June 2017

BACHELOR THESIS

Faculty of Behavioural, Management and Social Sciences (BMS)

α-Band lateralization to determine the validity of EEG as a method for measuring vigilance

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Abstract

Vigilance is defined as the capacity to monitor for changes by maintaining focus. Measuring the vigilant state using self-report or behavioral observations is limited. A solution is using electroencephalogram (EEG) to directly measure brain-activity. By considering the α-power and comparing the hemispheres using a lateralization index it was attempted to determine whether EEG can be used as a valid method to determine the vigilant state. Three participants were included using a small-*n*-randomization design. It was expected that a decrease in contralateral α-power would appear when focused. For the effect of the attended visual field on the visual cortex indices, the overall results showed the opposite effect: contralateral α-power increase appeared when focused. For the effect of the used index finger on the motor cortex there was contralateral alpha decrease when the participant focused. For both effects, it could not be determined whether the changes predicted performance. Therefore, it could not be concluded whether EEG was a valid method to determine the vigilant state. To answer the research question and to make predictions on the behavioral data using EEG, in the future it is advised to include more participants as this would enable the use of several additional statistical methods.

Introduction

Attention is defined by Banyard, Davies, Norman and Winer (2013) and Purves et al (2013) as the process that filters, directs and controls how we process the endless amount of external information thus as the capability to efficiently direct the limited neural resources available in the brain. Being able to focus and to detect when mistakes may be made can be very relevant. For job interviews, it can be useful to be able to measure the amount of focus people have on a certain task and for how long they remain focused. Currently, there are several measures for the attentional state, for example the Psychomotor Vigilance task (PVT) in which reaction time (RT) to respond to a stimulus is measured using a computer (Caldwell, Prazinko, & Caldwell, 2003). The measured RT gives an indication of the attentional state. However, there is currently no method to measure how focused someone is, without the need of an additional task. Developing such a method could be relevant because the performance of an attentional task might interfere with the measurement of the attentional state. As the participant is consciously trying to focus and knows what is measured, the results may be influenced. In the future, it would be interesting to know if it would be possible to measure the attentional state directly by measuring brain activity. This would exclude the need of a task and will enable measuring attention directly.

Attention, Vigilance and Measurements

To allow further investigating into measuring attention, some concepts first need to be clearly defined. Attention, which has already been defined may be confused with vigilance. Vigilance refers to a state of physiological awareness presented on a sleep to wake continuum (Clerc, Bougrain & Lotte, 2016). Vigilance can be seen as the capacity to monitor for changes in a certain task or a portion of the environment by maintaining internally generated focus or attention. (Martel, Dähne, & Blankertz, 2014). In several studies (Epling, Russell, & Helton, 2016; Martel, Dähne, & Blankertz, 2014; Wiggins, 2011) a decrease in the ability to detect stimuli over time has been observed. This effect is called vigilance decrement. Particularly, this decrement may differ between individuals, which is most likely caused by mental overload as the attentional resources are used up (Epling et al., 2016; Martel et al., 2014; Thomson, Smilek, & Besner, 2015). Malhotra, Coulthard, and Husain (2009) have researched vigilance decrement by examining the ability of neglect patients to maintain spatial attention and they compared this to their ability to maintain visual attention. They have shown that vigilance decrement mostly occurs when spatial attention is required. This implies that when the vigilance level of a person decreases, this will have the most effect on the spatial attention, which will consequently decrease as well.

Three methods for measuring vigilance will be discussed in detail. The first method for measuring vigilance is to use a form of behavioral data, namely the results of an attentional task, which can be used to determine whether someone can detect changes. This method includes using an attentional task such as the PVT (Caldwell et al., 2003). Attentional tasks are usually easy and quite long, so the decrement can be detected. A disadvantage is that the performance of the task might interfere with the results. A second way to measure the vigilant state to use self-report, to directly ask people how focused they feel while performing a task. This can measure the subjective report of the physiological awareness. This method is quick, easy and cheap but it has been criticized much. It was said that by asking a participant about their state, the state is already affected by the question. Furthermore, Fisher (1993) and Dooley (2009) showed that the answers were influenced by self-observation errors in and that that self-report is susceptible to social desirability bias. However, it has more recently been shown that a biased prediction is often better than an unbiased prediction and that self-report can make quite impressive predictions (Connor & Feldman Barrett, 2012). Therefore, it can be very interesting to see how well self-report is in accordance with the physiological state and how well it can predict the behavior.

Another method to determine the level of vigilance or the vigilant state is using the electroencephalogram (EEG) to determine the physiological state. Many researchers (Fan et al., 2007; Grent-'T-Jong, Boehler, Kenemans, & Woldorff, 2011; Martel et al., 2014) have used EEG to examine in what way different oscillations are related to different attentional states. They have for example concluded that an increase in power for lower frequencies, like delta and theta activity, indicates drowsiness and that as the power of the higher frequencies such as gamma increases, the wakefulness increases (Cacioppo, Tassinary, & Berntson, 2007). The increase of the power refers to an increase of the contribution of a frequency to the entire signal. These measurements can reflect the attentional state in one moment but it can also be interesting to consider the vigilant state over a longer period. Within a range of frequencies, small changes in power may indicate differences in the level of attention (Cacioppo et al., 2007). Changes in the power of the frequencies over time may be small, slow and can be influenced by individual differences in cognitive abilities (Gunzelmann, Moore, Gluck, Van Dongen, & Dinges, 2008). All the small changes can be measured using EEG as this detects the frequency and its power over a longer period. Consequently, EEG might be used to measure how the vigilant state changes over a longer period and it might be helpful to make predictions on when mistakes might be made. However, a disadvantage of EEG is that it picks up a lot of noise and this can limit its power to predict the behavior.

EEG and Lateralization

Thus, EEG might be used to measure the vigilant state of an individual, but the amount of random noise is problematic. The signal is either a result of an active brain-system or a result of a random fluctuation that produces irregularities in the signal (Pijn, Van Neerven, Noest, & Lopes da Silva, 1991). This is problematic for the reliability of the results and the predictive power. A way to solve this problem, mentioned by Van der Lubbe and Utzerath (2013) and by Van der Lubbe, Bundt, and Abrahamse (2014) is concerned with the general idea that many processes in the brain are lateralized. If a method is designed in a way that only one hemisphere is activated for the response of interest, the random noise will be picked up in both hemispheres, but the signal of interest will only be detected in the contralateral hemisphere. Thus, this provides an opportunity to use the ipsilateral hemisphere as a control for the contralateral hemisphere. This can help make sure that the number of random fluctuations in the results is as limited as possible, therefore increasing the reliability.

To create a deeper understanding of EEG, it should be determined which signal to focus on. Using EEG, Martel et al. (2014) looked into oscillations after a stimulus was presented using covert attention. In the case of covert attention, the participant continues gazing at a fixation point, but the attention is directed to another point of the visual field (Purves et al., 2013). Martel et al. (2014) found two predictors of an inadequate level of attention, resulting in a miss of the target. The first predictor P3, was the strongest predictor and would therefore seem useful to be used to examine vigilance. P3 is an event-related potential (ERP) component. ERPs represent tiny voltage fluctuations which are triggered by certain cognitive or sensory events, in an ongoing EEG (Purves et al., 2013). An ERP reflects the sum of the electrical activity of a neuronal population that is activated at a certain event. Despite the strength of the prediction, P3 is not a useful tool for determining the vigilant state over a period. The ERP signal is a sum of many trials which can be used to determine the vigilant state over the entire block (van der Lubbe, Blom, de Kleine & Bohlmeijer, 2017). However, it is quite complicated to examine transient changes throughout the block using ERP. Therefore, it is advised to shift attention to alpha waves, the second predictor found by Martel et al (2014).

Alpha waves

The alpha rhythm is brain activity in an EEG within the range of 8-13Hz and the current consensus is that it is linked to a state of relaxed wakefulness (Cacioppo et al., 2007). The thalamo-cortical activity within the brain underlies alpha activity (Lopes da Silva, 1991). According to Cacioppo et al., (2007), alpha waves can be detected best when a subject has closed the eyes and is resting. Furthermore, once the eyes are opened for mental concentration or when someone is suddenly alerted, the alpha rhythm diminishes or is completely abolished. This phenomenon is known as alpha blockage or alpha desynchronization. Gould, Rushworth, and Nobre (2011) state that this alpha contralateral desynchronization may reflect enhancement of processing for attended locations. Furthermore, they claim that increased ipsilateral alpha synchronization reflects suppression of processing of unattended information. Thus, the contralateral decrease in alpha power, which is shown when attention is directed to one part of the visual field, likely indicates a release of inhibition for the relevant visual area (Sauseng et al., 2005; Thut, Nietzel, Brandt, & Pascual-Leone, 2006; Worden, Foxe, Wang, & Simpson, 2000). This effect can be found for several modalities and the neuronal location varies based on which modality is investigated (Thut et al., 2006; Van der Lubbe, Blom, De Kleine, & Bohlmeijer, 2017; Worden et al., 2000). Furthermore, the alpha waves can be divided in two forms, lower alpha between 8 and 10Hz and upper alpha between 10 and 12Hz (Cacioppo et al., 2007). As the frequency of upper alpha is higher this is associated with more wakefulness, and lower alpha is associated more to drowsiness. According to Cacioppo et al. (2007) and Wascher et al. (2014) lower alpha desynchronization is associated with stimulus or task unspecific increases in attentional demands. On the other hand, upper alpha desynchronization appears to be task specific, it is linked to the processing of sensory-semantic information, stimulus-specific expectancies and increased semantic memory performance (Cacioppo, et al., 2007). It might be interesting to find out if a difference can be found in the amount of lower or upper alpha power, as compared to the performance on the attentional task.

Thus, alpha waves can be used to determine the vigilant state of an individual by taking advantage of the lateralization of many processes in the brain. Thut et al. (2006) interestingly first mentioned a method for calculating a lateralization index, which can be used to compare the alpha-waves between the left and the right hemisphere. This index is used to calculate the difference in α power between the contralateral and ipsilateral hemisphere and is shown in equation 1.

$$\text{Lateralization index } (\alpha)_t = \frac{\alpha_t(PO8) - \alpha_t(PO7)}{\alpha_t(PO7) + \alpha_t\,(PO8)} \qquad (1)$$

The α power at time point *t* $(\alpha)_t$ in this calculation, is determined for two symmetrical electrodes, in this example PO7 overlaying the left visual cortex and PO8 overlaying the right visual cortex. Next, the sum of the powers is used to scale the index, which results in an index that varies from -1 to +1. If the result is a negative value, this means that the α power in the left electrode (PO7) is higher than in the right electrode (PO8) which indicates leftward attentional bias. On the other hand, a positive value indicates that there is more α power in the right electrode (thus LVF) as compared to the left electrode (thus RVF) which indicates rightward attentional bias. As this index provides a correction of the signal, and is used to eliminate noise within the signal, it can be used for further statistical analysis. Thut et al. (2006) used this method to look into alpha lateralization and they found that contralateral alpha desynchronization can serve as an predictor for succesful visuospatial attention.

