Bachelor Thesis in Artificial Intelligence

Radboud University Nijmegen

Fixation Related Potentials for EEG based detection of complex targets

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Author:
Chris Kamphuis - s4202015
Artificial Intelligence
Radboud University Nijmegen

Supervisors:
Jason Farquhar
Donders Institute

Marjolein van der Waal
Donders Institute

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Chapter 1

Introduction

1.1 Hazards

A hazard is an event that poses a threat in society. If you are for example driving on the road and you see a child running on the sidewalk, this might lead to a dangerous situation. While if the child was in fact not running or the person running was actually an adult, the chance on a dangerous situation is much lower. Sometimes it might be hard to determine if something is in fact an hazard or not. In the case with the child running on the sidewalk, already two factors weigh in to determine if the situation is an hazard.
If people are aware of potential hazards, these hazards might be more easily avoided. This is why it is very interesting to test in which situations people are aware of hazards and which factors reduce or increase this awareness.

1.2 Electroenchephalogram

An electroencephalogram (EEG) is a device that can measure brain activity by recording the voltage fluctuations on the scalp. With an EEG it is possible to measure event related potentials (ERP), which are signals that occur after an event is presented [20]. Because an EEG has a high temporal resolution, the timing of an ERP is easy to measure. However, due to a low spatial resolution it is hard to determine which part of the brain is responsible for eliciting an ERP.
When using an EEG multiple electrodes are measuring electrical activity on the scalp. By spreading these electrodes over the whole surface of the scalp, it is more easy to detect in which general brain area the ERP occurs.
When an EEG measures brain activity, it also measures a lot of noise data [3]. The moment an ERP occurs is however time locked to stimulus presentation, this means that it possible to take a time locked average of multiple ERP's to average out the noise.

1.3 P300

A P300 signal is a component of the ERP which occurs around 250-500 milliseconds after a target stimulus is presented [18]. Because the power of the P300 depends on controlled endogenous attention and the fact that a P300 is easy to detect, it is often used in brain computer interfaces (BCI) with an EEG as measuring device [21]. In P300 BCI's different stimuli are presented after each other, stimuli that the observer focusses on elicit a stronger P300 signal than regular stimuli.

An observer can choose which stimulus he or she focusses on, which makes it for example possible to choose letters to form words [4][7]. This is done by presenting characters in a grid, in which rows and columns randomly flash. If the rows or the column of target character flashes a strong P300 can be measured. Long et al. [11] used the P300 in a hybrid BCI to control a simulated wheelchair, participants were able to control this wheelchair and steer through a known virtual environment.
Strayer et al. [19] investigated the P300 effect in an experiment where the subjects had to react in a driving simulator if the brake lights of the car in front them started going on. They found that if the subject was distracted by listening on the phone, the power of the P300 was lower. This effect suggest that the power of the P300 plays a role in hazard awareness.

1.4 Fixation Related Potentials

An fixation related potential (FRP) is an ERP after an eye movement, time locked on the moment of fixation. In the past FRPs have been used in a study by Marton et al. with subjects reading [15]. In this experiment the FRPs were fruitful enough to establish a time-line of cognitive processes.
Research done by Hale et al. [8] found an overall difference between multiple types of target and nontarget FRPs. This effect could however be explained by numerous different reasons. The saccades to targets could have been systematically different in length from saccades to nontargets, which could lead to different FRPs as Ploch et al showed [16]. It could also be the case that the targets had different visual properties, which also can affect the FRPs, as shown by Marton et al.[14]. Luo et al. [13] describe on a poster a classification approach where target FRPs could be distinguished from nontarget FRPs. In their research, subjects however had to press a button immediately after they identified if there was a target or not. This might have influenced the shapes of the target FRPs and nontarget FRPs, because after indentifying a target a motor response would be prepared. Kamienkowski et al [10] compared target and nontarget FRPs without the problems mentioned before. Kamienkowski et al. also found a difference between target FRPs and nontarget FRPs. Kamienkowski et al. did however not provide analyses to classify single trials.
Brouwer et al. researched if a FRP could be used to reliably distinguish between target and nontarget fixations [6]., this was done by first presenting a target stimulus in the middle of the screen. This target stimulus is the target the observer is looking for. After the target stimulus is presented, six stimuli are presented on an imaginary circle around the middle of the screen on 0°, 60°, 120°, 180°, 240°and 300°. The observer is instructed to look at these stimuli starting from the middle of the screen going up towards the stimulus on position 0°. Then from this location, the observer has to make eye movements to the other stimuli in a clockwise direction. This makes sure that the angle and the distance to the stimuli are the same. The observer has to remember the location of where the

