Radboud University Nijmegen

Bachelor degree thesis in Artificial Intelligence

The effect of prism adaptation on EEG-markers of spatial attention

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Abstract

Prism adaptation to a leftward optical deviation has been considered as a method to produce neglect-like symptoms in healthy subjects. There has been discussion whether these effects can be explained by sensorimotor effects, influence on perception or attention. Using EEG-recordings during a spatial attention task, this study compares ERPs and alpha lateralization before prism adaptation and after prism adaptation in healthy subjects. After prism adaptation there was a significant increase in alpha power, but it is unsure if this is directly caused by prism adaptation. Collectively, the results did not reliably confirm any effects on brain signals after prism adaptation, mainly due to low sample size. With machine learning the EEG-markers are studied on single trial level by comparing predictions based on classification using alpha with predictions based on classification using ERPs. Both, but especially alpha, showed a classification rate significantly better than chance.

Contents

1 Introduction

Spatial attention is the cognitive ability to process events and stimuli on a certain location in space faster and more accurately than events and stimuli on other locations. Especially visual-spatial attention is an essential brain function that enables us to select and preferentially process high priority information in the visual field. Without it, we would be prone to miss events in our periphery which would normally require our attention, e.g. sudden traffic changes.

1.1 Brain-computer interfacing

Heinze et al. [8] used a combination of electroencephalographs (EEG) for temporal scalp recordings of event-related potentials (ERPs) and position emission tomography (PET) for spatial imaging, to study the brain activity during visual attention tasks.
The temporal precision of EEG-recordings is very large, in comparison with for example an MRI or PET-scan which have much smaller temporal precision but a larger spatial precision (see Figure 1). Combining PET with EEG combines the best of both worlds when studying brain activity. However, since not all tasks are suitable for this set-up, often a trade-off is made.

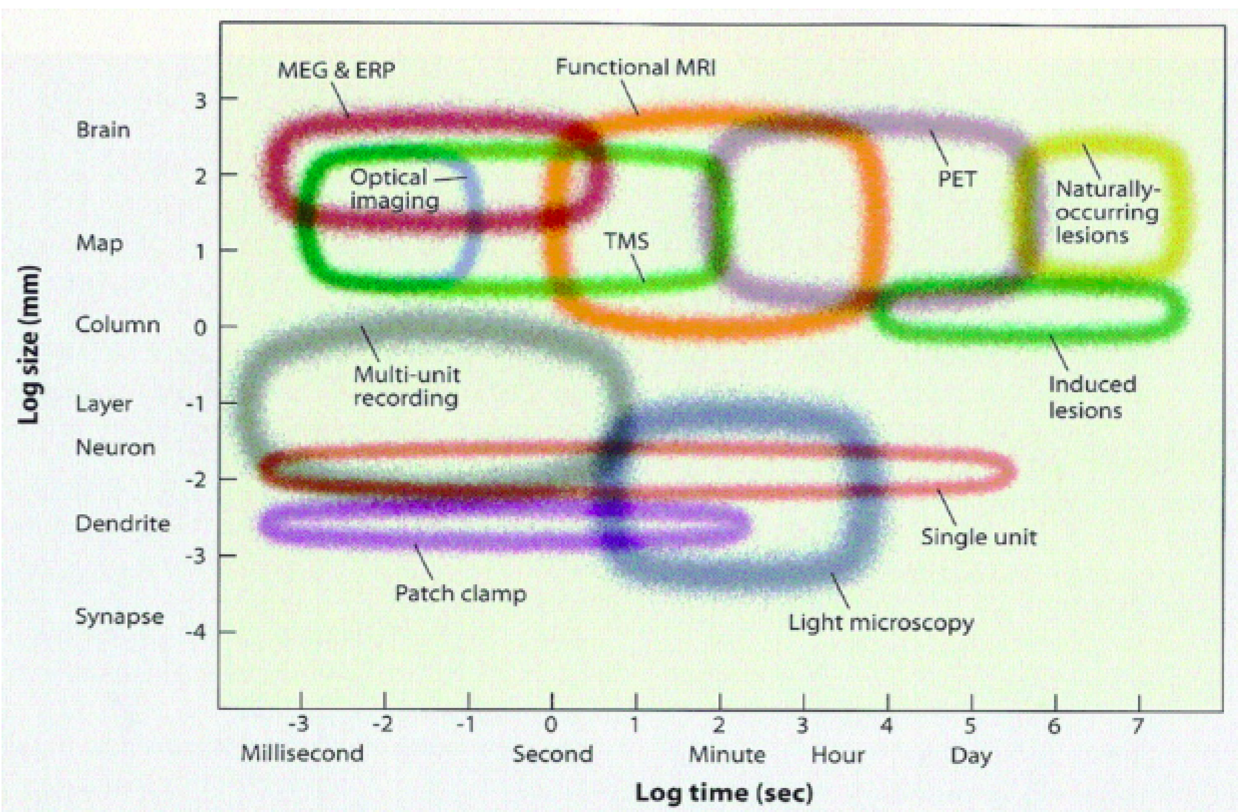


Figure 1: Spatial and temporal resolution of different neuroimaging methods. [1]

Brain functions such as visual-spatial attention can be studied using a task where the subject needs to respond to visual stimuli at a certain location. Brain signals evoked by stimuli, called Event-Related Potentials (ERPs), are recognizable in EEG-recordings. Since ERPs associated with attention are present in a matter of milliseconds, the fast EEG-recordings are preferred over spatial imaging when researching the nature of the brain activity.

EEG can be used in a brain-computer interface (BCI). A BCI is a system which allows someone to communicate information about their mental state without the use of the peripheral nervous system. Although measuring ERPs during a spatial attention task does not always mean the system directly responds to the EEG, the brain signals recorded by the EEG are saved and can be used as a source of information about the mental state. The fast recordings enable us to gain information on a single trial level, which is useful when measuring the difference in attention when attending to different stimuli. The ERPs that are measured may provide information about the level of attention, and, dependent of the location of the stimulus, about the direction of attention.

1.1.1 P300

ERPs are event-related, which means they are envoked by a stimulus, either internal or external. In case of an event, the EEG spikes [5]. One of the most characteristic signals is the P300 signal. When a subject must focus on a certain target and this target-stimulus occurs, the P300 signal - named after its 300 millisecond onset - spikes. The brain is typically active contralateral to the attended visual stimulus [7], but note that P300 is strongest at the Cz-electrode (central electrode at the top of the head). The peak is larger when the subject is more focused, and when the target appears on the attended side of the hemispace.

1.1.2 Alpha lateralization

Another characteristic in EEG-recordings are alpha waves. Alpha waves are related to different brain states. The alpha activity ($8-14$ Hz) correlates with the relaxed wakefulness state with closed eyes, but is also clearly observed in drowsiness before sleep and the rapid eye movement (REM) stage of sleep [2]. Although these stages are all related to sleep, sleepiness or relaxation, alpha activity is also related to attention. The alpha power increases ipsilaterally to the side towards attention is directed. This makes sense, since alpha is associated with rest and the active side is contralateral to the side towards attention is directed, so the ipsilateral side becomes less active.