For the current experiment, three participants have performed an attentional task while at the same time the activity in the brain was measured using EEG. In the attentional task the participants had to focus on the left or the right visual field, while stimuli appeared on both sides. They only needed to respond to the targets on the attended side. For the EEG data, the focus was on the alpha waves and their power, which could be related to the behavioral data. The main goal was to answer the question whether EEG could be used as a valid method to directly determine the vigilant state of an individual during a task, by examining the lateralization of the alpha power. By using the lateralization index to compare the alpha power difference between the left and right hemisphere, it was expected that the EEG could be used as a valid method to measure the vigilant state of an individual. More specifically, it was expected that a decrease in contralateral α power would appear as the participant was focused on one part of the visual field or was using only one index finger. For the behavioral data, it was expected that the number of mistakes would increase as the participant became fatigued and that most mistakes would occur in the condition in which there was is a target on the non-attended side. Finally, it was explored whether EEG would be a better predictor of the behavioral data as compared to self-report. As EEG could be used to look closely into the brain activity preceding one trial, it might be more specific in predicting performance than self-report.

Methods

Participants

Three Dutch students recruited from the local student population at the University of Twente participated in the experiment. The first participant was a female aged 21 who was right handed with 24 points on the Annett Handedness Inventory (Annett, 1970). She had contact lenses which corrected her vision to normal and she was not color blind, which was assessed using a Color-Blindness test (Ishihara, 1976). Her acuity scores, assessed using the Freiburg visual acuity test (Bach, 1996) on the left eye were Dec. VA: 1.02 and for the right eye the scores were Dec. VA: 1.7. The second participant was a male aged 21 who was right handed with 15 points on the Annett Handedness Inventory (Annett, 1970). He had a history of alcohol or drug abuse. Furthermore, his vision was impaired but he was not color blind. The acuity scores on the left eye were Dec. VA: 0.46 and for the right eye the scores were Dec. VA: 0.45. Despite his impaired vision, the research was continued as was expected that this would not be problematic for the research. The third participant was a female aged 19 who was right handed with 23 points on the Annett Handedness Inventory (Annett, 1970). She had normal vision and was not color blind. Her acuity scores on the left eye were Dec. VA: 1.52 and for the right eye the scores were Dec. VA: 1.71. In the experiment, a convenience sample was used. At the start of the research, all the participants signed an informed consent form. The ethics committee at the Faculty of Behavioral Sciences at the University of Twente approved of the employed procedures.

Task and procedure

Firstly, the participant was asked to fill in some demographics. After some tests, the participant was placed in an office chair, at ~85 cm from the screen which was 24 inch and ~45 cm above the table. Next, the EEG-cap with 32 electrodes was carefully placed on the head. Then the conductive gel was placed between the electrodes and the skin using a squirt. The EOG electrodes were placed on the head and gel was added. After making sure that the impedance was below 10kΩ and the signal looked calm, the experiment could start. Throughout the experiment, the participant sat in a darkened room, in front of the experimental computer. The computer showed the test which was shown and programmed using Presentation software version 18.1 (Neurobehavioral Systems, Inc., 2012). The task was first introduced and instructions were given on what to do, on the screen and verbally. Within a trial a fixation point was presented in the middle of a black background. This white square was 3 mm long and 3 mm high. The participants were instructed to focus on the fixation point but to attend either the right or the left visual field and to respond with either the right or the left index finger. After the start of each block, approximately every two seconds (every 2034 ms) two stimuli were presented. The two stimuli were 8 mm wide and 8 mm high and were presented 5cm to the left and the right of the fixation point. The angle between the eye and the stimulus, when looking at the fixation point, was 3.7˚. The presentation of these two stimuli was one trial and one block consisted of 100 trials. For the stimuli that were presented to the left and the right side of the circle, 90 out of 100 stimuli were an ‘M’ and 10 out of 100 were a ‘W’.

Only if a ‘W’ was presented on the attended side, the participants were instructed to respond by pressing the spacebar. A schematic representation of five trials is presented in Figure 1. After each block, there was a pause in which the participants were asked to indicate how focused they felt on a scale of 0 to 99, with “0” being the least focused and “99” being the most focused. This was also asked before the start of the first block and after the final block. After the 20 blocks, the experiment was finished, the EEG cap was removed and the participant could wash their hair. Finally, a debriefing took place in which the participant was informed about the research goal. The duration of the entire research for each participant was about three to four hours. The duration of the task itself was about 75 minutes.

Materials and Electroencephalogram

The experimental computer used a QWERTY keyboard of which only the spacebar and the enter button were used. Cortical activity was recorded using an EEG cap with 32 active Ag/AgCl electrodes. The electrodes were placed in an elastic cap (Braincap, Brainproducts GmbH) at the following electrode positions: AF7, AFz, AF7, F7, F3, Fz, F4, F8, FC5, FC1, FC2, FC6, T7, T7, C3, Cz, C4, CP1, CP2, P7, P3, Pz, P4, P8, PO7, PO3, POz, PO4, PO8, O1, Oz and O2 (Figure 2). The ground electrode for these channels was placed on the forehead. A high-cutoff filter on the EEG was used, which cut signals off above 280 Hz. Using electro-oculogram horizontal saccades were recorded by placing electrodes at the outer canthi of both eyes (hEOG) and vertical saccades were recorded by placing electrodes above and below the left eye (vEOG). The ground EOG electrode was placed on the forehead, above the right eye. To improve the conductivity electrode gel was inserted between the skin and the electrode. To amplify both the EEG and the EOG signal, a 64-channels Actichamp (Brain Products GmbH) amplifier was

Figure 1. Schematic representation of five trials

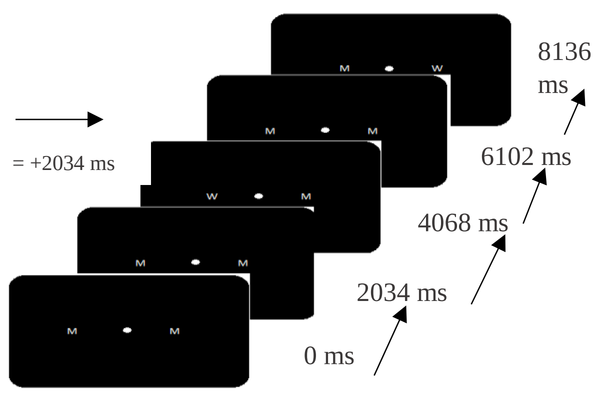

Figure 1: Schematic representation of five trials within a block in the experiment. In the middle, the fixation point is presented. On the left and the right side of the fixation point the stimuli that had to be attended are presented. In between the presentations of two stimuli was 2034 ms.

Figure 2. Schematic representation of the EEG-Cap

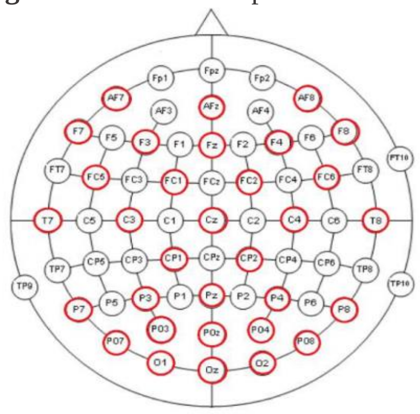

Figure 2: A schematic representation of the EEG-Cap. This image presents the head from nasion to inion, respectively from top to bottom in the image. This shows 64 electrodes, the 32 electrodes that are circled in red were used in the experiment.

used, which had a built-in reference. BrainVision Recorder (BrainProducts GmbH, 2012) was installed on a separate acquisition computer to register task related events such as stimulus presentation and responses and to register the EEG and EOG signals.

Design

In this paper, a small-*n* randomization test was used in which, more specifically an alternation design was used. This design makes comparisons between time series for the different levels of independent variables. An alternation design can take several forms, the design employed here was a Randomized block design (Bulté & Onghena, 2008, 2013). As human participants are very variable, this design tries to find the differences within a participant and averages these results so the participant can act as its own control. Within this design, there were two conditions to compare, which could be divided further into four conditions. Each participant received all four conditions five times, in random order. The two conditions were formed by varying which side of the visual field had to be attended, thus whether to focus at the right visual field (RFV) of the left visual field (LVF). These two conditions could be divided further into four conditions by varying which index finger, the left index finger (LIF) or the right index finger (RIF) needed to be used for the responses.

Within the design, there were three dependent variables; the alpha lateralization EEG data, the behavioral data and the self-report data which will all be discussed in more detail. The first dependent variable was the alpha lateralization EEG data, which was a result of the activity within the brain. The power of the alpha frequency of the electrodes of interest was inserted into equation 1 and the alpha lateralization index was calculated. The second dependent variable was the behavioral data. This included two things, the first was the hit rate and the false alarm rate. This was used to check whether the participants were capable of detecting the target stimulus. Secondly, the reaction time was measured, which included the time it took for the participant to detect the target stimulus and to physically respond by pressing a button. Furthermore, the third variable measured was the self-report on how focused someone felt. This was measured to consider the difference between the EEG data and the self-report data. This included several questionnaires throughout the experiment in which the participant had to indicate how focused they felt.

Data analysis

Self-report For the self-report, a descriptive analysis was used and a prediction was made on the behavioral data. Therefore, a correlation was calculated which needed to be considered carefully as the data were not independent. This was done using IBM SPSS Statistics Version 22 (IBM Corporation).

Behavioral data If the participant responded to the target stimulus, this reaction was labelled as a ‘hit’. There were three forms of hits; a ‘normal hit’ if the reaction occurred within 100 to 1000 ms after the stimulus presentation, a ‘premature hit’ within -200 to 100 ms after the stimulus presentation and a ‘slow hit’ if the response occurred after 1000 ms after the stimulus presentation. If there was no response the trial was coded as a ‘miss’. The hit rate for each block was calculated. If a response was given to a stimulus that did not require a response, the response was labelled as a ‘false alarm’. There were two types of false alarm. One when the target occurred on the unattended side and one where there was no target at all. Furthermore, for each block the average reaction time to the target stimulus was calculated.

EEG data The EEG data was analyzed using Brain Vision Analyser Version 2.1 (Brain Products GmbH, 2012). The software used a high cut off filter of 200Hz and a notch of 50Hz, the sample frequency was 1000Hz. Firstly, the data was segmented and the portions with extreme activity were rejected. After this the data were portioned in segments from -1000 to -1500 ms from the cue onset and the baseline was set from -100 to 0 ms from the cue onset. Furthermore, the data has been corrected for eye blinks and a narrower segmentation was employed (lowest allowed activity: 0.1μV for 50 ms; gradient criterion: 50μV/ms; min-max criterion: -/+ 150μV). Next, all the trials that contained horizontal eye movements were rejected. For participant 1 this rejected 3.85% of the trials, for participant 2 4.65% and for participant 3 5.75%. The segments that contained the non-target information were selected as these contained no responses. The target data was rejected the interest lay with the data in which there was no behavioral information. Finally, all the EEG-segments that contained artefacts were excluded. Using a wavelet analysis, the contribution of the alpha frequency to the signal was determined and the alpha power could be exported (Center frequency=10; Gauss Low 7.21; Gauss High: 14.43;). Next, a single subtraction was employed using equation 1. The data from -300 ms to 300 ms from the cue onset was analyzed in segments of 100 ms, which resulted in 6 segments. The statistical analysis was limited to two electrodes pairs. Electrode pair PO7/PO8 provided information on the visual attention and electrode pair C3/C4 provided information on the motor cortex.