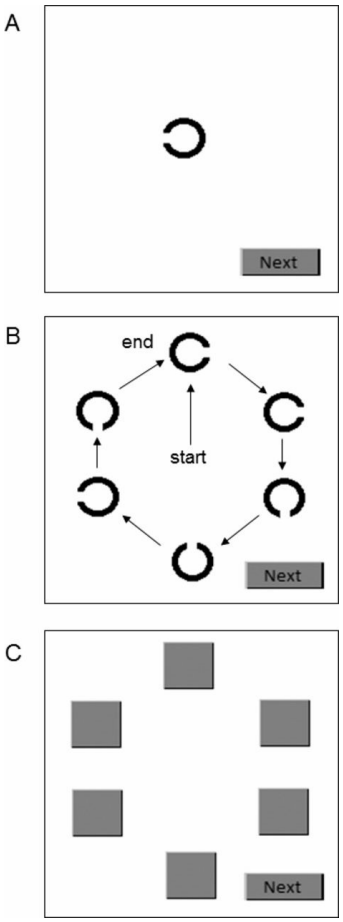


Figure 1.1: Stimulus presentations - Brouwer et al. [6]

target stimuli were presented which has to be reported after the stimuli presentation. The series of events are shown in figure 1.1.

This study showed that FRP's can be used to reliably distinguish between target and non-target fixations.
Wenzel et al. [22] tested in a FRP experiment if it was possible to predict target stimuli with different saliences. They showed that EEG data and eye tracking data can provide some information about the importance of items on a computer screen. Knowing which items on the screen are important could be used for online applications.

1.5 My experiment

In my experiment I want to investigate if it is possible to distinguish P300 FRP's when target stimuli are hard to distinguish from distractor stimuli. I do this by taking inspiration of Brouwer et al. [6] their experiment and adding an extra hard condition to see if it is still possible to measure a P300. It is important that this is the case, because the use of FRP P300 in online applications would be limited if this would not be possible. The usage would be limtited because in online applications targets can hard to be distinguised from distractors. Because of the fact that the stimuli are somewhat more complex, you have to think a bit to see if the stimulus is a target. In order to create an online application for hazard awarness, it is important that multi-feature targets P300 effects can be distinguised from non-targets.
The complexity of a task has influence on shape of the P300 in regular ERP experiments [17], so I would expect to find the same effect in a FRP experiment.

Chapter 2

Methods

2.1 Participants

Five participants (four male and 1 female) took part in this experiment. All but one participant were between 20 and 25 years old, the other participant was 56 years old. All participants signed a consent form for taking part in this experiment. All participants volunteered to take part in this experiment for no compensation. Prior to the experiment a pilot experiment was run with two participants. These two participants were the experimenters themselves, the data from the pilot experiment was only used for prior testing and is not used in this thesis.

2.2 Measuring devices

In the experiment data was measured with an EEG Biosemi Active Two device with 64 electrodes to measure the brain activity. Electrooculography (EOG) data was also gathered with electrodes near the eyes. By measuring the activity of the eyes it is easier the pre-process the EEG data, which will be explained more thoroughly in a later paragraph.
Eye tracking was done by an eyelink 100 eyetracker, using this device it is possible to track the position on the screen the subject is looking for. This way it is possible to know which stimulus is looked at.

2.3 Conditions

In the experiment all participants had to do the experiment in five different conditions. Two control conditions, one complex target conditions and two distractor conditions which are conditions of another thesis. Initially we only had one control condition, however because the pilot data did not show any results another control conditions was added to be able to tell if the EEG data was correct. All conditions were done twice by each participant in blocks of 18 trials, except for two participants who did the conditions twice in blocks of 12 trials. Initially the experiment was in blocks of 12 trials, however because there was some spare time after each experiment it was decided to make each condition somewhat longer. The conditions were presented in random order. I will give a short overview of all the conditions.