1.2 Machine learning

Machine learning can be used to determine the quality of the different EEG-signals as classifiers of the data. On a single trial level, where every trial contains a stimulus at the attended side and the unattended side, the presence and height of the P300 peak give information about the likelihood that the subject has focused his attention to a certain location. The same goes for alpha: the difference in alpha power between the left and right side of the brain, for samples of both attention directed toward the left and toward the right, provides information about the side towards which attention is directed.

Comparing the predictions made by the classifiers based on the EEG-recordings with the actual markers, results in a classification accuracy. The accuracy tells us in what degree the EEG data predicts which side the subject has focused on. In other words, how well the EEG shows the differentiation between direction of attention.

1.3 Spatial neglect

If the brain is damaged, this may cause an impairment in spatial attention: spatial neglect. Neglect occurs most often to the contralesional side of the hemispace. Patients with neglect usually perform badly on spatial attention tasks. There are several behavioral symptoms associated with neglect, but there may also be changes in brain activity. Several treatments are available for patients with neglect, mostly behavioral therapy such as prism adaptation. Since neglect is an impairment in the brain, we want to research the implications of the different therapies on restoring brain function. Therefore it is important to study the effect of the therapy methods on the brain activity.

First, understanding of the condition spatial neglect and its influence on behavior and brain signals is needed. Spatial neglect is mostly recognized by the specific behavior it causes, but may also show certain characteristics in brain signals (see Section 1.3.3).

1.3.1 Etiology

A cerebrovascular accident (CVA) - or in common language, a stroke - are infarctions of the brain. Large infarctions in the right, less often the left middle cerebral artery can cause lesions which center on the inferior parietal cortex, and are the most frequent cause of neglect [10]. Not only the parietal cortex, but damage to the superior temporal cortex or basal ganglia can cause neglect. Also intracerebral bleedings, tumors or traumatic injuries in or of the aforementioned areas can result in neglect.
Kerkhoff states there is a clear asymmetry showing that neglect occurs more often after lesions in the right hemisphere (and is more frequent contralesional in the right hemisphere), causing left-sided neglect.

1.3.2 Behavioral effects

Neglect is usually used synonymous with sensory neglect, but Kerkhoff also elaborates on motor neglect and representational neglect. In this thesis, the focus lies on sensory neglect - and more specifically, visual neglect. There are different modalities in which neglect can occur. Visual, auditory and tactile (and sometimes olfactory) all denote the (partial) inability to react or process sensory stimuli, presented in the hemispace contralateral to a lesion of the cerebral hemisphere [10].

Typical behavior of patients with visual neglect is recognized as deviated searching for stimuli and attention to stimuli. This can be directing their eye- and head-movements more to the ipsilesional hemispace, not noticing people entering the room when they enter at their neglected side, only eating the ipsilesional side of their plate or omitting contralesional stimuli during reading, writing and drawing. Other behavior can be acquired to compensate for their disorder, such as searching by touch to find the edge of a piece of paper to find all stimuli on it. This is why it can be useful to measure the time required to complete standard neglect test alongside the score [15].

1.3.3 Effects in EEG

The failure to detect and respond to stimuli, even in the absence of sensory or motor loss, has raised the question if neglect is a disorder in perceptual processing or in attention and higher-level functions. ERPs have unique components that can be associated with different levels of processing. That is why ERPs can differentiate between perceptual and cognitive processes [4].

Deouell et al. [4] studied the effect on the early sensory, preattentive processing by examining ERP components such as the N_1/P_1 complex. For the effect on the disruption in attention mechanisms, they also studied the effect on P300 amplitude. They only reviewed studies on patients with right-hemisphere damage.
The N_1 components are smaller over the damaged hemisphere, regardless of side of stimulation. In healthy subjects, N_1 is larger over the hemisphere contralateral to the stimulus. The abnormality decreased with recovery. This reflects the patient's difficulty orienting towards the contralesional side of space. For P300, Deouell et al. found a delay of the peak and a smaller amplitude. The late positive potential was largest for a right cue and left target.
More recently, Saevarsson et al. studied P300 in neglect [15]. They also reported a reduced P300 to contralesional targets. However, patients still produced stronger P300 responses to contralesional targets than distractors. The P300 amplitudes are correlated with scores and time in standard neglect tests.

Research on the effect of neglect on alpha is still in progress.

1.4 Prism adaptation

Prism adaptation is using a prism glasses (which deviates the visual field) to shift the gaze of the user toward a certain direction. This is a behavioral therapy for patients with neglect, to shift the attention of the patient toward the neglected side in hemispace. Besides therapy for neglect, prism adaptation has become a subject of interest because of its effect in healthy subjects. Colent et al. [3] and Michel et al. [11][12] have both studied the use of prism adaptation to simulate neglect. The behavioral effects of using prism adaptation in healthy subjects are neglect-like, since the shift in visual field is not reducing the deviation as in patients, but induces a deviation.

Prism adaptation is used in patients alongside therapies where the patient learns to cope with neglect. This coping is usually compensating on a behavioral level, whereas neglect is an impairment on brain level. The neglect simulating effect of prism adaptation in healthy subjects provides an opportunity to research (in healthy subjects) whether prism adaptation has an effect on brain signals - instead of visuo-motor effects alone - which might help physicians improve therapy for patients with neglect, or stimulate research with prism adaptation to understand spatial neglect better.

Rosetti et al. [14] have used rightward deviated prism glasses to study the effect on rehabilitation of left hemispatial neglect. Prism adaptation is merely a visual distortion, but according to Rosetti et al. this stimulates neural structures responsible for the transformation of sensorimotor coordinates and can improve the pathological shift of the patients. Rosetti et al. focused their research on the shift of the subjective midline of the patients, and compared this to the effect of prism glasses in healthy subjects. See Figure 2.