To determine whether the pattern that appeared was a coincidence or whether it was truly related to the vigilant state or lateral hand preparation, a non-parametric test was used. This was done using R-studio extended with R commander (R-studio Inc.). R commander was extended with a package called R-SCDA, which included the single case randomization tests (SCRT) function (Bulté & Onghena, 2013). The method that was used was designed by Bulté and Onghena (2008) and is described in more detail in Appendix 1. To determine whether there was a significant effect of the attended visual field, the data were divided into two sets. Set A contained all the blocks in which the participant focused on the left visual field, set B contained all the blocks in which the participant focused on the right visual field. For the statistical analysis, firstly the test statistic was calculated, which used a randomized block design with an A-B test statistic. This test statistic was chosen as it was expected that the index for the trials in condition A would be more positive as compared to the trials in condition B. Secondly, a 1000 random distributions were made and their test statistic was calculated. To make the random distributions, the conditions assignments were kept fixed while the measurements were randomly shuffled. For each new distribution, the test statistic was calculated and these statistics were sorted in ascending order. Finally, the *p*-value was calculated, which was the proportion of the test statistics in this random distribution that exceeded or was equal to the observed test statistic. The chosen significance level was $\alpha=0.05$. To determine whether there was an effect of the used left or right index finger, the same method was used. In this case, set A contained the data in which the left index finger (LIF) was used and set B contained the data in which the right index finger (RIF) was used. The analysis itself was equal to the previous mentioned. After the calculation, it appeared that in some instances the A-B test statistic was not significant but the B-A test statistic was. Therefore, both have been calculated for all conditions. For the B-A test statistic, only the p-value will be presented as the test statistic is -(A-B).

To determine whether the indices changed over time, no statistical methods were available as the data was not independent. Therefore, two descriptive methods have been employed. Firstly, the figures that resulted from the indices were used to determine whether there seemed to be an increase or a decrease over time. Secondly, for both electrode pairs, PO7/PO8 and C3/C4, the average alpha power per block was calculated. Then, it was determined what the average increase or decrease of these averages was. This gave an indication of whether the indices changed over time.

Finally, there was a check for two possibly influences. For the first, it was analyzed whether there was an effect of the used IF on the visual attention. In this case the indices from PO7 and PO8 were used. The conditions A and B were based on the motor information thus condition A contained the indices in which the LIF was used and condition B contained the indices in which the RIF was used. These conditions have been used to calculate the test statistic, make the random distribution and calculate the p-value in the previous mentioned way. For the second interaction, it was analyzed whether there was an effect of the attended side on the alpha power in the motor cortex. In this case, the indices from C3 and C4 were used. The conditions A and B were based on the visual attention thus condition A contained the indices in which the attention was on the LVF and condition B contained the indices in which the attention was on the RVF. These conditions have been used to calculate the test statistic, make the random distribution and calculate the p-value in the previous mentioned way.

Results

The next section will give an overview of the results. The EEG Data and the analyses on these data will be described firstly. Secondly, the self-report data will be discussed. Finally, the hit rates and false-alarm rates and the reaction times will be discussed in the section on behavioral data.

EEG Data on PO7/PO8

Participant 1 During the measuring, the impedance of all the electrodes was constantly held below 10kΩ. The average of the impedances of all the electrodes was 4.5kΩ. The indices that resulted from this analyses with electrode pair PO7/PO8 are presented in Figure 3. The figures for each segment separately can be found in Appendix 2.1, Figure 14. These figures indicate that there is an effect of the attended side on the alpha lateralization. This has been further investigated using statistics (see Table 1). For the attended side, there is a significant effect for all the segments showing that the indices in condition B (RVF) are larger than the indices in condition A (LVF) (Segment 1-4: B-A ≈ 0.4, $p<0.001$; Segment 5: B-A =0.023, $p<0.001$; Segment 6: B-A =0.09, $p<0.002$). Figure 3 further indicates that there is a slight increase in the indices as the tasks proceeds. Furthermore, the pattern tends to be more negative than positive, especially for the later segments which indicates that power was larger in the right hemisphere. Finally, there was a check whether the used IF had any effect on the visual attention. These results are presented in Table 1 which shows that the used IF had no effect on the visual indices.

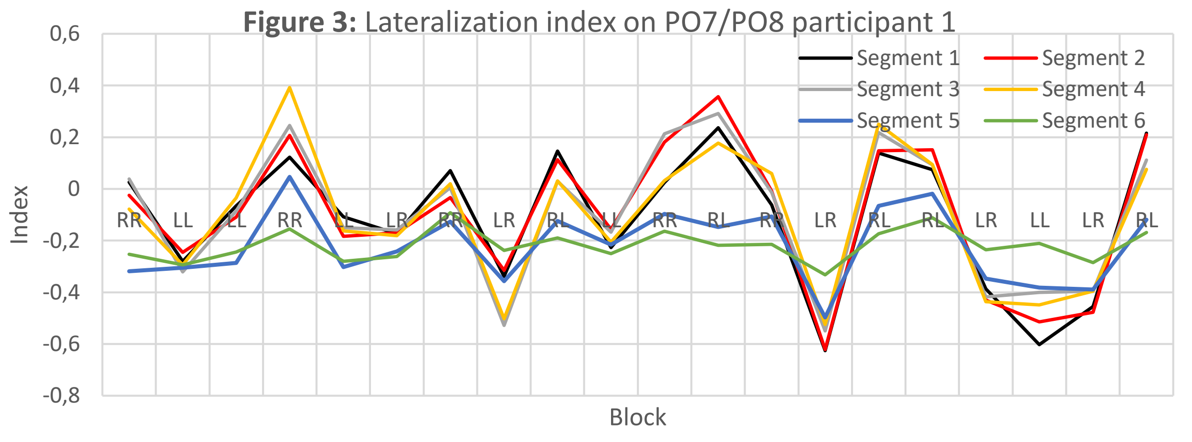

Figure 3: Schematic representation of the indices of the electrode pair PO7/PO8 of the first participant. The colored lines represent the six segments that show the indices over the 20 blocks

Table 1

The test statistics and p-values of the 6 segments presented for the effect of the spatial focus and the used index finger on the PO7/PO8 indices of the first participant

Segment	Effect of the attended side on the indices			Effect of the used IF on the indices		
	Test statistic A-B	P value A-B	P value B-A	Test statistic A-B	P value A-B	P value B-A
1	-0.425	1	<0.001**	0.132	0.138	0.863
2	-0.452	1	<0.001**	0.145	0.126	0.875
3	-0.441	1	<0.001**	0.118	0.138	0.863
4	-0.424	1	<0.001**	0.110	0.145	0.856
5	-0.225	0.999	<0.001**	0.047	0.258	0.743
6	-0.089	1	<0.002**	0.009	0.399	0.602

Note: *significant with α=0.05 ** significant with α=0.01

Participant 2 During the measuring, it was attempted to hold the impedance of all the electrodes below 10kΩ, which nearly succeeded for each electrode. The average of the impedances of all the electrodes was 5.8kΩ. The indices that resulted from this analyses of electrode pair PO7/PO8 are presented in Figure 4. The figures for each segment separately can be found in Appendix 2.2, Figure 16. These figures indicate that at some points there might be an effect of the attended side on the indices but overall there seems to be no influence of the attended side. This has been further investigated using statistics (see Table 2). For the attended side, there is only a significant effect for segment 5 and nearly for segment 4 which indicates that the indices in condition A are larger than the indices in condition B (Segment 5: A-B=0.049, p=0.039; Segment 4: A-B= 0.049, p=0.075). Figure 4 further indicates that there is no increase nor a decrease in the indices over time. Furthermore, the pattern tends to be more positive than negative, which indicates that there was more power in the left hemisphere. Finally, there was a check whether the used IF had any effect on the visual attention (see Table 2). It shows that the used index finger had no significant effect on the indices.

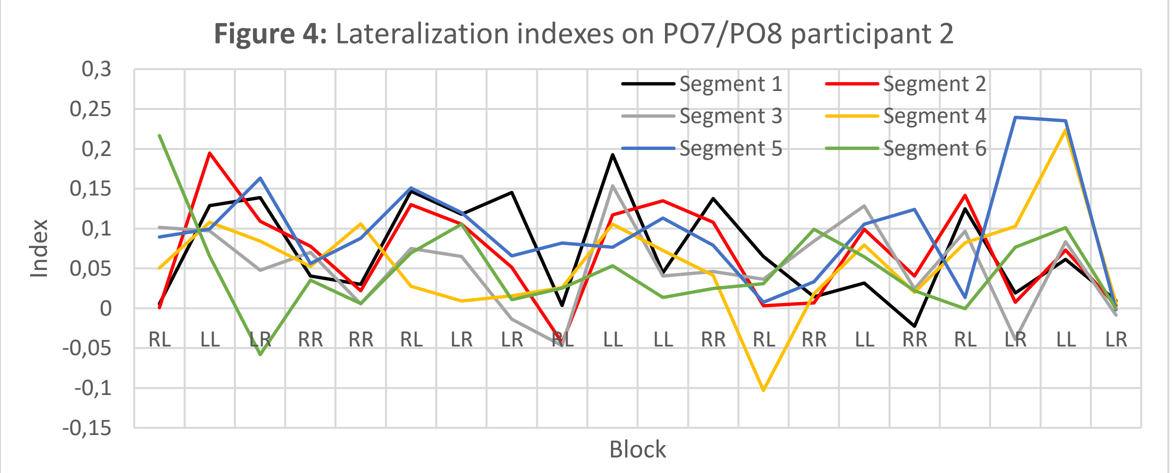

Figure 4: Schematic representation of the indices of the electrode pair PO7/PO8 of the second participant. The colored lines represent the six segments that show the indices over the 20 blocks

Table 2
The test statistics and p-values of the 6 segments presented for the effect of the spatial focus and the used index finger on the PO7/PO8 indices of the second participant

Segment	Effect of the attended side on the indices			Effect of the used IF on the indices		
	Test statistic A-B	P value A-B	P value B-A	Test statistic A-B	P value A-B	P value B-A
1	0.034	0.153	0.848	0.017	0.278	0.723
2	0.041	0.110	0.891	0.032	0.151	0.850
3	0.006	0.424	0.577	0.048	0.052	0.948
4	0.049	0.075	0.926	0.022	0.257	0.744
5	0049	0.039*	0.962	<0.001	0.492	0.509
6	-0.010	0.649	0.352	0.032	0.208	0.793

Note: *significant with α=0.05

Participant 3 It was attempted to keep the impedance of the electrodes below 10k. However, despite the EEG signal looking calm, for most electrodes the impedance was not beneath 10kΩ. The average of the impedances of all the electrodes was 18.2kΩ. The indices that resulted from the analysis of PO7/PO8 are presented in Figure 5. The separate figures for each segment are presented in Appendix 2.3, Figure 18. These figures indicate that in some blocks there seems to be an effect of the attended side on the index. This has been further investigated using statistics (see Table 3). For the attended side, there is a significant effect for segments 1 and 2 and nearly for 3 and 4 showing that the indices in condition B (RVF) are larger than those in condition A (LVF) (Segment 1: B-A=0.054, p<0.001; Segment 2: B-A=0.038, p=0.029; Segment 3: B-A=0.026, p=0.088; Segment 4: B-A=0.024, p=0.072). Furthermore, there is a significant effect for segment 6 showing that the indices in condition A are larger than those in condition B (A-B= 0.057, p=0.035). Figure 5 further does not give an indication of a change in the indices over time. Furthermore, the pattern tends to be more negative than positive, which indicates that there was more power in the right hemisphere. Finally, there was a check whether the used IF had any