Control: The control condition is a very similar to the experiment Brouwer et al. [6] did. It looks like the experiment shown in 1.1. First the target stimulus is shown to the subject.

The target stimulus is a Landolt C with an opening in a particular direction. Landolt C's with openings in other directions are distractors. A second after the target stimulus is shown it will disappear, and six stimuli will be shown on the screen. The locations of the stimuli are 0°, 60°, 120°, 180°, 240°and 300°. The exact locations on the screen are calculated with the sine and cosine of the angle and a fixed distance of 723 pixels of the middle of the screen using a 1920x1080 resolution. The diameter of the stimuli was 108 pixels. The subject is instructed to start at the stimulus at 0°and then has to make eye movements clockwise to the other stimuli. After the subject has seen the stimuli he or she can continue by pressing a button. If the subject went too fast through the stimuli (3 seconds or less), a warning will be shown so the subject will slow down. The reason that the subject has to look at least three seconds to all the stimuli is that we at least need half a second of data per stimulus to be able to find a proper P300.
The subject has to remember which of the stimuli were target stimuli, and has to report on these after the stimulus presentation has finished. This is done by pressing the numbers on the keyboard that are paired with the locations were the stimuli were presented. This is then repeated for the whole block.

No eye movement control: The no eye movement condition was added after the pilot phase of the experiment in order to see if it was possible to find a P300 without eye movements. If this condition was not added to the experiment and no P300 was found in the regular FRP control condition it would be very hard to find the cause of this.
The no eye movement control condition looks a lot like a traditional P300 oddball experiment. First the target stimulus is shown to the subject on the middle of the screen. After the target stimulus disappears, several stimuli are shown after each other on the same place as the target stimulus. Each stimulus is shown for 0.9 seconds before it disappears. The next stimulus is then shown 0.1 second after the previous disappeared. The subject is instructed to remember when in the presentation order the target is presented. So if the second and fourth one were targets and the rest were distractors, the subject has to report two and four. Subjects had to report in the same way as with the FRP control condition.

Complex: The complex target condition was the condition that checked if it is still possible to find P300 effect if the targets were more complex. The complex target condition can be seen as an extension of the FRP control condition. Instead of the stimuli being Landolt C's, they have some extra features. The features these Landolt C's constist of are colour, direction and presence of a dot in the middle. The Landolt C's can have four different colours, four different directions and have a dot in the middle or not.
The presentation of the stimuli is the same as with the FRP control conditions, first a target stimulus is shown. Then when the stimuli are presented in a circle, the target stimuli are the ones that have at least two features the same as the target shown in the beginning. Subjects had to report in the same way as with the FRP control condition.

Attend audio: The attend audio condition is not part of my thesis, but part of someone else. This condition is the same as the control FRP condition with an extra audio file running while the stimuli are presented. The subjects then later have to report which words were said in the audio. The idea of this condition is to see if the power of the P300 is lower when there is an intermodal distractor.

Unattend audio: The unattend audio condition is also not a part of my thesis. This condition was to see if the effect of audio on the P300 was also present if someone does not attend to the audio. This was done by instructing the subjects not to attend to the audio

and playing the audio files of the attend condition backwards so that they also could not attend to it by accident.

I also reported on the attend audio and unattend audio conditions because all the subjects did do these conditions between the conditions that are interesting for me. I will not report on the results in this thesis.

2.4 Data

When an experiment is run, data gets written to three different places. For the analysis data from all these sources are used. I will give a short overview of the data sources.

Psychopy: PsychoPy is the libary that was used for stimulus presentation. Everything that is presented to the subjects is written using this library. The order in which the conditions are presented is random. The places of targets are also determined random in the code. This information is crucial for the analysis, because in order to analyse we need to know which data corresponds to targets and distractors in combination with their condition. After the order is determined the program will write this information to a logfile so it is possible to look it up later on.