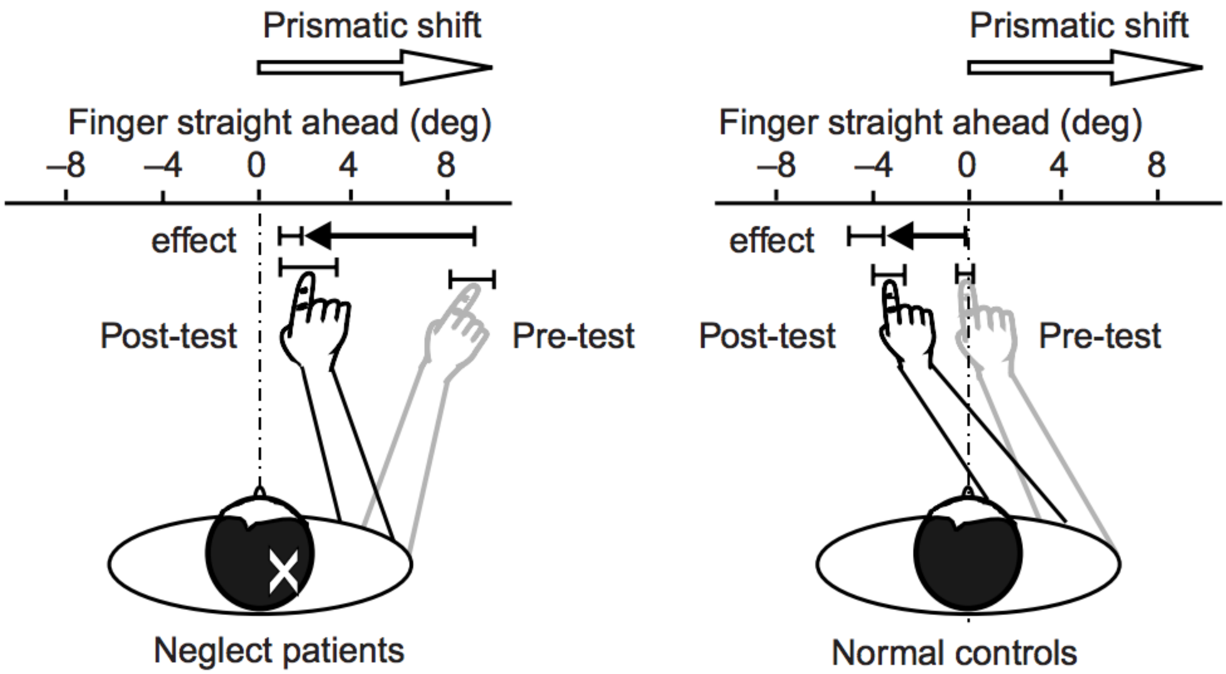


Figure 2: Effects of rightward prism adaptation on subjective midline in neglect patients and control group [14].

Actively steering their attention toward the right with prism glasses, has a rehabilitating effect on patients. In healthy subjects, no side of the hemispace is neglected and putting the glasses on shifts the gaze of the subjects toward the right, causing them to overestimate where the midline is. The prism adaptation reduced the deviation in neglect patients, but caused a deviation in healthy subjects. The deviation in pointing to the subjective midline is considered a neglect-like symptom and the aftereffects of prism adaptation on healthy participants have since become a new subject of interest. Although Rosetti et al. argue that the prism adaptation stimulates neural structures, and results are shown that the deviations in patients decrease with a lasting effect, the effect in healthy subjects merely lasts a few minutes, since the healthy neural structures easily adapt back to the normal situation. The question is raised if there are perceptual effects alongside the sensorimotor effects found in the experiment by Rosetti et al., and if prism adaptation is a valid method to simulate unilateral neglect symptoms. Previously there has been research on neck muscle vibrations in directing attention elsewhere in neglect patients and healthy subjects [9], that had respectively rehabilitating and neglect simulating effects, but prism adaptation provides a more comfortable opportunity to study neglect-like symptoms in healthy subjects.

1.4.1 Sensorimotor effects versus cognitive effect

Colent et al. studied both rightward and leftward optical deviation in healthy subjects. The goal was to asses the cognitive effect of prism adaptation in normal individuals [3]. The subjects had to perform perceptual and motor line bisection tasks. The left-deviating prisms induced a stronger rightward bias for the perceptual, than the motor line bisection task. However, no significant effect is produced by right-deviating prisms. Since Rosetti et al. found symmetrical effects of prism adaptation, these asymmetrical results cannot be explained by the sensorimotor effects alone. Michel et al. assessed several uncertainties of prism adaptation by conducting experiments with leftward deviating prisms. They concluded that it is possible to produce a reliable bias on line bisection, a rightward deviation, that the aftereffect is specific to active adaptation rather than passive exposure, and re-adaptation is slower when movement under normal vision is restricted [11]. The last of these conclusion confirm earlier findings by Redding and Wallace [13]. They studied the effects of pointing rate and visual feedback of prism adaptation.

Three years after her paper on theoretical implications of prism adaptation, Michel reviewed the several methods of simulation of spatial neglect and questioned in what degree they are a simulation [12]. She argues that neglect-like behavior induced by these methods are strongly restricted to experimental conditions and need to be considered with caution. Nevertheless, the results are deemed promising and helpful to offer insights into the neurophysiological processes of neglect. Striemer and Danckert however, dispute the dominant view that prisms influence higher order visuospatial processes by acting on brain circuits controlling spatial attention and perception [17]. They propose alternative explanations for the beneficial effects of prisms, concerning the dorsal visual stream, and argue that prisms have little influence on the perceptual biases that characterize neglect.

From this point on, a discussion has started between Striemer and Danckert and Saevarsson [16][18]. They both critize the interpretations made about the effects on motor and perceptual components. Both hypotheses get support and critizism, which leaves the interpretation of the effects of prism adaptation open for further investigation.

1.5 Goals

Using EEG-recordings to measure brain activity, this thesis is about the effects of prism adaptation on P300 and alpha waves. The brain signals are measured during a spatial attention task, before and after prism adaptation.

EEG is used to study the effects on single trial level. The classification rate of P300 and alpha is determined using machine learning, to find out which predicts the direction of attention best and in what degree.

The research question for the experiment consists of three main parts:

1. 'Is there a difference in P300 and alpha between the normal state and after prism adaptation?'

2. 'Is there a left versus right difference in P300 and alpha between attention left and attention right and is this difference the same before prism adaptation compared to after prism adaptation?'
3. 'How well do P300 and alpha recordings predict whether the participant directed his attention to the right or left?'

The third question helps us gain insight in the usefulness of the task and EEG-recording and the first two questions help answer the question if prism adaptation has an effect on the brain activity during spatial attention tasks.

2 Methods

2.1 Participants

Ten right-handed healthy subjects participated in this experiment (three females, seven males; age: 19−26 years (mean = 20.9 years; S.E. = 2.1 years)). The experiment was approved by the ethical committee of the Faculty of Social Sciences of the Radboud University and all the participants gave informed consent.

Participants were primarily found amongst AI students at the Radboud University. Participants were excluded from the experiment when they exhibit certain symptoms or disorders, amongst poor-sightedness and dyslexia. The following exclusion criteria were used:

- Low score (<100) on the Behavioural Inattention Test (BIT). This is a standardised test for neglect [19]. Only three subtests of the conventional part to detect neglect were used: letter cancellation, star cancellation and line bisection.
- Cognitive deficits that made comprehension of the information letter and intructions difficult, or motor impairment that made holding a pen or pushing a button impossible. These deficits are common for patients after a CVA and uncommon amongst students, but still needed to be absent in my participants as well.
- Epilepsy. I used flickering stimuli in the experiment.
- Dyslexia. I used the letters X, A, B and C in the experiment and the participant should have no trouble distinguishing between letters.
- Correctional glasses. Poorsightedness can make detection of the letters more difficult. Corrected sight is usually fine, although the eyetracker has difficulty detecting the eye when the participant wears glasses. People wearing contact lenses were not excluded.

2.2 Experimental paradigm

The experiment had a within subject design. Every subject performed the same sessions. The conditions were always in the same order. Eventhough the aftereffects of prism adaptation subside, the time needed for the aftereffects to disappear completely is unknown and could vary between subjects. Therefore the condition without adaptation should preferably be measured before the adaptation, or during a session on another day.

The experiment started with the three subtests of the BIT: letter cancellation, star cancellation and line bisection. The participant was capfitted, the position of the camera of the eyetracker was adjusted and the eyetracker was calibrated to the eyemovements of the participant.