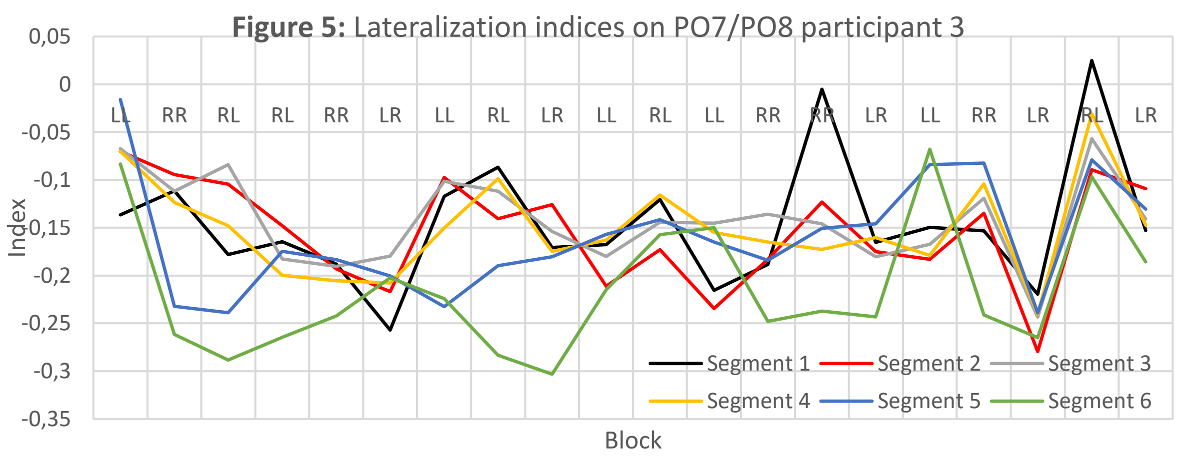

Figure 5: Schematic representation of the indices of the electrode pair PO7/PO8 of the third participant. The colored lines represent the six segments that show the indices over the 20 blocks

effect on the visual attention. These results are presented in Table 3. It shows that there is an effect of the used IF. In segments 3, In segments 3, 4 and 6 the indices in condition A (LIF) are larger than those in condition B (RIF) (Segment 3: A-B=0.036, p=0.022; Segment 4: A-B=0.039, p=0.010; Segment 6: A-B=0.060, p=0.032).

Table 3
The test statistics and p-values of the 6 segments presented for the effect of the spatial focus and the used index finger on the PO7/PO8 indices of the third participant.

	Effect of the attended side on the indices			Effect of the used IF on the indices		
Segment	Test statistic A-B	P value A-B	P value B-A	Test statistic A-B	P value A-B	P value B-A
1	-0.054	1	<0.001**	0.030	0.179	0.829
2	-0.038	0.971	0.029*	0.018	0.198	0.803
3	-0.026	0.912	0.088	0.036	0.022*	0.979
4	-0.024	0.927	0.072	0.039	0.010*	0.991
5	0.015	0.348	0.656	0.025	0.224	0.777
6	0.057	0.035*	0.965	0.060	0.032*	0.969

Note: *significant with α=0.05 ** significant with α=0.01

EEG Data on C3/C4

Participant 1 The indices resulting from the analysis with electrode pair C3/C4 are presented in Figure 6. The figures for each segment separately can be found in Appendix 2.1, Figure 15. These figures indicate that there might be an effect of the used index finger on the indices. This has been further investigated using statistics (see Table 4). For the used index finger, there is a significant effect for segment 3 showing that the indices in condition A are more positive than the indices in condition B (A-B=0.062, p=0.012). Figure 6 also indicates that there is a slight decrease in the indices over time. However similar, this cannot be statistically confirmed. Furthermore, the pattern tends to be slightly more negative than positive, which indicates that power was larger in the right hemisphere. Finally,

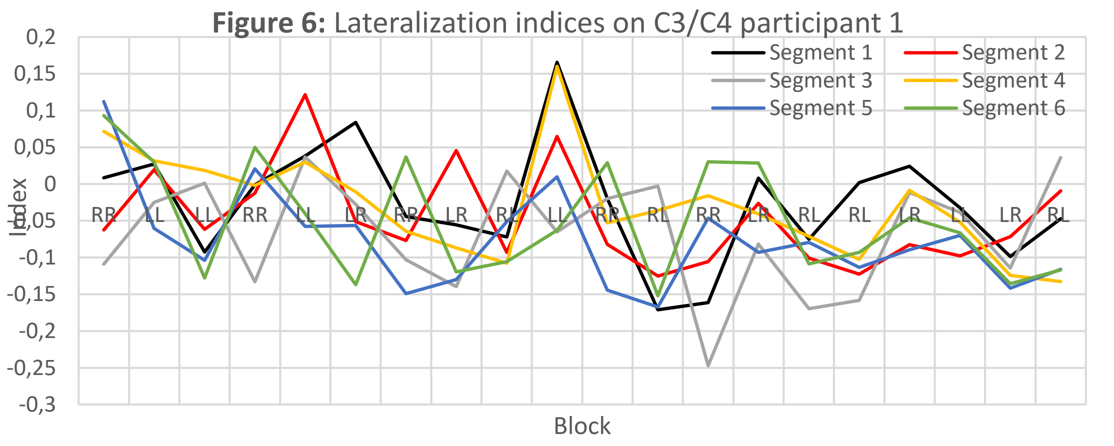

Figure 6: Schematic representation of the indices of the electrode pair C3/C4 of the first participant. The colored lines represent the six segments that show the indices over the 20 blocks

there was a check whether the attended visual field had any effect on the motor cortex. These results are presented in Table 4. It shows that in segments 1, 2 and 4 there is (nearly) a significant effect of the attended visual field on the indices of C3/C4 (Segment 1: A-B= 0.065, p=0.077; Segment 2: A-B=0.065, p=0.025; Segment 4: A-B=0.043, p=0.046) showing that the indices in condition A (LVF) are larger than those in condition B (RVF).

Table 4
The test statistics and p-values of the 6 segments presented for the effect of the used index finger and the spatial focus on the C3/C4 indices of the first participant.

Segment	Effect of used IF side on the indices			Effect of the attended VF on the indices		
	Test statistic A-B	P value A-B	P value B-A	Test statistic A-B	P value A-B	P value B-A
1	<0.001	0.503	0.498	0.065	0.077	0.924
2	0.012	0.323	0.678	0.065	0.025*	0.976
3	0.062	0.012	0.984	0.042	0.146	0.855
4	0.007	0.463	0.538	0.046	0.046*	0.955
5	-0.009	0.637	0.364	0.574	0.574	0.427
6	-0.067	0.969	0.032*	0.878	0.878	0.123

Note: *significant with α=0.05 ** significant with α=0.01

Participant 2 The indices that resulted from electrode pair C3/C4 are presented in Figure 7. The figures for each segment separately can be found in Appendix 2.2, Figure 17. These figures indicate that there is no influence of the used index finger on the observed indices on electrode pair C3/C4. This has been further investigated using statistics (see Table 5). For the used index finger, there was no significant effect for the used index finger on the indices. Figure 7 also further indicates that there is no increase nor a decrease in the indices over time. Furthermore, the pattern tends to be more positive than negative, which indicates that there was more power in the left hemisphere. Finally, there was a check whether

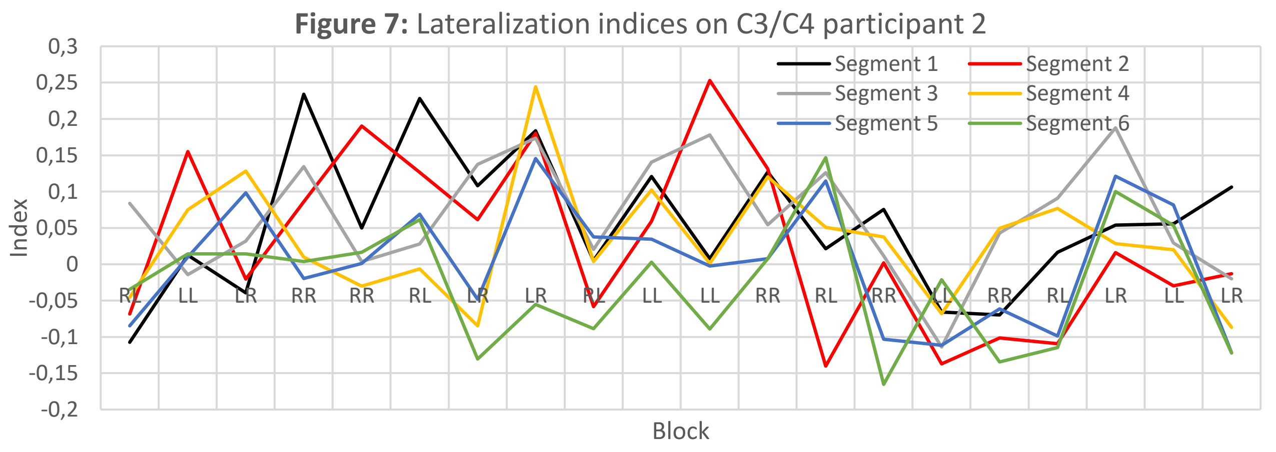

Figure 7: Schematic representation of the indices of the electrode pair C3/C4 of the second participant. The colored lines represent the six segments that show the indices over the 20 blocks

the attended visual field had any effect on the motor cortex. These results are presented in Table 5 as well. It shows that there is no significant effect of the attended visual field on the motor indices.

Table 5
The test statistics and p-values of the 6 segments presented for the effect of the used index finger and the spatial focus on the C3/C4 indices of the second participant.