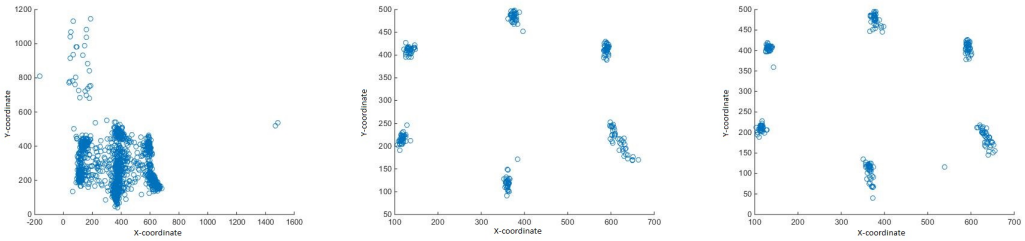
EEG: The EEG measures brain signals with 64 electrodes. Four electrodes with EOG data are added to this. This data is written to a buffer file. The EEG was a Biosemi active two which measured with a sample rate of 2048 Hertz. In the EEG buffer this is downsampled to 256 Hertz. The EEG measures constantly and all data measured during the experiment is send to this buffer. Along with the raw EEG data, markers are also send to this buffer. These markers are send on the moment the stimuli are presented, using these markers it is possible to extract the useful EEG data.
In the no eyemovement control condition multiple markers are send, on the presentation of each stimulus a marker is sent.

Eyetracker: The eyetracker measures the location on the screen of which the right eye of the subject is looking at. This data is then written to an eyelink buffer. This data contains the X and Y location of the screen for each moment the subject was fixating on a particular place on the screen. The begin time and end time of these fixations are also saved. The program that presents the stimuli also sends markers to the Eyetracker. Using these markers it is possible to determine where the subject was looking on the screen the seconds after the stimuli are presented. The eyetracking data was measured using an eyelink 100 with a sample rate of 1000 Hertz.

2.5 Data analysis

2.5.1 Fixations

The first part of the data analysis was getting the right eye tracker information. The eyelink stream contained all fixations that were measured during the experiment. From this the fixations that were made after a marker was sent were taken. Figure 2.1a shows a plot of all these fixations. As you can see there are clusters of fixations on the places where the stimuli are presented on the screen. There is also a cluster on the middle of the screen, this cluster is formed due the fact that the target was presented there before each trial.



(a) All fixations (b) Filtered fixations complex (c) Filtered fixations control

Figure 2.1: Fixations plots for first pilot subject

From these fixations the ones that were at most 80 pixels off the location of the stimuli were extracted. Plots of these can be seen in figures 2.1b and 2.1c.

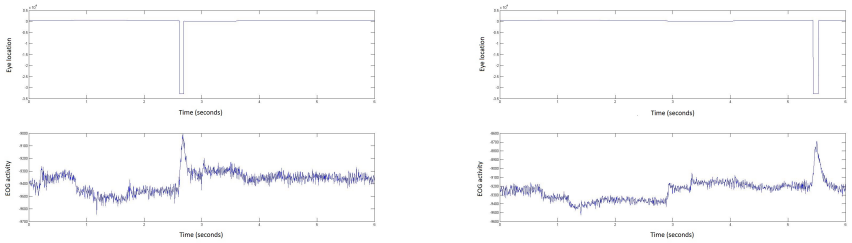
These fixations are the most interesting, because these are the ones that are the fixations on the stimuli in the right timeframe. However, for each trial there can still be multiple fixations on one stimulus per trial. Reasons for this can be that persons look back to a stimulus they had already seen or that they made a small shift with their eyes on the stimulus.
Brouwer et al. [6] chose to remove all fixations that were shorter than half a second to make sure the P300 would fall in this fixations. If that was done in this experiment a lot of fixations would have been removed, for one participant even more than halve. Which is the reason that in this experiment the longest fixation was used.

2.5.2 EEG slicing

From the EEG data stream, smaller EEG packages were created. This was done by looking for the markers in the EEG data stream, which contains the stimulus information. This stimulus information contains the condition of the stimuli and which of the stimuli were targets and which ones were distractors. An EEG data package is then created by taking 15 seconds of EEG data after the marker is read. This guarantees that all the information that is coupled with that marker is contained in this EEG data package.
In order to know for sure that the EEG was properly synchronized with the eyetracker data, some plots were made plotting the eyetracker data against EEG data that were coupled to each other according to the markers send. This was done by looking for blinks in the data. The reason for this is that blinks appear both in the eyetracker data and the EEG data. In the eyetracker data blinks can be found by looking for an error value of -32768, which means that the eye was lost. Which for example happens if the subject blinks. In the EEG data blinks can be found by looking for spikes in the EEG data. These spikes are the result from the movement from the eye muscle which creates a lot of voltage changes.
When plotting this data against each other both effect should be found at the same moment in time. Two of these plots are shown in figure 2.2a and figure 2.2b.