The participant had to perform three sessions in the experiment. The task (see Section 2.2.1) was explained beforehand and the first session was a training session to get acquainted with the task and practice, with opportunity to ask questions. The training session began with the task where the subject did not have to look at the fixation cross. When the subject had reached 25 points (five correct answers), the training session continued with the task where the subject did have to look at the fixation cross. When 80 points were reached (an additional eleven correct answers or eyegazes), the training session was completed and the second session commenced. The second session was the normal state, without prism adaptation. This session consisted of 60 trials of the spatial attention task. The third session consisted of three subsessions, each began with prism adaptation followed by 20 trials of the same task as before. This session was divided into three subsessions, because the aftereffects of prism adaptation subside after a few minutes. Between subsessions, there was time to re-adapt to the prism glasses so during the next subsession the subject was still adapted to the glasses. The timeline of the experiment is shown in Figure 3. Since trials with incorrect eyegaze were discarded and the amount of data has a high priority, participants sometimes took additional trials if they had difficulty with the eyegaze. This was monitored live and adjusted immediately, so the order of the conditions remained the same. When necessary, there were 20 trials added to the second session, or one subsession (including prism adaptation) to the third session.

Only the brain data gathered in the 'before prism' session and the 'after prism' sessions are used. During the practice session the participant was still allowed to ask questions, not all trials measured for correct eyegaze and the amount of trials in the practice session was dependent of the difficulty the participant had with the task.

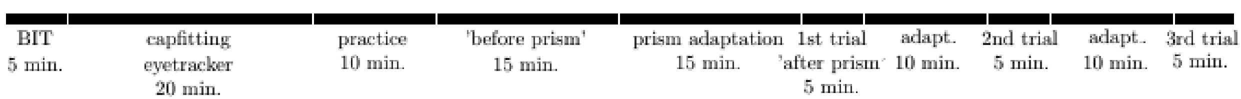


Figure 3: Figure 3 shows the estimated timeline, not including breaks, of the experiment. The experiment starts with the BIT, capfitting, calibrating the eyetracker and a practice session. The second session 'before prism' starts immediately after. The third session 'after prism' starts with 15 minutes of prism adaptation and the first 20 trials, followed by two times 10 minutes of prism adaptation and 20 trials.

2.2.1 Task

The task was a spatial attention task, where the participant had to focus on Xs in one of two blocks, left or right. In each block the letters A, B, C and X were flickering in pseudorandom order. The X was the target stimulus, and the A, B and C were non-targets. Both sides showed Xs, never two Xs immediately after each other and never two Xs at the same time.
There was a small + in the middle of the blocks to fixate the eyegaze. The participant had to keep his gaze on the fixation cross, while counting the amount of Xs on the target side. At the beginning of each trial, above the fixation cross an arrow was shown to indicate the target direction. The task is shown in Figure 4.

Each trial lasted six seconds in which five or six Xs were shown. In the end, the participant was asked how many Xs he had counted, a multiple-choice question with these two options which can be answered with button presses.

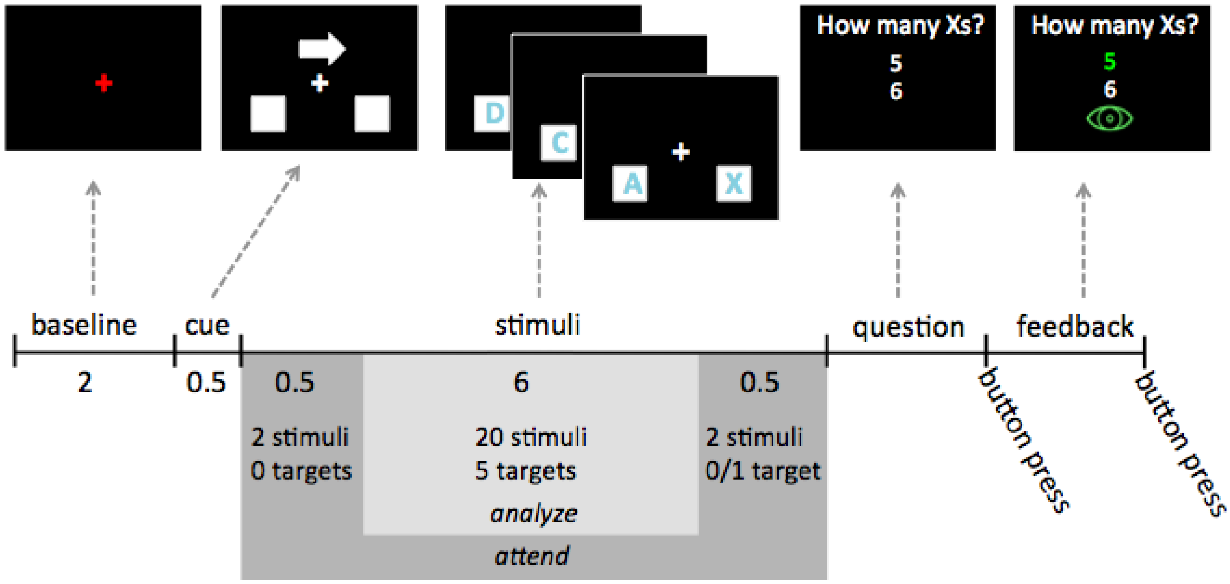


Figure 4: The timeline of a single trial is shown. The baseline is the fixation cross. The cue for direction of attention is given and the stimuli commence. After the stimuli, the system asks the participant how many Xs he has counted at the attended side and feedback is shown immediately after.

2.2.2 Feedback

In the experiment feedback is given to motivate the participants to perform well. During each trial, the participant is asked to answer a multiple choice question on how many Xs he has counted. The participant will receive a score of +5 if the answer is correct, and an additional +5 if the eyegaze was correct, when the eyegaze did not move too close to the blocks with stimuli and the subject did not blink. This score plus the total score is given directly after the answer is given. The feedback screen is the last screen shown in Figure 4.

Besides motivational purpose, the score was irrelevant for the research. Since trials were discarded due to incorrect eyegaze or added when too much trials had to be discarded, the additive score was not representative.

2.2.3 Prism adaptation

For the experiment a prism glasses were used, with a leftward optical deviation of 15 degrees. The participant trained actively to adapt to the glasses. The adaptation lasted 15 minutes the first time, and 10 minutes the second and third time. In front of the participant, a piece of paper (A4 format, landscape orientation) was taped to the desk with a dot in the middle and two star-shaped figures at both ends. The participant must point continuously with his right hand at the star-shaped figures alternated while wearing the glasses, to adapt his hand-eye coordination. The participants were observed while pointing and instructed if necessary to minimize dissimilarities between participants. When the glasses were removed, the participant was asked to look once at the dot in the middle, and then close his eyes and try to point at the dot. The deviation from the dot in the middle was measured in centimeters (positive number for

the right side and negative for the left side) and were not reported to the participant untill all trials were done. After each round of trials the participant was asked again to point at the dot with his eyes closed, to determine if there was still a shift.
Between adapting, the participant was asked to use his right hand as little as possible and keep his eyes closed as much time as possible. The participant was asked to press the buttons with his left hand during the trials, and only open his eyes during the trials and to look at the dot before pointing.