Segment	Effect of used IF side on the indices			Effect of the attended VF on the indices		
	Test statistic A-B	P value A-B	P value B-A	Test statistic A-B	P value A-B	P value B-A
1	-0.053	0.932	0.070	-0.004	0.535	0.466
2	-0.048	0.938	0.063	0.047	0.099	0.902
3	-0.189	0.709	0.292	0.013	0.382	0.619
4	-0.021	0.730	0.271	0.009	0.406	0.595
5	0.003	0.473	0.529	0.034	0.202	0.799
6	0.040	0.203	0.789	0.007	0.441	0.560

Note: *significant with α=0.05 ** significant with α=0.01

Participant 3 The indices that resulted from the analysis of pair C3/C4 are presented in Figure 8. The separate figures for each segment are presented in Appendix 2.3, Figure 19. These figures indicate that there is an effect of the used IF on the indices. This has been further investigated using statistics (see Table 6). For the used index finger, there is a significant effect for all segments showing that the indices in A (LIF) are larger than those in B (RIF) (Segment 1: A-B=0.131, p=0.007; Segment 2: A-B-0.137; p=0.004; Segment 3: A-B=0.152, p<0.001; Segment 4: A-B= 0.134, p=0.003; Segment5: A-B=0.124, p=0.005; Segment 6: A-B=0.172, p=0.003). Figure 8 also indicates that there is an increase in the indices over time. Furthermore, the pattern tends to be more negative than positive in the beginning but later this effect fades out, this indicates that in the beginning there was more power in the right hemisphere. Finally, there was a check whether the attended VF had an effect on the motor cortex (see Table 6). It shows that in the final three segments, the visual field had a (nearly) significant effect on the C3/C4

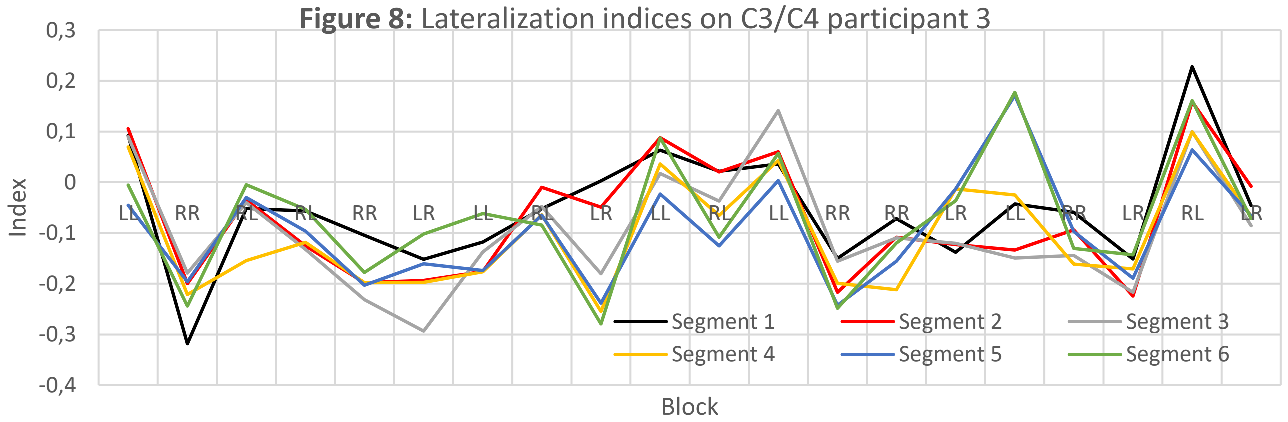

Figure 8: Schematic representation of the indices of the electrode C3/C4 of the third participant. The colored lines represent the six segments that show the indices over the 20 blocks

indices showing that the indices in condition A (LVF) are larger than those in condition B (RVF) (Segment 4: A-B=0.085, p=0.058; Segment 5: A-B=0.071, p=0.77; Segment 6: A-B=0.106, p=0.031).

Table 6

The test statistics and p-values of the 6 segments presented for the effect of the used index finger and the spatial focus on the C3/C4 indices of the third participant.

Segment	Effect of used IF side on the indices			Effect of the attended VF on the indices		
	Test statistic A-B	P value A-B	P value B-A	Test statistic A-B	P value A-B	P value B-A
1	0.131	0.007**	0.8994	0.005	0.475	0.525
2	0.137	0.004**	0.997	0.011	0.424	0.576
3	0.152	<0.001**	1	0.021	0.362	0.638
4	0.134	0.003**	0.998	0.085	0.058	0.942
5	0.124	0.005**	0.996	0.071	0.077	0.923
6	0.172	0.003**	0.998	0.106	0.031*	0.969

Note: *significant with α=0.05 ** significant with α=0.01

EEG Data: Changes over time

Figure 9 shows the average increase over the 20 blocks of the average of the alpha power of PO7&PO8 and C3&C4 per participant. For the PO7/PO8 indices, it is shown that for the first and second participant there is a slight increase in the average alpha power of PO7 and PO8 over time. For the third participant, there is quite a large increase in the average over time. For the C3/C4 indices it is shown that for all the participants, there is little to no increase in the indices over time. However, for this part of the analysis there is limitation to descriptive statistics thus this cannot be statistically confirmed.

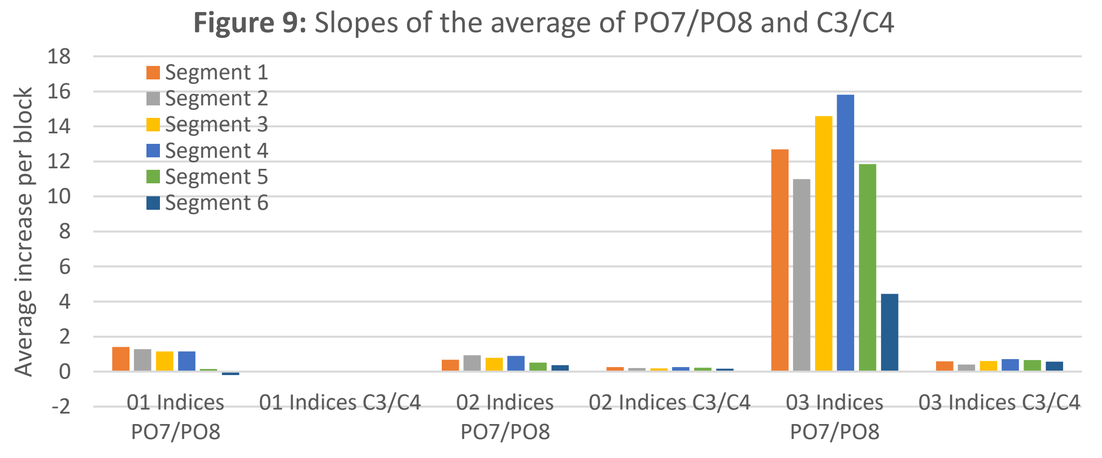

Figure 9: Schematic representation of the average increase over the 20 blocks of the average of the alpha power of electrode pair PO7/PO8 and C3/C4 per participant, presented for each segment separately.

Self-report

Participant 1 The self-report scores of the first participant decreased continuously. It started at 72.5, which was the highest measurement and slowly decreased to 30, which was the lowest measurement. The average decrease for each block was -2 points. These results can be seen in Figure 10.

Participant 2 The self-report scores of the second participant decreased in the beginning with an average decrease of -4 per block and after the 12th block it increased with an average increase of 1.5 per block. In the final blocks it was mostly constant. It started at 55 and it ended at to 22.5. The highest report score was reported in block 2, which was 60. The lowest report score was reported in block 13, which was 10. Overall, the average decrease for each block was -1.6 points. These results can be seen in Figure 10.

Participant 3 The self-report scores of the third participant decreased continuously till the 16th block, after which it stayed constant. It started at 72.5 and it ended at to 35. The highest self-report was reported in the first block and the lowest in block 16 to 20. Overall, there was an average decrease for each block which was 2.1 points. These results can be seen in Figure 10.

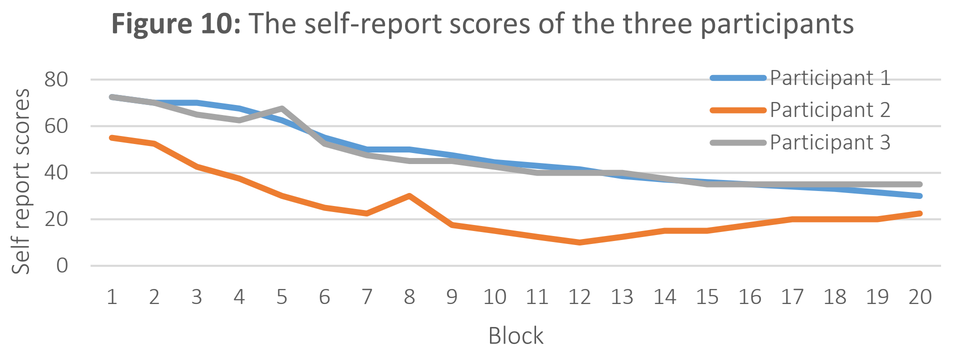

Figure 10: Schematic representation of the self-report scores during the 20 blocks. These scores indicate how focused the participant felt on a scale of 0 (asleep) to 99 (extremely focused).

Behavioral data

Participant 1 The reaction time of the first participant increased. It started at 552.2 ms after stimulus presentation and ended at 845.9 ms after stimulus presentation. The highest reaction time was measured in the 20th block and was 854.9 ms, the lowest reaction time was measured in block 3 and was 517.5 ms. The average reaction time was 647.6 ms and the average reaction time for the false alarms was 781.3 ms. Overall, the average increase for a block was 12.16 ms (Figure 11). The participant missed in total 3 out of 200 targets and of the 197 hits, 5 hits were slow hits. The participant had 3 false alarms, all of which were a result of a non-target-trial and all were normal responses (Figure 12).

Participant 2 The reaction time of the second participant fluctuated. It started at 543.3 ms after stimulus presentation and ended at 525.1 ms after stimulus presentation. The average reaction time for the hits was 554.4 ms, the average reaction time for the false alarms was 690.5 ms. The highest reaction time was measured in block 13, which was 628.1 ms and the lowest reaction time was measured in block 13 which was 498.7 ms. There was average increase for each block which was 1.38 ms (Figure 11). The participant missed in total 6 out of 200 targets. All 195 hits were normal hits. The participant had 24 false alarms, of which 2 were a result of a trial in which the target was presented on the unattended side. 2 of these false alarms were slow responses (Figure 12).

Participant 3 The reaction time of the third participant fluctuated heavily. The reaction time increased in the beginning, until block ten with an average increase of 9.8 ms for each block. After this the reaction time decreased until the end with an average of -7.8 ms per block. The average reaction time for the hits was 513.0 ms and the average reaction time for the misses was 582.6 ms. Overall, there was a small increase for each block which was 1.1 ms. In the first block the reaction time was 500.2 ms and in the final block it was 488.0 ms. The highest reaction time was measured in block 10, which was 581.6 ms and the lowest reaction time was measured in block 3 which was 484.3 ms (Figure 11). The participant missed in total 3 out of 200 targets. All 197 hits were normal hits. The participant had 10 false alarms, all of which were a result of a non-target-trial and all were normal responses (Figure 12).

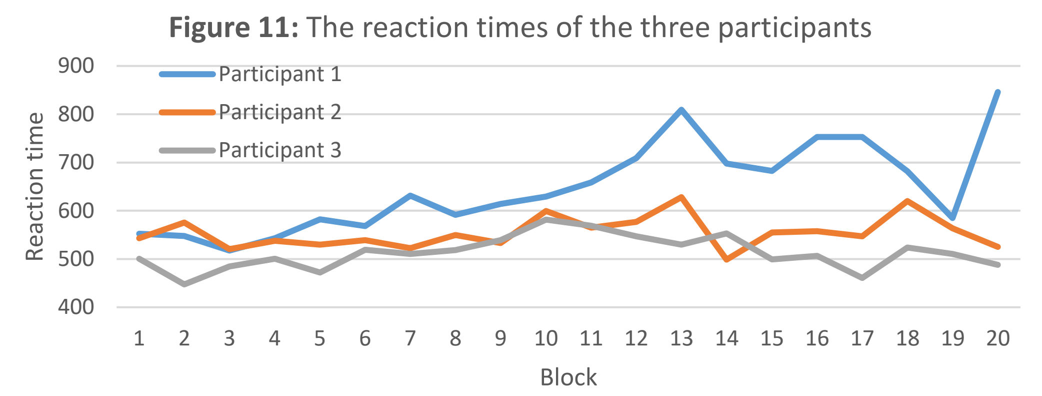

Figure 11: Schematic representation of the measured reaction times. The reaction time indicates the time between the stimulus presentation and the response of the participant.