2.5.3 Preprocessing

The EEG packages that are created in the EEG slicing process contain data that might be contaminated with noise. In the preprocessing stage an effort is done to polish away this noise. First if channels or trials have a standard deviations that is 3.5 times larger than the average standard deviations they are removed from the data. This is done because the data is probably not reliable.



(a) (b)

Figure 2.2

After this noise from the outside is filtered out. This is done by the common average reference method[5][12]. This is followed by interpolating the bad channels [9]. This takes away the bad channels and makes a guess of data by averaging the data of the channels around it. Then the eye artefacts are removed by using a surface LaPlacian reference [2][1]. Then a frequency bandpass filter is used to supress noise in the frequency domain. The problem however is that this filter did not filter frequencies from 5 Hertz to 12 Hertz which sometimes left in noise from 10 Hz in the data.

2.5.4 No eye movement

After the preprocessing it is possible to analyse the data of the no eyemovement condition, the EEG slices are made and since the markers in this condition are send for each stimulus no subslicing has to be done for this condition on eyemovements.
The markers did not contain the information if a stimulus was a target or not, this information was however written to the psychopy log file. After extracting the data from this logfile and labelling the EEG data correctly the target vs non-target data can be plotted. The results of one of these is shown in figure 2.3. Here you can see a clear difference 300 ms after stimulus onset if you compare target versus non-target.

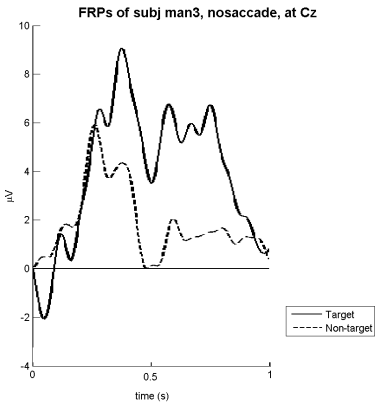


Figure 2.3: P300 no eye movement

2.5.5 Subslicing

Subslicing the EEG data was the last step of
data analysis for the other two conditions. This is done by taking the fixations found in the fixations analysis, and then creating EEG data packages of one second when the moment of fixations found in the fixations analysis overlaps with one of the moments created in the EEG packages created in the EEG slicing. These packages created in this subslicing process then contain the EEG data of the moment of fixation. These packages then have to be labelled to target and non-target. This information is found in the psychopy log. One of the results is shown

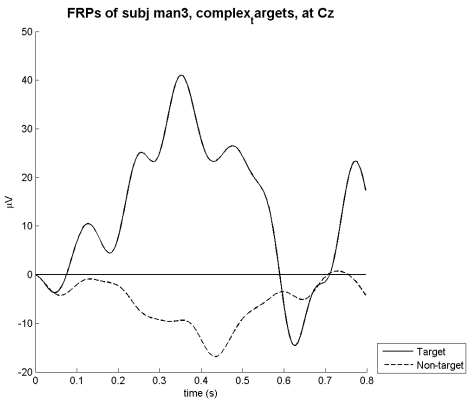


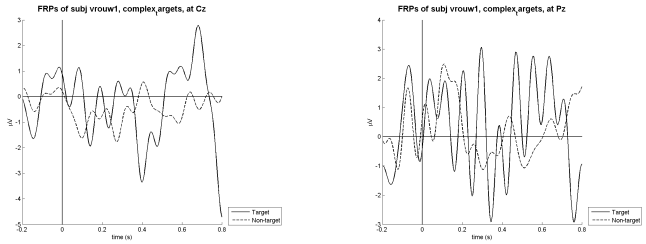
Figure 2.4: P300 complex

in figure 2.4.
This image shows that there is a big difference between target and non-target, however the other subjects had other random effects which suggets that there was effect.