2.3 EEG recording

The EEG is recorded with a BioSemi Active Two system (`http://www.biosemi.com/products.htm`) with 64 electrodes. The electrodes are gel-based. For reference the CMS and DRL electrodes are used. The sample rate was 2048 Hz.

2.4 Eyetracker

An eyetracker was used to determine whether or not the participant looked correctly at the fixation cross (+) on the screen instead of at the blocks. I used an EyeLink 1000 eyetracker (`http://www.sr-research.com/EL_1000.html`) to register eyemovements. Adjusting camera position and calibration of the eyetracker took about five minutes. The sample rate was 1000 Hz.

2.5 Preprocessing

First, the raw EEG-data was sliced to keep the trials - of six seconds - and throw away the rest. The trials with incorrect eyegaze were removed. The data is rereferenced with common average reference, subtracting the average over channels from the channels to remove noise. The outlying trials and outlying channels (standard deviation >3.5) were removed. The rejected channels are interpolated, based on the recordings of the channels proximate to the faulty channel the missing data was approximated to prevent too much loss of data. The ERP data is also filtered spectrally, discarding all data <.1 Hz and >15 Hz, gradually discarding data between .1 and .5 and between 12 and 15 Hz, and keeping all data between .5 and 12 Hz. Most ERP components are measured between .5 and 12 Hz, so this data is of the greatest importance when studying ERPs. For alpha, preprocessing is the same except there is no filtering, since the alpha waves are typically between 8 and 14 Hz and it is important to keep all data of alpha.

2.6 Statistical analysis

For all tests, α was 0.05 to ensure a 95% confidence level. A one sample t-test was used to determine whether there was a shift after prism adaptation, comparing the results of pointing at the dot with the assumption of no shift at all in the 'before prism' state. This was done for both the average deviation directly after adaptation versus zero and the average deviation after the trials versus zero. A paired samples t-test was used to analyse the decline of prism adaptation during the trial.

A repeated measures ANOVA was used with factor Adaptation (before versus after) and factor StimulusSide (left versus right) as factors. Multiple dependent variables

were analyzed, one behavioral (percentage correct answers), P300 onset time, P300 peak height, alpha power and alpha frequency. For the dependent variables concerning P300 (onset time and peak height) the third factor Target (target versus non-target) was added.
The average shift in centimeters after prism adaptation (see Section 2.6.1) was used as a covariate in linear regression for the dependent variables.
Each trial contained several targets at the attended side and the unattended side, and non-targets. For every subject the average over trials of each type was taken. For each of these stimuli the mean strength (in μV) and onset time (in milliseconds) of the peak closest to 300 milliseconds after the stimuli are presented is measured. For attended targets and non-targets, the peaks measured at the Cz-electrode are used for analysis.

For the alpha waves the measurements at all occipital electrodes were averaged, and the maximum power in the alpha band (in μV) and frequencies (in Hz) were used for analysis. The frequency of alpha waves are roughly between 8 and 14 Hz.

2.6.1 Prism adaptation as covariate

The shift in centimeters was primarily used to determine whether the participants adapted to the glasses. The individual values are not very representative since some participants did not follow instructions one time and opened their eyes while pointing, or there was a missing value. Per participant the deviations in centimeters were averaged, both for the deviations directly after adaptation and the deviations after the trials. The average between these two (after adaptation versus after the trial), indicating as good as possible the average amount of adaptation during the task, was calculated and used as covariate in analysis. Since deviation is only present in the condition 'after prism', and thus not the same during 'before prism', this is a time-varying covariate. For time-varying covariates the variable cannot be used the same as a covariate like age or sex (which stay the same during the whole experiment), and both the deviation in 'before prism' and 'after prism' needed to be measured. Unfortunately, the deviation is not measured during 'before prism' so the covariate cannot be used as such. To determine whether the amount of deviation has influence on the separate dependent variables in 'after prism' and thus should have been taken into account as covariate for this analysis, linear regression is used per dependent variable.

2.6.2 Classification rate

After preprocessing, a classifier was trained using the EEG data, to determine whether the participant was attending to the left or to the right. The accuracy was determined by comparing predictions of the trained classifier with the actual labels of the stimuli. The better the accuracy of the classifier, the better the EEG data shows to which side the participant is directing his attention. See Chapter 3 for more information on the classifiers used in this project.

3 Classifiers

3.1 Targets versus non-targets

Responses to transient stimuli were spatially whitened to remove cross correlation between channels. The number of targets (the letter X) and non-targets (A, B and C) was not the same, since there are more non-targets than targets. This amount was balanced by taking a random selection of the non-target letters instead of all non-targets, so there are just as much targets as non-targets. A regularized linear classifier was trained to separate the target and non-target classes. The codebook C is a matrix of two sides (left and right) by twenty stimuli, such that each value in the matrix corresponds to one stimulus during a trial, either attended or unattended. The height of the values indicate for each side-stimulus-combination whether it is a target or non-target. A linear logistic regression objective was used, with ten-fold cross validation to set the L2 regularization strength. The classification performance of the separated responses to target letters from responses to non-target letters was calculated.

3.2 Attention left versus attention right

The goal was to separate responses in attention directed to the left from attention directed to the right. The sliced data (into trials of six seconds containing twenty stimuli) was used in the decoding procedure, where the responses to the twenty stimuli were combined to determine whether each stimulus was a target or non-target. Since codebook C consists of the information where the targets were both for the left side as the right side, the decision values for direction of attention can also be derived using the codebook. By the end of the sequence the twenty decision values for the target versus non-target classification were multiplied by the actual targets in the codebook and summed, resulting in one decision value for right-sided attention and one for left-sided attention. The side with the highest decision value was selected.

3.3 Alpha lateralization

The power in the frequencies from $8-14$ Hz was used to classify alpha lateralization. Since attention to the left increases alpha power at the left occipital side and decreases alpha power at the right side, and vice versa, the comparison between these left to right differences also provides information about which side the attended side is and alpha can be used as a classifier for direction of attention. Only occipital electrodes (PO3, PO4, PO7, PO8, POz, O1, O2 and Oz) were used. Regularized linear classifiers were again trained with ten-fold cross validation and classification performance was calculated from the binary problem.

For classification based on multiple signatures (both on ERP and alpha), we summed the decision values of the single signature classifiers and computed the proportion of correctly classified trials.

4 Results

4.1 Prism adaptation

First, a one sample t-test was used to determine whether there was deviation when pointing at the dot after adaptation. The average of shifts directly after the prism glasses were removed (mean = 7.9567, S.D. = 2.02834, N = 9) was compared to the assumption that before adaptation there was a shift of zero ($t = 11.768$, d.f. 8, $p < .001$).

Second, a paired sample t-test was used to determine whether there was a decline in adaptation directly after adaptation and after the trial. The average of shifts directly after the trial was compared to the average directly after adaption (mean difference = 2.003, S.D. = 1.15716, $t = 5.194$, d.f. 8, $p < .001$).

Third, since there must be a deviation during the whole trial, the average of shifts at the end of the trials (mean = 5.9533, S.D. = 1.50924, N = 9) was compared to the assumption that before adaptation there was no shift. Again, a one sample t-test was used ($t = 11.834$, d.f. 8, $p < .001$).