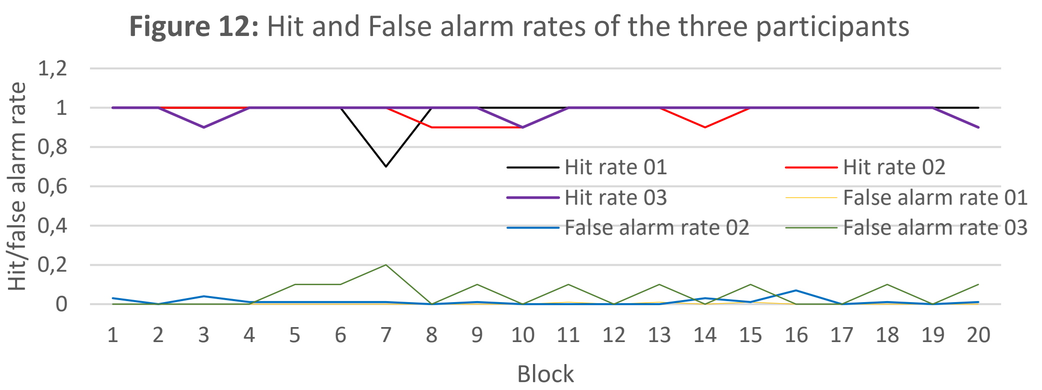

Figure 12: Schematic representation of the hit- and false alarm rates of the three participants. The colored lines represent the six segments that show the hit and false alarm rates over the 20 blocks.

For the behavioral data, the correlation with the self-report scores was calculated for each participant (Figure 13). For the first participant the correlation was -0.795 ($p<0.001$, $R^2=0.632$), for the second participant the correlation was -0.250 ($p=0.288$, $R^2=0.062$) and for the third participant the correlation was -0.437 ($p=0.054$, $R^2=0.437$).

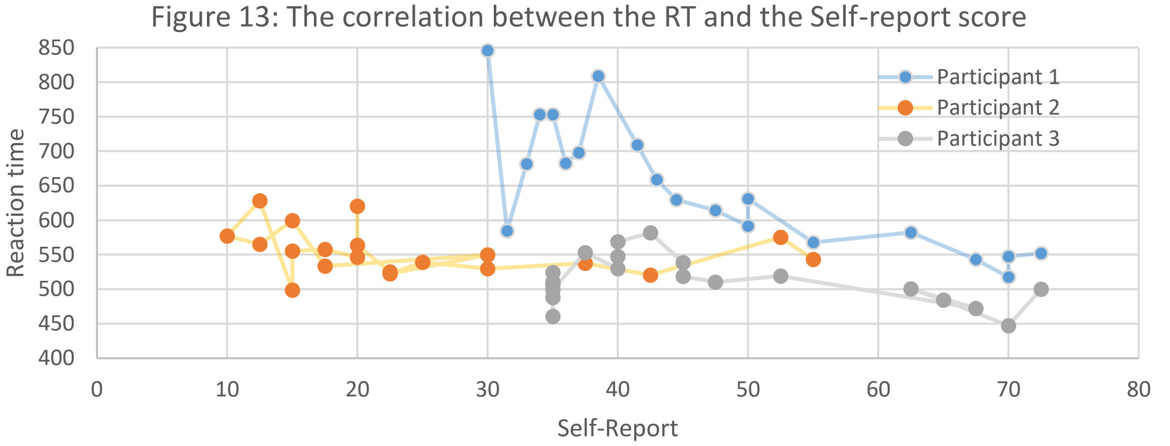

Figure 13: Schematic representation of the correlation between the reaction times and the self-report scores of the three participants.

Discussion

Here, the research question '*can EEG be used as a valid method to directly determine the vigilant state of an individual during a task, by examining the lateralization of the alpha power?'* will be discussed. The research question led to several expectations; Firstly, it was expected that the number of mistakes would increase as the participants became fatigued and that most mistakes would occur in the condition with a target on the non-attended side. Next, it was expected that a decrease in contralateral α power would appear as the participant was focused on one part of the visual field or was using only one index finger. Finally, the predictive power of EEG and self-report were examined. In the next section firstly, the results will be discussed and then the expectations will be considered. Then, the conclusions that were drawn from the experiments will be stated and the possible answer to the research question will be discussed. Finally, the limitations and future research suggestions will be discussed.

EEG data

Here, the results will be summed and possible explanations for the results will be given. For the first participant, it was shown that the indices for the RVF are more positive than those for the LVF, which is partially confirmed by the third participant but also partially contradicted. For the third participant, it was shown that the indices for the LIF are more positive than those for the RIF which is partially confirmed by the first participant but also partially contradicted. For the second participant, there was one significant segment showing that the indices for the LVF were more positive. However, the analysis of the EEG data in Brain Vision Analyzer was very problematic for this participant which resulted in an inability to properly remove all the eye movements, which can be problematic for the reliability.

These results of the first and third participant that the indices of the RVF are more positive are contradictory to the current consent that alpha wave power decreases as a person focuses on one part of the visual field (Gould et al., 2011; Sauseng et al., 2005; Thut et al., 2006; Van der Lubbe et al., 2014; Worden et al., 2000). There are three possible explanations for this pattern. The first explanation concerns the effect of the used IF on the results. For the third participant there was an effect of the used IF on the indices, so the significance is not solely caused by the visual field. This is not the strongest explanation and cannot explain all results but it is a factor that needs to be considered. The second explanation is mentioned in a review by Klimesch (1999). He points out that in some cases with growing fatigue alpha activity actually decreases. He also states that the increase in the lower alpha power that is mentioned often reflects an effort to stay awake. This could further explain why the pattern shifted for the third participant. There is a possibility that at first, the participant was compensating for the fatigue by an increase in alpha but after a while the contralateral hemisphere starts processing the stimulus which results in a decrease in alpha. Unfortunately, for this paper it was currently not possible to distinguish between the frequencies. The third explanation assumes that the participants did not follow the instructions correctly. As the attended side remained the same during the whole block, the participant could have gazed continuously at the attended side. In this situation, they would not have made any eye movements so this cannot be detected using EOG. If for example the attended side is the left side, the expectation is that in the contralateral hemisphere the alpha will decrease. However, if one focuses on the left field, this information enters both hemispheres. Furthermore, to the right of the left field there are two more stimuli, the fixation point and the unattended stimulus. The information of these points will enter the left ipsilateral hemisphere which might cause a decrease in alpha power which can be the cause of the observation that the results contradict the expectations. Thus, there are several explanations, none of which can be confirmed yet. The results of the first and third participant were contradictory to the results of the second participant, who had one significant results showing that the indices for the LVF were more positive, which was in consensus with the expectancy. These results need to be considered carefully, as there were several problems with the analysis of this data. However, there was a significant pattern which implies that this participant did follow the instructions correctly and therefore had a contralateral α decrease. This implies that for the other two participants, the third explanation seems to be the most likely.

The results on the index finger were more in line with the prediction. Especially for the third participant, all the results indicated that the indices for the LIF were more positive than those for the RIF. This was in accordance with the expectancy that the mu power would decrease as the hemisphere had to focus by physically responding (Gould et al., 2011; Sauseng et al., 2005; Thut et al., 2006; Worden et al., 2000). Important to notice is the influence of the attended field, in the final three segments there was some (nearly) significant influence of the attended field on the indices. Therefore, these need to be considered carefully. For the second participant, there were no significant results for the index finger but as mentioned before there were many problems with the analysis. Interestingly, for the first participant the results shifted throughout the segments. In segment 1, 2, 4 and 5 the results were not significant. However, in segment 3 it was significantly shown that the indices for the LIF were more positive and in segment 6 is was shown that the indices for the RIF were more positive. This unexpected pattern can be caused by a couple of factors. One of which is the influence of the attended field on the results. It has been shown that the attended field influenced the results in several segments (nearly) significant. The second option refers to the previous mentioned argument by Klimesch (1999). As the participant became more fatigued, it is possible that the lower alpha power increased as the participant focused in an attempt to stay awake. This does not explain the entire result but it might be an aspect that had influence, especially for the final segment.

Finally, the development over time was checked. Despite some indications of increases or decreases, there was no clear effect that could be found in the several figures presenting the indices. In Figure 12, the results showed more clearly that overall, the average of the alpha power of PO7/PO8 seemed to increase over the 20 blocks, especially for the third participant. This is in accordance with the literature; as the participants became more fatigued the alpha desynchronization declined (Gould et al., 2011; Grent-'T-Jong et al., 2011; Sauseng et al., 2005). For the average of C3/C4, there seemed to be a very slight increase over time, but overall the averages did not change much over time. The small increase that seemed to appear is, simultaneously, in accordance with the literature. However, for neither electrode pair it could be statistically confirmed that there is indeed an increase over time.

The expectation that a decrease in contralateral α power would appear as the participant was focused on one part of the visual field or was using only one index finger cannot be confirmed completely. For the used index finger, most results were in accordance with the expectation. However, for the attended visual field most results contradicted this expectation. In the current experiment, this expectation can solely be confirmed for the index finger. It was also examined what the predictive power of EEG was. The results seemed to indicate that the indices increased over time which indicates that the participants were having trouble to focus, which seems to correlate negatively with the RT. However, it was, due to the design, not statistically possible to determine whether there is an increase or a decrease in the indices over time, thus the indices could not be used to make predictions.

Self-report and behavioral data

The self-report scores of the participants decreased throughout most of the experiment. This was expected as the experiment was designed to be fatiguing. For the behavioral data, the reaction time increased for all participants throughout the 20 blocks. However, there were few false alarms or misses and there seemed to be no gradual change in the number of mistakes throughout the experiment. This indicated that, despite the tiring effect of the experiment, the participants could still perform the task correctly. Therefore, vigilance decrement has not been detected in this experiment. Wascher et al. (2014) suggested that participants can sometimes be capable of compensating for their fatigue. This compensation can be as large to remain successful for over 30 hours, as has been shown by Kiroy, Warsawskaya, and Voynov (1996). Sarter, Gehring, and Kozak (2006) state that this compensation can be successful in overcoming fatigue as long as the participant remains motivated as this causes several neurobiological changes. This explanation can also be applicable to the current experiment. As the experimenter was present during the measurement and had instructed the participants to do their best, the participants were likely to be motivated to perform optimally and were thus capable to compensate. This effect was also visible in the number of false alarms. In contrary to the expectancy, nearly all the false alarms that occurred resulted from a non-target trial rather than a trial with the target on the non-attended side. This indicates that the participants were able to remain focused on the attended side and compensated for their fatigue, thus their spatial attention was not affected much. The false alarms after non-target trials likely indicate a short loss of concentration, which made them guess.

Looking back at the research question, one of the predictions concerned how well self-report could predict the behavior. The results indicate that the participants should have responded more slowly and should have made more mistakes as the task proceeded. Focusing at the reaction time, there was a correlation, which indicated that as the participant got more tired they responded more slowly. However, despite the participants fatiguing they still performed successfully in contrary to the prediction made by the self-report. Therefore, self-report seems to be a suitable method to predict the reaction time but it does not seem to be capable of predicting the ability to detect changes in the environment.