Chapter 3

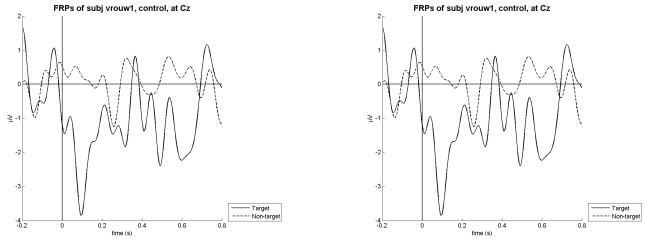
Results

The control condition with no eye movements shows a clear difference in the power of the P300, where the power of P300 of target stimuli is greater than the power of distractors. As shown earlier in figure 2.3. In the control FRP condition there is no indication of a P300 effect and in the complex target condition there is is not an indication of a P300 effect either. The data of these conditions look very noisy as can be seen in figures 3.1a, 3.1b, 3.2a and 3.2b.



(a) (b)

Figure 3.1



(a) (b)

Figure 3.2

The allignment of the eyetracker data and the EEG data seems to be correct as shown earlier in figures 2.2a and 2.2b.

Subject	Control condition	No eye-movement control condition
Male1	0.9861	0.8333
Male2	1.0000	0.9931
Male3	1.0000	1.0000
Male4	0.9955	0.9954
Female1	0.9867	0.9722
Average	0.9937	0.9588

Table 3.1: Response accuracy

As shown in table 3.1 the response accuaracy on both control conditions is quite good, one participant even made no mistakes on both control conditions. However, because something went wrong during the experiments when writing to the psychopy log files, the response data of the participants of complex condition is lost.

Chapter 4

Conclusion and Discussion

No clear P300 effect was found in the control FRP condition and the complex target condition. So no conclusion can be drawn in respect to the complexity of the targets. It is unexpected that no P300 effect was found in the FRP control condition, since this condition was basically a copy of the work of Brouwer et al. [6], who did find a P300 effect.

In this experiment the size of the stimuli was larger than with the experiment of Brouwer et al. [6], maybe the subjects already saw the stimuli in the corner of their eyes. Which might have led to no P300 effect because the stimulus was already seen by the subjects. In further research it might be a good idea to make the stimuli smaller so it can not potentially have an effect on the results.
Another reason why a P300 in the complex and FRP control condition was not found might be because there were less samples in this experiment than in the experiment of Brouwer et al. [6]. In their experiment 240 stimuli circles were presented to the particpiants, while in this experiment 120 or 180 circles were presented. In this experiment this was divided over five different conditions. Therefore, only 10 or 15 percent of the amount of circels were presented in comparison to the research done by Brouwer et al. [6]. Moreover, Brouwer et al. threw away all fixations that were shorter than half a second. This is something that was not done in this experiment, because then there would be even less stimuli that we could have used for the experiment. For all but one participant this would be less than 50 percent. Because a less strict measurement for fixations was used, the data that we found might have been less clean according to Brouwer et al. and Kamienkowski et al. [6] [10]

Several things were done to explain the results that were found. Firstly a check was done to see if the data of the eyetracker and the EEG was correctly synchronized. This was in fact the case as shown in the results.
An extra condition was added to the experiment to see if it was possible to find P300 effects for regular ERP's instead of FRP's, these were also found which suggest that the EEG data is correct.
During the experiment the eye tracker sometimes lost the eye. This led to restarting the experiment. When the experiment was restarted it start labelling the events from the beginning again. This led to markers having the same name sometimes. Since this was spotted it was possible to work around it, however the labelling of the packages was made hard by this. If I would do the experiment again, I would rename the labels in another way such that it is not dependent in which order it was presented.

In the no eyemovement condition labels were not properly named, because of this the labelling of target and non-target had to be done afterwards. Although a P300 effect was found in this condition, thinking about a good labelling would be something I do in a next experiment.

The repsonses of the participants in the complex target condition were not properly written to the psychopy logfiles. Because of this, I was not able to report on the accuracy of the responses in this condition. In further research I would immediately check if all data was saved properly before going further to make sure such mistakes will not be made again.

For further research I would try to do the same experiment again, however this time I would make sure that the same mistakes would not be made again. I would try to gather more data such that there is more data to analyse, which would also make it possible to use a more strict filter for which fixations are used.

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