4.1.1 Deviation as covariate

With linear regression is determined whether the average deviation in centimeters (mean = 6.9547, S.D. = 1.69147, N = 9) has an effect on P300 peak height, P300 onset time, alpha power, alpha frequency or percentage correct answers. This is tested for each dependent variable in the 'after prism' condition only.

Strength of adaptation was not significantly correlated with any of the dependent variables.

4.2 Behavioral

A repeated measures ANOVA was used to test the effects of the factors Adaptation (before versus after) and StimulusSide (left versus right) and the interaction effect Adaptation × StimulusSide on the percentage correct answers (67.94% before prism, 71.56% after prism). No significant results were found. However, for Adaptation there was a medium effect-size found ($\eta^2 = .155$) which suggests that the N-size is too small.

4.3 Classification accuracy

See Figure 5 for the performance of the classifier averaged for all subjects. Both the classification rate of ERP and alpha and ERP + alpha combined perform significantly better than chance. Especially alpha has a high classification accuracy. ERP seems to add little to the accuracy when combined with alpha.

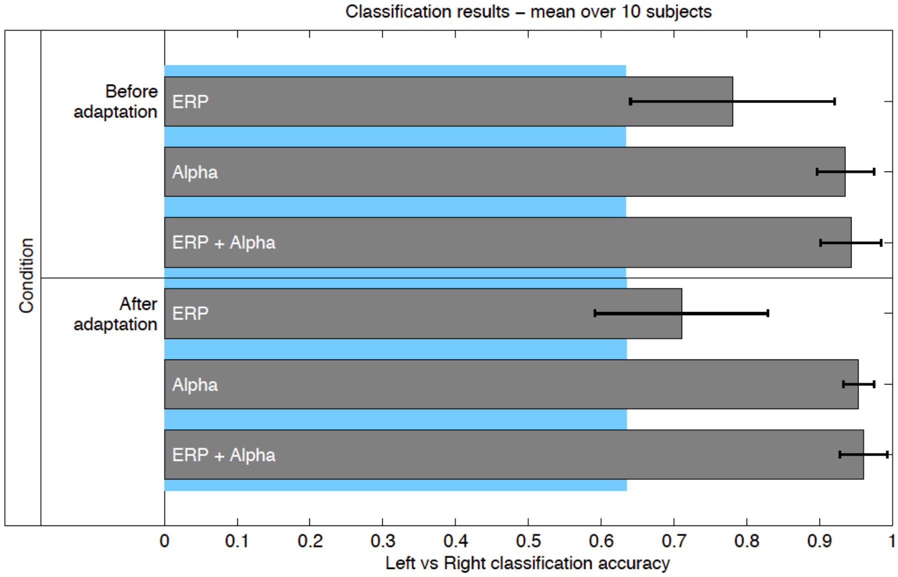


Figure 5: Grand average over all subjects of classification accuracy using ERP, alpha or ERP + alpha combined. The blue markings indicate the chance level, so the classifications perform significantly better than chance.

4.4 ERP

A 2×2×2 repeated measures ANOVA was used for the effect on P300 onset time. The three main effects of the factors Adaptation, StimulusSide and the third within subject factor Target (target versus nontarget), the three first-order interaction effects and the second-order interaction effect were tested. None of the effects were significant. Again, a medium effect-size was found for Target (η^2 = .122), for Adaptation × StimulusSide (η^2 = .134) and even a large effect-size for Adaptation × StimulusSide × Target (η^2 = .239), which again suggests that the N-size is too small.

Also for the P300 peak height a 2×2×2 repeated measures ANOVA was used with the same factors. None of the effects were significant.

The plots do show (see Figure 6) that the difference between target and non-target is not the same for before and after prism adaptation. Especially around 400 ms after stimulus onset, the difference between target and non-target is much greater before prism than after prism.

4.5 Alpha

A repeated measures ANOVA was used to test the effects of the factors Adaptation and StimulusSide and the interaction effect Adaptation × StimulusSide on the alpha power and the alpha frequency. No significant result was found for the alpha frequency, although there was a large effect-size found for Adaptation with p <.1 (F(1,9) = 3.692, d.f. 9, η^2 = .291).

For the alpha power, there was a significant effect of Adaptation (F(1,0) = 4.000, d.f. 9, η^2 = .308, p <.01). The results of the ANOVA for alpha power, are shown in Table 1.

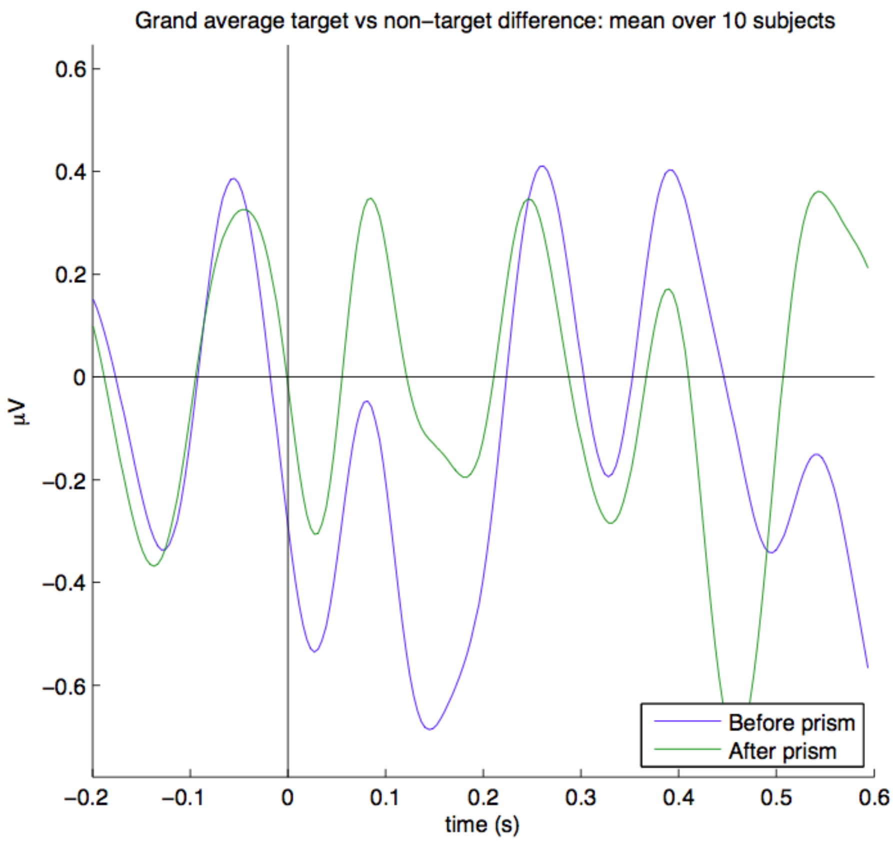


Figure 6: The difference between target and non-target responses is shown for both before prism adaptation and after prism adaptation. There is a small change in onset time and around 400 ms after stimulus onset the differences between target and non-target increase.