Conclusion

Using the current results, the research question could not yet be answered but it will be attempted to answer as complete as possible. The overall research question was: *can EEG be used as a valid method to directly determine the vigilant state of an individual during a task, by examining the lateralization of the alpha power?* This question led to several expectations. For the behavioral data, it was expected that the number of mistakes would increase as the participants became fatigued and that most mistakes would occur in the condition in which there is a target on the non-attended side. Both these expectancies appeared to be incorrect. It was also expected that a decrease in contralateral α power would appear as the participants focused on a visual field or was using one IF. This appeared to be partially true as only for the index finger this pattern was observed and for the visual field the opposite pattern was observed. Furthermore, with the current design EEG could statistically not be applied to make behavioral predictions. Therefore, with this design self-report seemed to be a more suitable predictor, but this is limited as well. Thus, it cannot be concluded that EEG be used as a valid method to directly determine the vigilant state of an individual during a task, by examining the lateralization of the alpha power as the design and results rose some questions, unexpected results and had several statistical limitations.

Limitations and future recommendations

The current experiment had several limitations which could be adjusted in the future to improve the experiment. Firstly, one limitation in the experiment was that the attended side was the same throughout the entire block. This leads to two problems; The first was that the participant could have gazed at the attended side the entire time without making any eye movements, which could not be detected using EOG. Secondly, there is always a systematic difference between the two hemispheres and the current method does not take this into account. If each trial would have a new attended side, differences between the hemispheres could be averaged out using a double subtraction, mentioned by Van der Lubbe and Utzerath (2013), to determine the index. Both problems could thus be solved by varying the attended side for each trial and giving a cue on what side to focus on in advance of each trial

Another issue in the experiment was that the performance of the participants did not deteriorate, due to the compensation mechanism. This can be solved in two ways, firstly the task can be made more difficult. This will cause more errors and it can be interesting to check whether the compensation will work on a more difficult task as well. Secondly, it can be interesting to check for the compensation mechanism in the EEG data. This can be done by comparing the data of participants motivated to perform good to the data of participants that are not motivated to perform good. Another limitation in this study were the statistical analysis. As the analysis were on individual level, it was solely possible to determine whether there was a significant effect of the attended field and the index finger on the indices.

However, there is still much to learn for example on whether there is a change over time. This problem can be most easily solved by including more participants.

To properly answer the research question some additional research is required. Firstly, both the effect of the attended field on the indices for electrode pair C3/C4 and the effect of the used index finger on the indices for electrode pair PO7/PO8 need to be filtered out. This can be achieved by splitting up the research. So, for the indices on electrode pair C3/C4 one could only vary the used index finger and let people attend the middle of the screen and for the indices on electrode pair PO7/PO8 one could only vary the attended field and make people respond differently, for example verbally. Secondly, it can be quite interesting to consider the difference between the upper and lower alpha results. As has been mentioned, the lower alpha waves can be a cause for the unexpected results. Third, if a group of participants would be used, the statistical analysis would be much easier. One can then employ a regression to determine the effect over time and a correlational analysis to check for how good EEG predicts the performance. Finally, for two participants the results shifted, first the indices for one side were more positive and next the indices for the other side were more positive. In the current paper, no solid explanation was found for this. It can be interesting to repeat the experiment and check whether this effect is found again to help find out what causes this.

If these limitations can be solved, then the research question can be answered. Should the answer be that EEG can indeed be used as valid method to determine the vigilant state of an individual, this can provide a tool for determining the level of vigilance of an individual. Then the vigilant state can be measured directly by considering brain activity thus an attentional task will be superfluous. This provides the opportunity to measure the vigilant state of individuals while they are performing several tasks, to determine when the vigilance decreases and when the likelihood of mistakes increases and it allows the researcher to distinguish between people based on their vigilant state.

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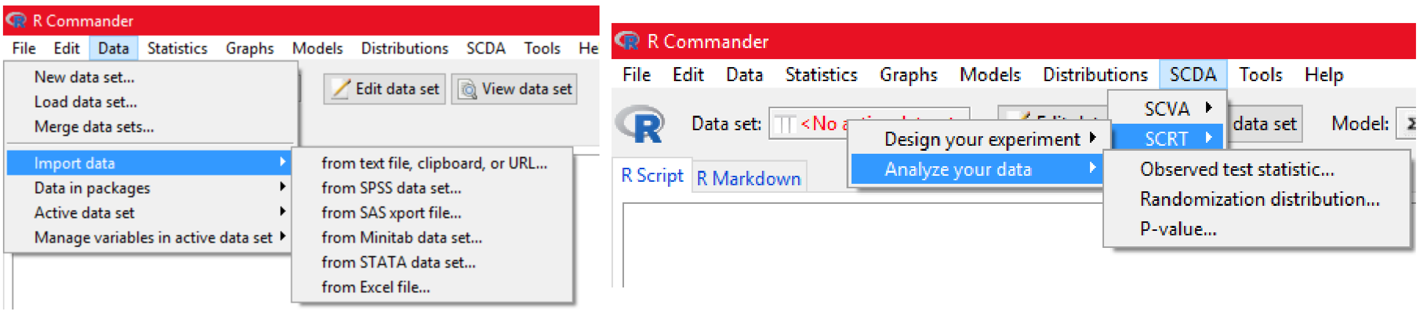
Appendix

1 Single case randomization tests in R studio

In psychology, small-n studies are not used often but they can have great effect on individual level. Being able to analyze the results of these studies is therefore just as important as studies in which groups of people are analyzed. In this Appendix, the statistical method used in paper will be described in more detail. The entire analysis has been based on Bulté and Onghena (2008) and Bulté and Onghena (2013). To perform the analysis, first one must download R and R studio. R studio must be supplemented with an additional package, which is called R commander. This can be done using the command *install.packages("Rcmdr").* For R commander to work, some extra packages need to be installed. These packages are 'splines', 'car', 'sandwich', and 'RcmdrMisc'. These packages can be installed in a similar way. Finally, an extension package of R commander must be installed. This is called R commander SCDA and this can be installed using the command *install.packages("RcmdrPlugin.SCDA").* After this is done, R commander can be opened with the command *library(RcmdrPlugin.SCDA).* If the R commander screen does not open after this, this can be accomplished with the command *library(Rcmdr).* This will open an additional screen, in which the analysis can be executed.

For the analysis to work, the dataset must have a certain outlook. The dataset needs to have two columns. The first column contains the condition labels 'A' and 'B' and the second column contains the obtained scores for the conditions. This dataset needs to be loaded into R Commander using *data→ import data*. If it is loaded into R Studio, the analysis will not function. When this is done, the SCDA command can be used to perform the single case randomization test. The SCRT command contains two options (see Figure 13). In the first, the experiment can be designed in which R Commander can give the number of possible assignments, it can present all the possible assignment and it can choose 1 random assignment. In the second command, the data can be analyzed. This contains three options. In the first, the observed test statistic is calculated. In the case of an alternating treatment design, which includes the randomized block design, the test statistic can be either A-B, B-A or |A-B|. When it is expected that A>B, then A-B is used, B-A is employed when it is expected that B>A. If there is no direction expected than |A-B| can be used. The second option calculates a 1000 random distributions are

Figure 13: Two displays of R commander showing how import data and the SCRT menu



made and calculates their test statistic. To perform this, one needs to enter the design (RBD), the test statistic and the maximum number of consecutive administrations of one condition. The third option calculates the p value, which is the portion of test statistics that is equal or higher to the obtained one. To obtain this value, one needs to enter the same information as for the random distributions. All the values will appear in R Studio.

2 The indices in the separate segments

In the paper the graphs present the indices of PO7/PO8 and C3/C4 in one Figure. In some cases, the lateralization was not as consistent and therefore it can be interesting to look at the segments in more detail. Therefore, the graphs for each segment are presented here.

Participant 1

Figure 14: The indices of electrode pair PO7 and PO8 for participant one on the six segments

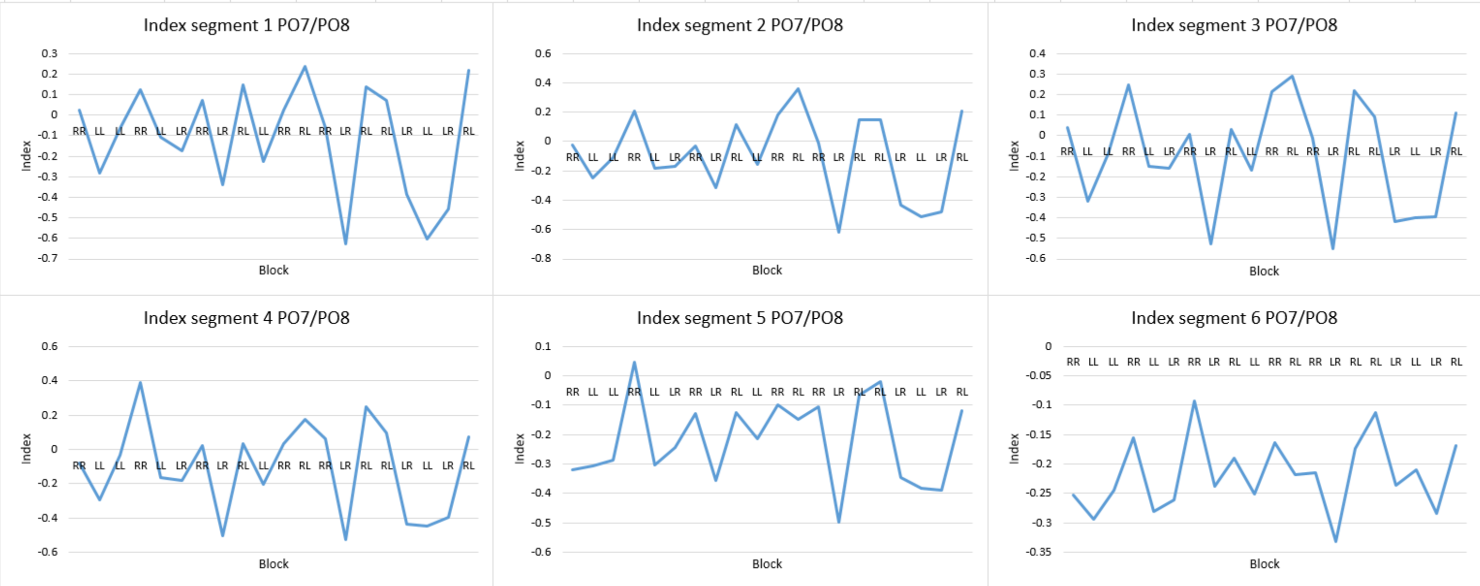
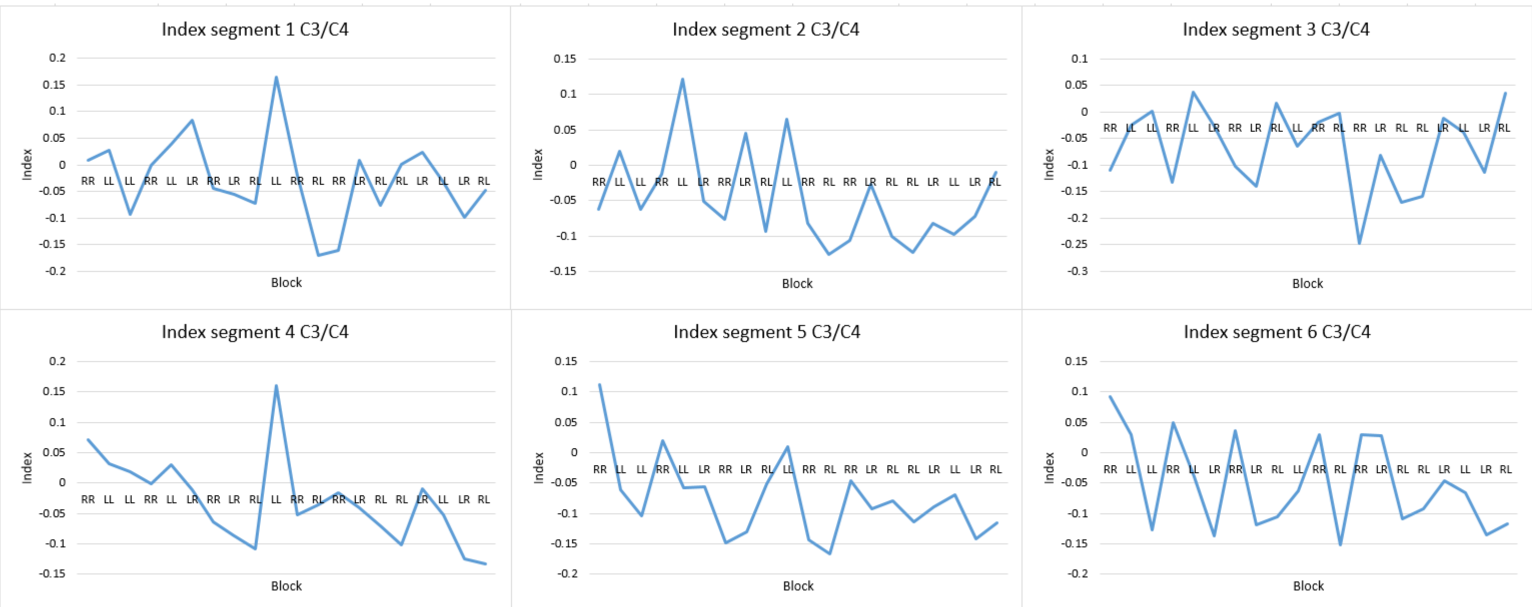


