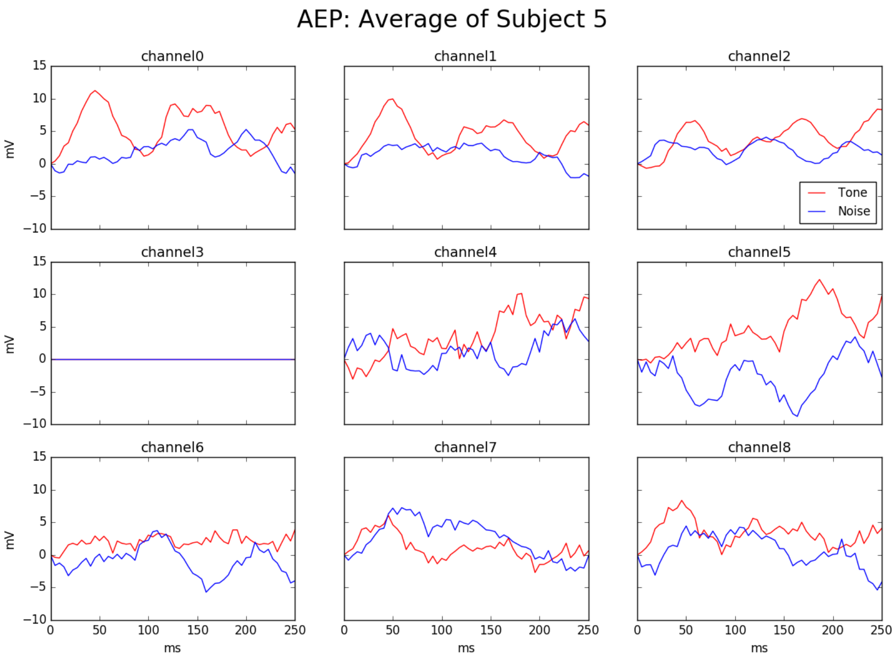

Figure 71: ERP, AEP, Subject 5

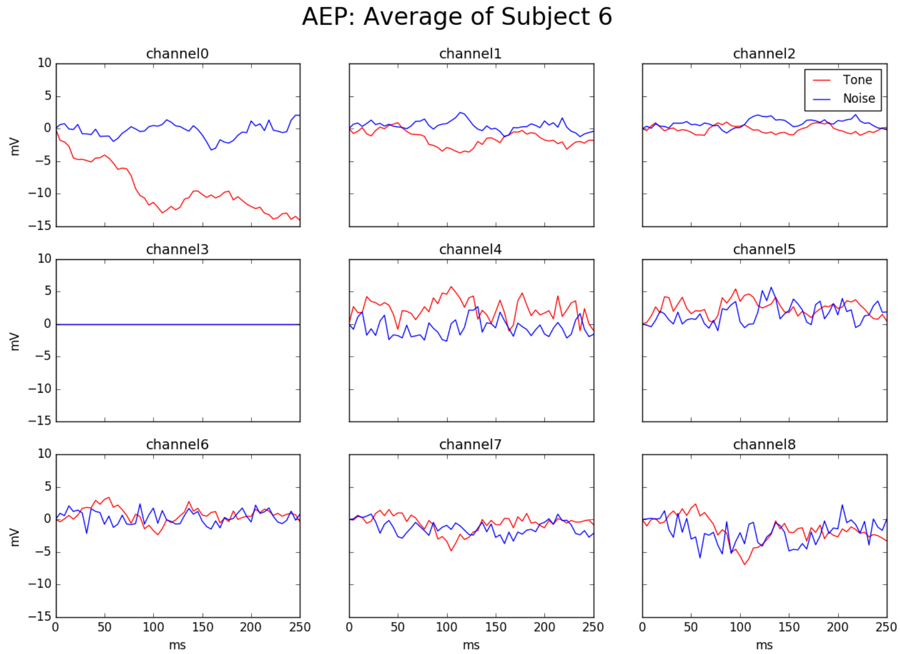

Figure 72: ERP, AEP, Subject 6

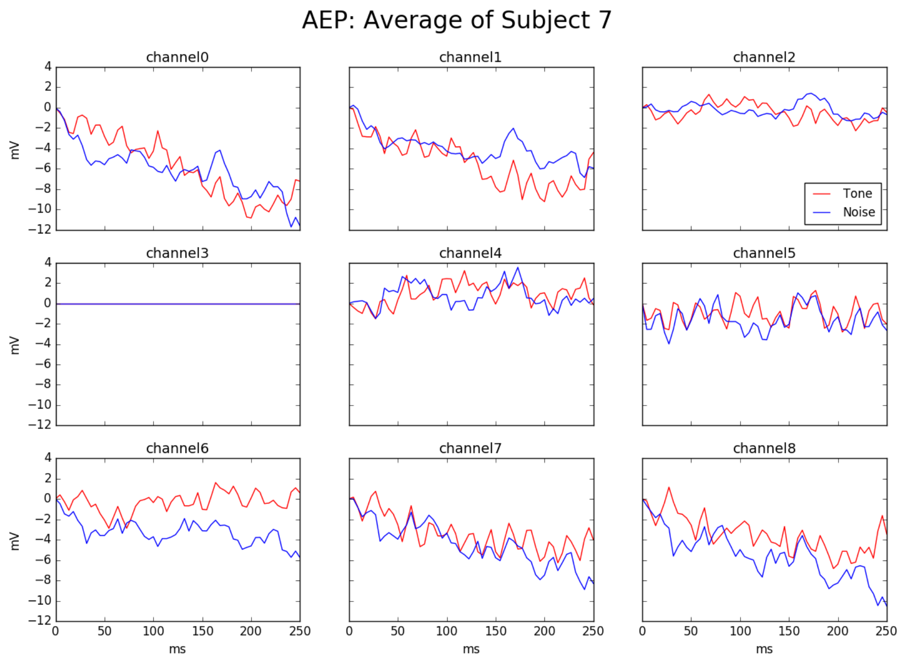

Figure 73: ERP, AEP, Subject 7

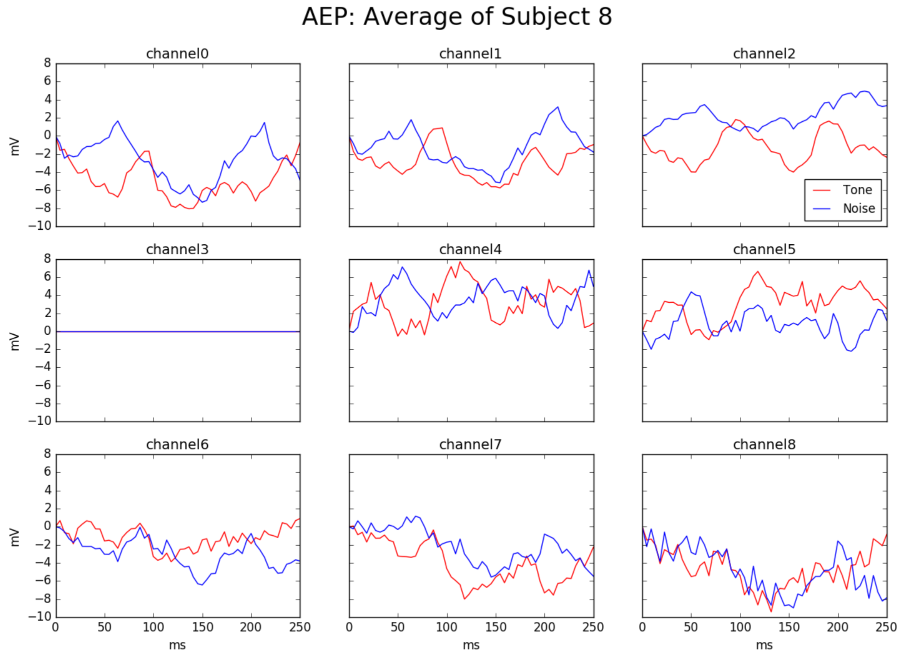

Figure 74: ERP, AEP, Subject 8

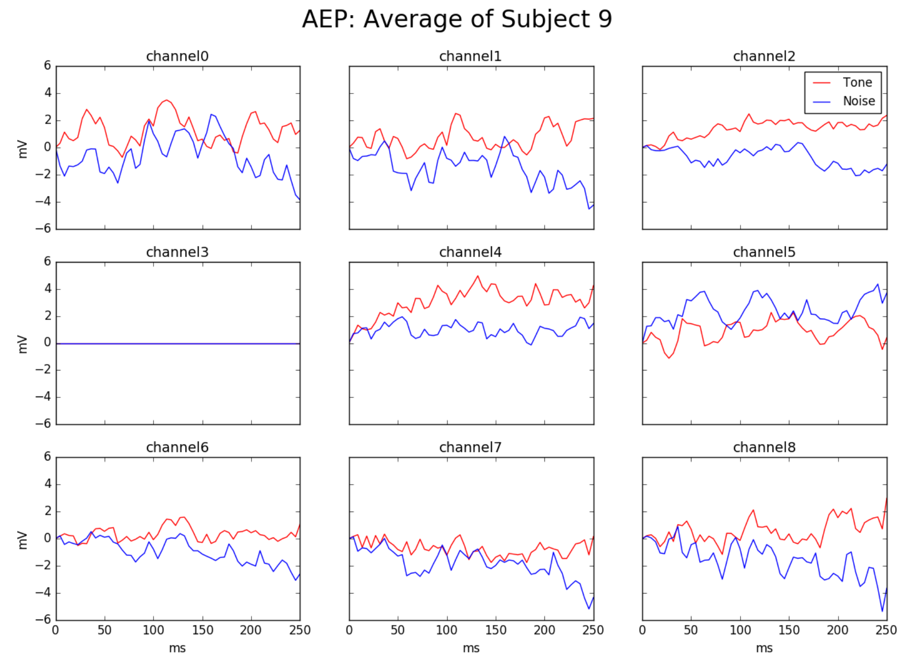

Figure 75: ERP, AEP, Subject 9

E. Mobile version and code

Declaration of Authorship

I hereby certify that the work presented here is, to the best of my knowledge and belief, original and the result of my own investigations, except as acknowledged, and has not been submitted, either in part or whole, for a degree at this or any other university.

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signature

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city, date