Dependent variable	*Contrast*	*StimulusSide*	*Adaptation*	*Adaptation × StimulusSide*
Alpha power	Before + After	F(1,9) = 4.000* η^2 = .308		
	After vs. Before		F(1,9) = 15.586** η^2 = .634	F(1,9) = 1.385 η^2 = .133

Table 1: The results of the repeated measured ANOVA on alpha power. ** p <.1; ** p <.01*

There is a significant effect of Adaptation on alpha power. This effect increases the alpha power in the condition 'after prism'. The direction of the effect can be seen in Figure 7. Although the EEG-recordings from the occipital electrodes are averaged for analysis, the powerspectra in different electrodes of the different conditions of Adaptation (before versus after) can be seen in Figure 9.
When averaging the occipital electrodes we lose the left versus right differences in electrodes. In Figure 8 the alpha modulation averaged over subjects is shown. Alpha

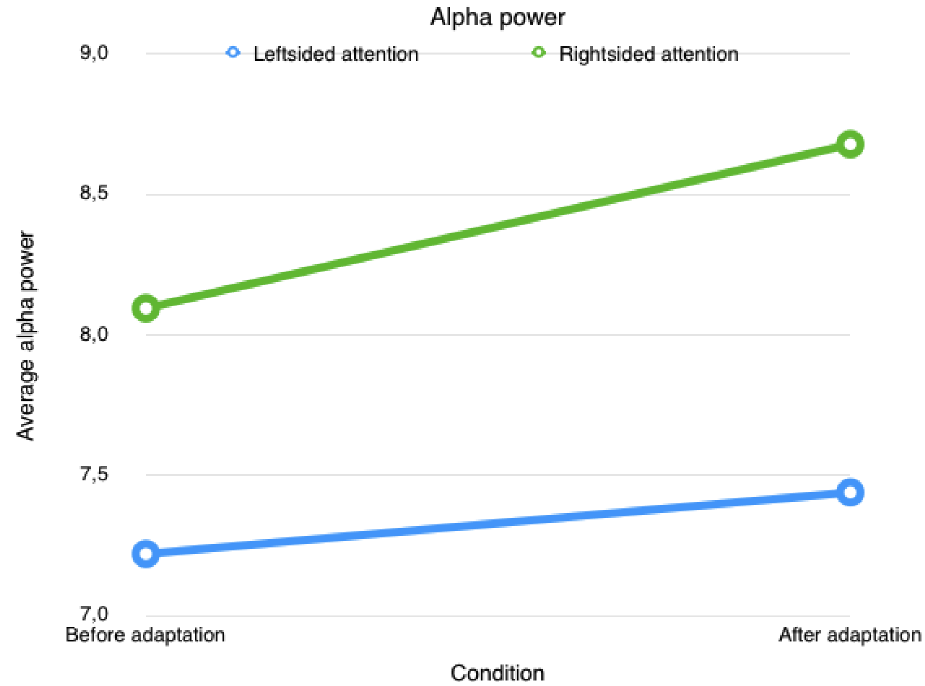


Figure 7: The effect of Adaptation on the alpha power is shown. The marginal means are in uV.

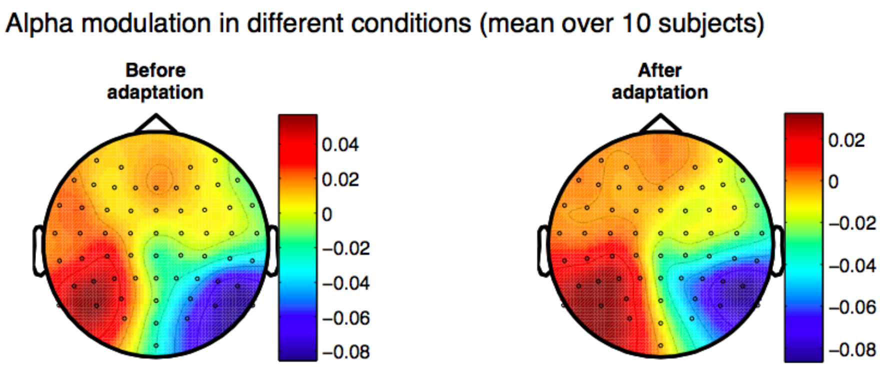
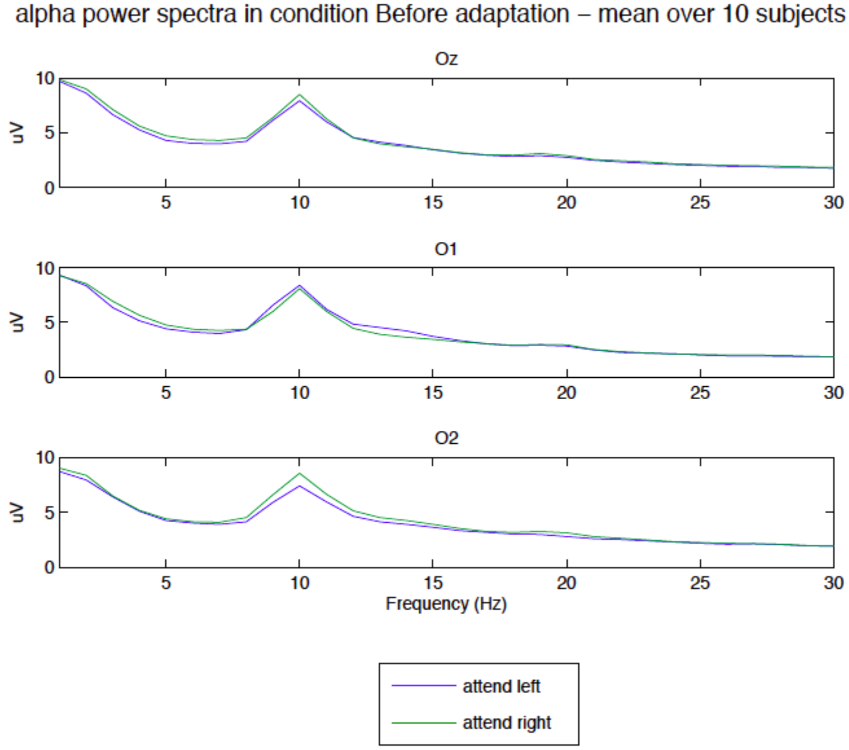


Figure 8: Alpha modulation is the difference between left and right occipital brain activity, divided by the sum of left and right activity.

