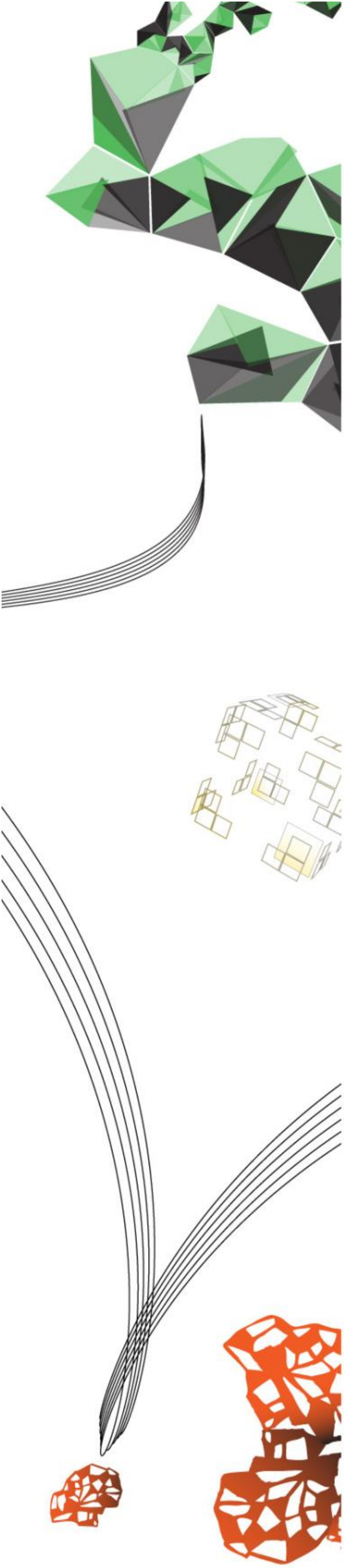

Bachelor Thesis

The lateralization of anticipatory alpha oscillations while allocating visuospatial attention

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Content

Appendix

Samenvatting

Het eerste doel van deze studie was om te onderzoeken of alpha lateralisatie gelinkt is aan spatiële aandacht. Er is onderzocht of de manipulatie van de cue validiteit effect heeft op de lateralisatie van alpha synchronisatie. Het tweede doel van dit onderzoek was om te achterhalen of voorspellingen met betrekking tot prestatie gemaakt kunnen worden op basis van alpha synchronisatie. Om deze vragen te beantwoorden werd een endogenous cueing paradigma aangeboden aan 13 respondenten. De cues verschilden in de validiteit dat de stimulus, waarop de respondent moest reageren, correct voorspelt wordt. EEG is gemeten gedurende het experiment en wavelet analyses zijn toegepast on de ruwe EEG. De resultaten van de laterlized power spectra (LPS) data indiceert dat er een grotere lateralisatie in de conditie met hogere validiteit is ten op zichte van de conditie met lagere validiteit en dat de alpha band desynchronisatie hoger was bij contralaterale dan ipsilaterale elektrodes. Aanvullend indiceren de resultaten dat individuele prestatieverschillen voorspeld kunnen worden door de LPS index van de elektrodes. De resultaten gevonden in dit onderzoek laten zien dat alpha lateralisatie een adequate methode is om aandacht te onderzoeken.

Summary

The first aim of this study was to examine whether alpha lateralization is linked to spatial attention. It was examined whether the manipulation of cue validity has an influence on the lateralization of alpha synchronization. The second aim of this study was to examine whether predictions regarding performance can be made based on alpha synchronization. To address these questions, 13 participants were presented with an endogenous orienting paradigm. The cues differed in the validity that the stimulus, the respondent had to respond to, was correct predicted by the cue. EEG was measured during the whole experiment and wavelet analyses were applied on the raw EEG. Results of the lateralized power spectra (LPS) data indicates that there is a greater lateralization in the condition with higher spatial certainty compared to the condition with lower spatial certainty and that the alpha band desynchronization was higher at contralateral than on ipsilateral electrodes. Additionally, results indicate that individual performance differences can be predicted by the LPS index of the electrodes. The results found in this study indicate that alpha lateralization is an adequate method to examine attention.

1. Introduction

Maintaining goal-directed behavior such as directing attention gives us the ability to select and process relevant sensory stimuli. Therefore, a goal of cognitive neuroscience has been to understand the neural mechanisms which play a role in the allocation of selective attention. One possible neural mechanism underlying the allocation of selective visuospatial attention is anticipatory modulation of alpha band (8-12 Hz) oscillations during cue-target delays, which can be observed in the EEG, as first reported in Worden, Foxe, Wang and Simpson (2000).

In the current study two questions are addressed. The first question is whether the magnitude of anticipatory alpha rhythm lateralization covaried with the degree to which attention was allocated to a particular location (see Gould, Rushworth and Nobre (2011), explained in detail later on). The second question examined in this study is whether there is a relation between the lateralization of alpha rhythm and individual differences in performance (see Mathewson, Gratton, Fabiani, Beck and Ro (2009), explained in detail later on).