Figure 15: The indices of electrode pair C3 and C4 for participant one on the six segments



Participant 2

Figure 16: The indices of electrode pair PO7 and PO8 for participant two on the six segments

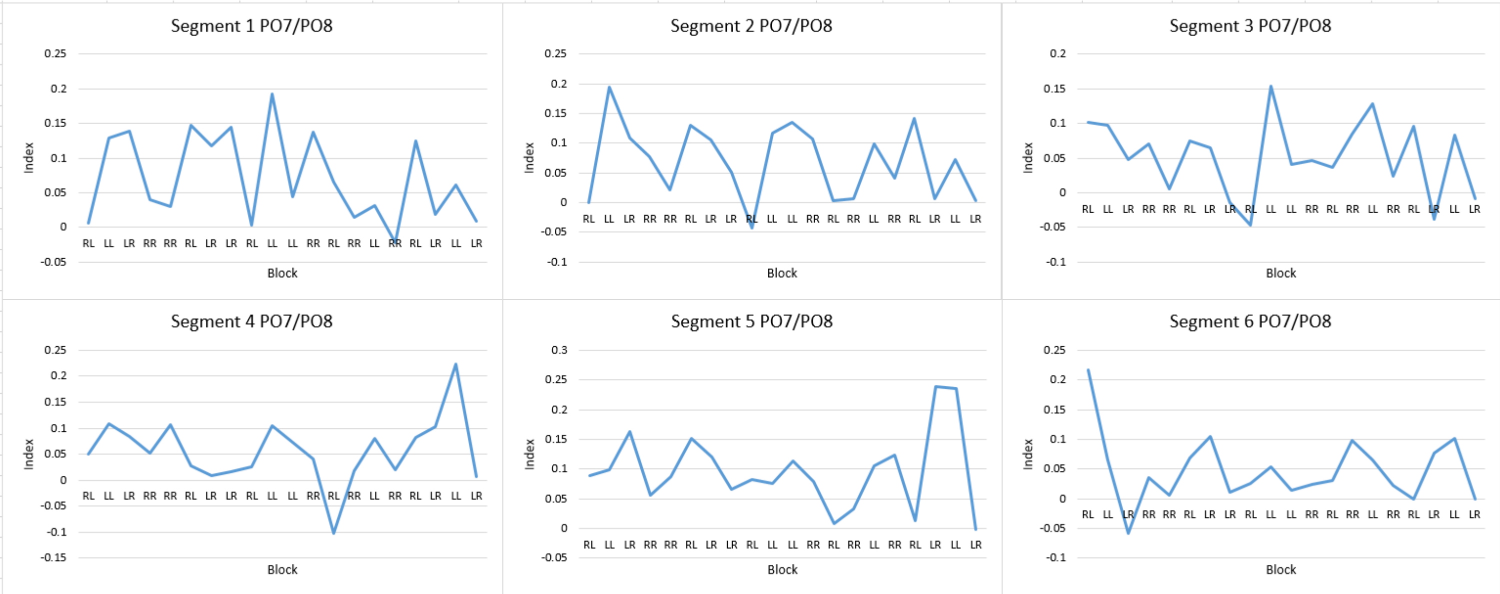
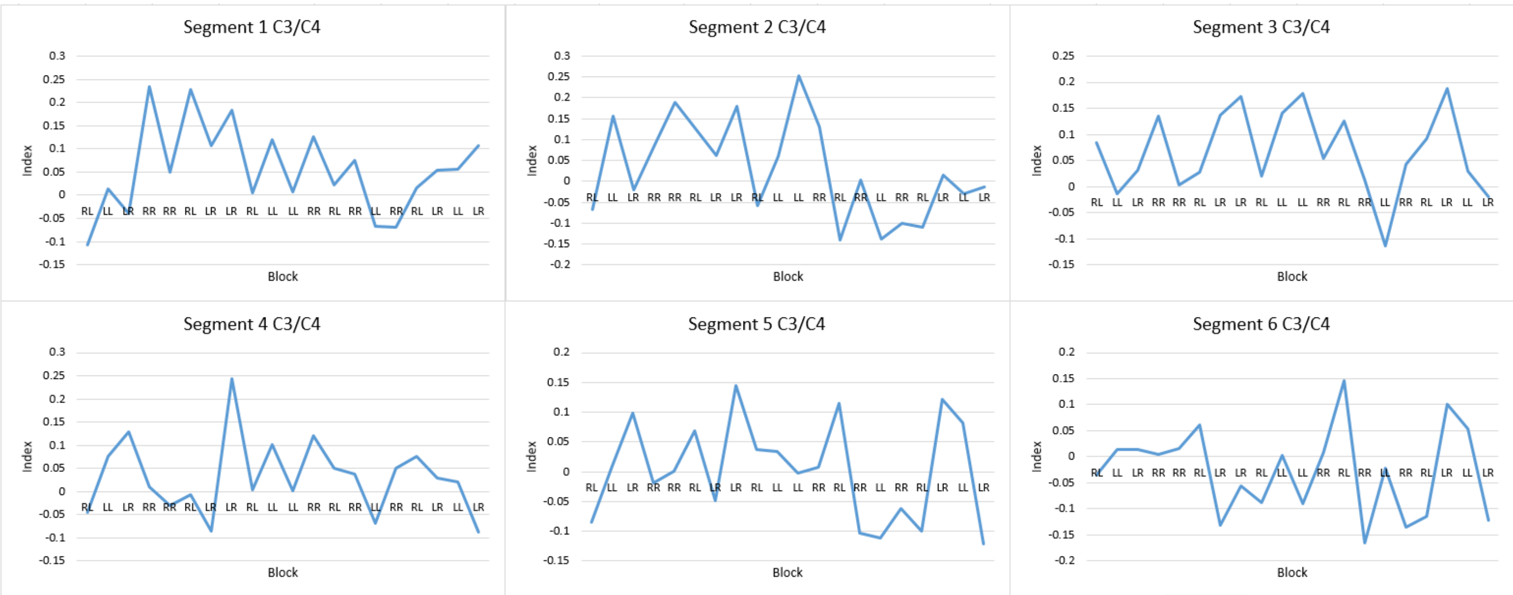


Figure 17: The indices of electrode pair C3 and C4 for participant two on the six segments



Participant 3

Figure 18: The indices of electrode pair PO7 and PO8 for participant two on the six segments

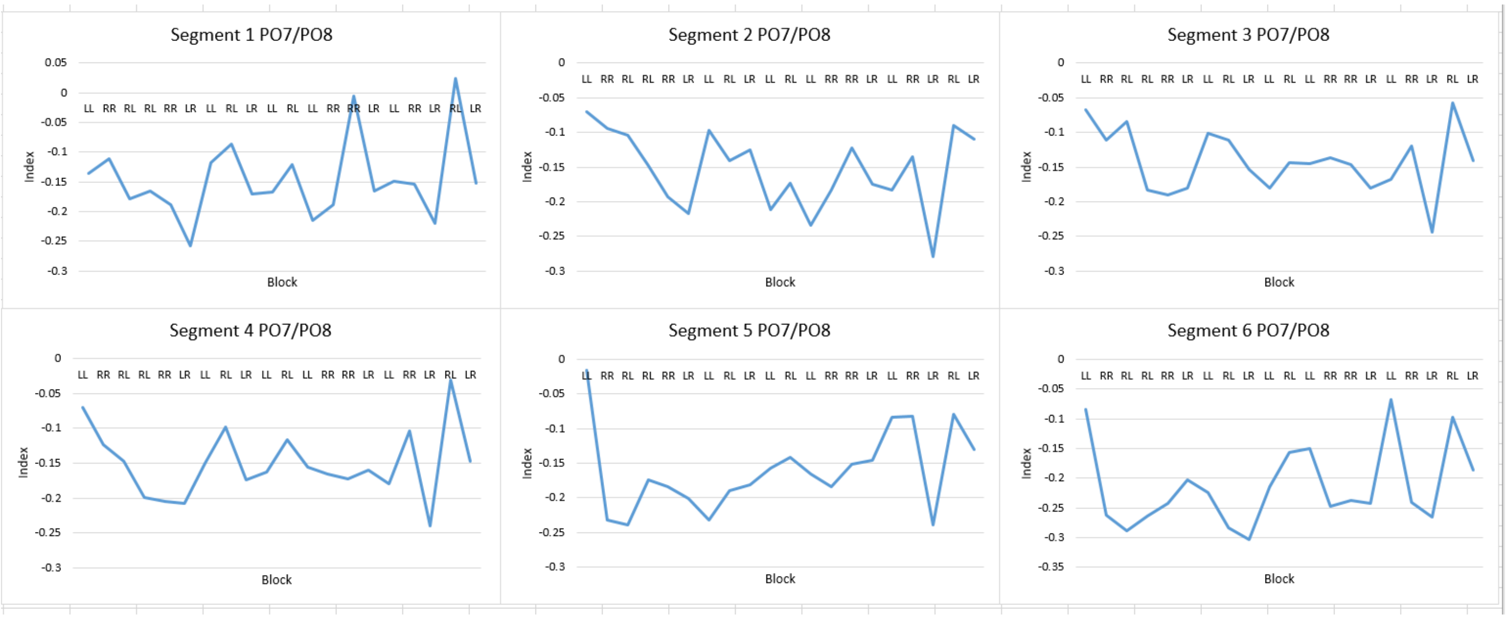


Figure 19: The indices of electrode pair C3 and C4 for participant two on the six segments