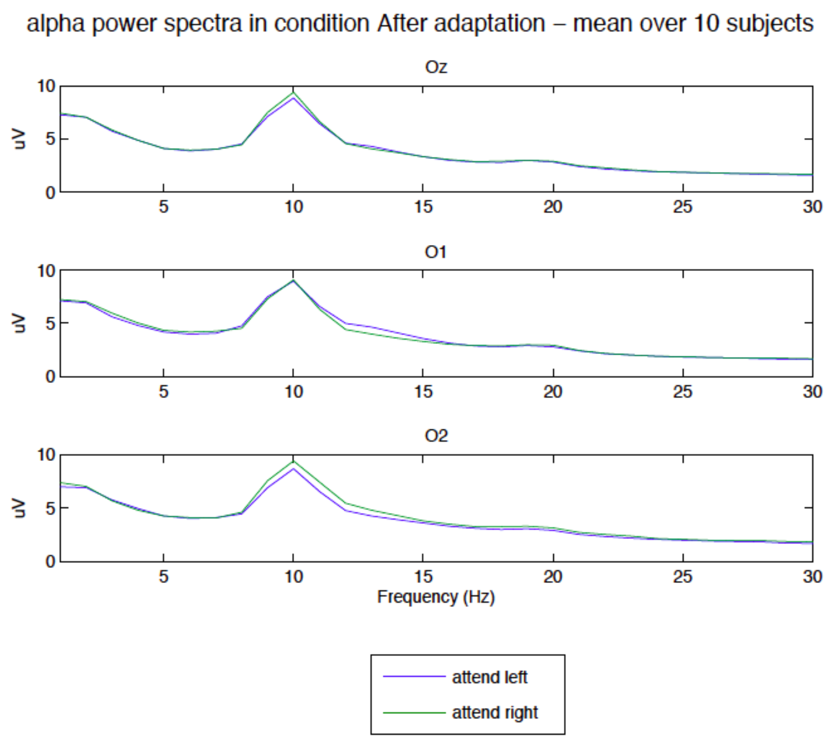
is modulated by taking the difference between left and right, and divide it by the total of left and right ($\frac{alphaleft-alpharight}{alphaleft+alpharight}$). The modulation plots look very typical.

4.6 Power

Since medium or large effect-sizes were found but with the p-value below the critical α of .05, this could indicate that N was too small. With G*Power (`http://www.gpower.hhu.de/`), a tool to compute statistical power, for this data analysis the achieved power (1-β error probability) is .205. To increase the power to .8, N should be 52 or higher.



(a)



(b)

Figure 9: The average over subjects in powerspectra of alpha 'before prism' is shown in Figure 9a, whereas the average result for condition 'after prism' is shown in Figure 9b. Oz is the central occipital electrode, O1 the left occipital electrode and O2 the right occipital electrode. A small difference in uV can be seen between conditions at the peak. Also, as we would expect based on theory, the left electrode has a slightly higher alpha power when attending left, and the right electrode has a higher alpha power when attending right.

5 Discussion

5.1 Experiment

5.1.1 Findings

There was only a significant effect found of condition Adaptation on alpha power ($F(1,9) = 15.586$, $\eta^2 = .634$, $p < .01$). This effect was positive. The primary explanation is that prism adaptation is associated with the alpha power, but several remarks can be made. First, the statistical power of the analysis is very low, making a bias due to small sample size (wrongly assuming normal distribution) more probable, wrongly assuming significance since the data could not be representative for the population. Second, the conditions were not randomized over participants and elapsed time could be a confounding variable. Considering the nature of alpha lateralization (see Section 1.1.2) - the left to right differences in drowsiness -, a possible explanation is that the increased power is a natural effect of performing repetitive tasks and not due to prism adaptation.

Another consideration that has to be made, is why all other effects were not significant. This does not necessarily mean that the factors did not have any effect on the dependent variables. The low statistical power makes a type II error more probable, wrongly assuming H_0 to be true.

No effect of the amount of deviation in centimeters has been found on the different dependent variables. However, since the covariate is usually analyzed as an interaction effect of the variable with the factors involved and not with separate regressions, the effect of amount of deviation should be researched further to ensure that, with information both before and after prism, the results are conclusive and do not lack conviction.

To answer whether or not prism adaptation actually simulates neglect, the findings would rather support the answer that it does not. Since EEG-markers in patients with neglect show certain characteristics (lower P300, delayed P300) of which no significant effects are found during this experiment, the data would not support this hypothesis. However, since the graphs of P300 peaks do show a small delay, this provides an interesting prospect for further research.

5.2 Classification

The classifier performance was high. The EEG data was a good predictor in itself to determine whether the participant was attending left or attending right. However, the classifier was trained on the 'before prism' data and again on the 'after prism' data, instead of being trained once for 'before prism' and used for the classification of all data. The results for classifier performance would mean more if the classifier was used properly.
However, the accuracies found do support the general theories about spatial attention. Alpha power data confirm the expected alpha lateralization, which shows to be a good classifier for direction of attention. This means that the predictions made by the classifier, based on the EEG data, is consistent with the theories about the difference

in left and right brain signals. Classifying the direction of attention based on ERPs also has a better than chance performance, which also indicates that the ERPs in the data are consistent with the expected results when attending to a target stimulus.

5.2.1 Improvements

To remove the confounding variable 'elapsed time' when analyzing the difference between before and after prism adaptation, the order of the conditions 'before prism' and 'after prism' has to be randomly assigned to the participants. Since prism adaptation has an aftereffect which is not diminished entirely after the task, preferably the measurements have to be done on separate days.

The deviation in centimeters after prism adaptation was initially only used to determine whether all participants responded to prism adaptation. Later on, the use of deviation as a covariant seemed a great idea to help determine whether prism adaptation has an effect on ERP, alpha and the percentage of correct answers given. Since the individual values varied from a minimum of 4.625 cm to a maximum of 10.29 cm, having the deviation as a reliable measure for analysis could effect the outcome. Therefore it is important to measure if there is a interpersonal difference in deviation in centimeters befóre prism adaptation. Having information about the initial values compared to the values after adaptation, makes the change in value a proper covariate.

Beside the experimental paradigm, the analysis of P300 can be improved. The peak closest to 300 milliseconds after the stimulus onset is used, but since P300 onset time has a great interpersonal variance, some participants may show a P300 at 350 milliseconds after stimulus onset, 400 milliseconds after, or earlier than 300 milliseconds after. The peak closest to 300 milliseconds after stimulus onset may not be the P300 peak at all. The EEG data needs to be evaluated for each participant individually to determine the interval in which the P300 should be for that participant, to reduce the risk that a peak other than P300 is used for analysis.

In general, the sample size of the experiment should be increased to reduce the probability of wrongly assuming normal distribution. Preferably sample size should be equal to or greater than 52. However, in BCI is it not uncommon to have small sample size. Except the most obvious reason, which are time-consuming experiments, another reason is that most BCI researchers look at certain patterns and characteristics in the large amount of EEG data per participant, instead of just differences between participants. EEG data has a great interpersonal variance.

6 Conclusion

Prism adaptation to the left in healthy subjects produced deviating pointing behavior to the right. Before and after adaptation the ERPs and alpha waves were measured during a spatial attention task, using EEG recordings. Except increased alpha power in the 'after prism' condition, there were no significant effects observed. The increased alpha power can be an effect of prism adaptation, but other explanations are possible - e.g. elapsed time or drowsiness caused by the repetitive task. There were no differences observed between leftsided attention and rightsided attention and no interaction effect of direction of attention and before versus after adaptation on behavioral performance, P300 and alpha.
Due to the low statistical power of the experiment, the results remain unsure. Consequently, rather than consider prism adaptation to have no effect on P300 and alpha, I would recommend future investigation. Especially P300 onset time, which shows some small differences in the plots and is also known to be somewhat delayed in patients with neglect, would be interesting to study further. Looking at the personal differences in onset time to determine the interval for the analysis of the P300 peak height and P300 onset time, more precise data can be gained.

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