In the following, the concept of attention is discussed first. We will focus on the main paradigm to examine spatial attention and the related mechanisms which are elaborated with EEG.

1.1 Endogenous attention

In the context of information processing is attention the process that enhances some information, so that we are able to select information for further processing, and inhibits other information, which enables us to ignore some information. In this study, the focus lies on visual - spatial attention, where attention is directed to a specific location in the visual field. The result is an enhancement in the processing of stimuli appearing at the attended spatial location, while stimuli appearing at unattended regions will be suppressed. Visuospatial attention can be deployed prior to stimulus onset to bias processing of an upcoming stimuli. In visuospatial attention, a difference is made between overt and covert attention. During overt orienting, attention is linked to eye movements. During covert orienting, attention systems operate independently. Covert attention results in improved processing of stimuli occurring at the locus of attention while attenuating processing of stimuli located elsewhere in the visual field. (Binder, Hirokawa & Windhorst, 2009, p. 4359). In the current study the focus lies on covert, endogenous attention. There is a difference between endogenous and exogenous attention. Whereas endogenous attention has a voluntary aspect and is oriented according to an observer's goals, exogenous attention is driven by a stimulus outside oneself, it is thus under control of the stimulus (Hopfinger & West, 2006; Smith & Kosslyn, 2007).

The standard way to examine spatial attention and its effects is the Posner (1980) cueing paradigm, which has been an important paradigm for studying visual attention (Eckstein, Shimozak & Abbey, 2002). An endogenous cue, such as an arrow, predicts the likely locus of a lateral to-be-detected target. The participant has to focus attention to that location, while the eyes are kept on the fixation point. Areas that are activated in response to the cue, prior to presentation of the target stimulus, are those areas that are involved in top-down control of attention (Giesbrecht, Woldorff, Song & Mangun, 2003; Smith & Kosslyn, 2007; Van der Lubbe & Utzerath, 2013).

In these studies, a difference is made between validly and invalidly cued trials. On validly cued trials, the cue points in the direction of the position of the target, on invalidly cued trials the cue appears pointing the opposite direction of the position of the target. Research shows that attended stimuli are perceived more accurately and that those stimuli receive faster responses than unattended target stimuli. Participants perform thus better on validly cued trials than on invalidly cued trials (Posner, 1980; Van der Lubbe & Utzerath, 2013). This is called cue validity effect (Eckstein, Pham & Shimozaki, 2004; Petersen & Posner, 1990). An interpretation of this result is that visual attention has limited resources that can be allocated at one of the locations. When the resources are allocated at the cued location, there are benefits at the attended location. These benefits are expressed in decreased reaction times and enhanced detection rates (Rihs, Michel & Thut, 2007; Eckstein et al., 2002).

Tasks as the endogenous orienting tasks, allow us to assess the extent to which voluntary allocation of attention, in response to the cue, differentially modulates activity in cortical areas in preparation for the processing of an expected stimulus (Fu et al. 2001).

There are thus many studies which have examined the influence of attention on perception. However, there is no clarity of the attentional mechanisms, which are related to the behavioral benefits discussed above. Currently, the widespread view is that spatial attention causes sensory gain, which is linked to the idea that attention increase neural activity, related to the target. Klimesch (2011) showed that the increased target- induced P1 component on validly cued trials compared to invalidly cued trials is interpreted in terms of sensory gain (Van der Lubbe & Utzerath, 2013). A second way to interpret the attentional mechanisms underlying the behavioral benefits, is evoked by recent EEG studies suggesting that inhibition of neural activity may be the crucial mechanism to regulate visual information processing (Sauseng et al., 2005; Rihs et al., 2007; Van der Lubbe & Utzerath, 2013; Klimesch, Sauseng, Hanslmayr, 2006; Gould et al., 2011).

1.2 EEG

To study the precise nature of the attentional mechanism, many studies make use of the electroencephalogram (EEG). Over the past decades, the human EEG has been shown to be a useful tool in the understanding of attention and the processes involved in directing attention (Cooper, Croft, Dominey, Burgess & Gruzelier, 2003).

The human EEG was first described by Hans Berger in 1929, who observed rhythmic brain waves around 10 Hz that he termed alpha waves. He demonstrated that an important characteristic of these alpha rhythms (8-12 Hz) was the suppression (desynchronization) in amplitude seen in response to opening the eyes or under mental effort (Bazanova & Vernon, 2014, Sauseng et al., 2005). This has become known as the 'Berger effect' (Barry et al., 2007 cited in Bazanova & Vernon, 2014). To conclude, strong EEG alpha can usually be observed during relaxed wakefulness without high cognitive load, whereas amplitude reduction reflects cortical activity (Sauseng et al., 2005).

1.3 Alpha suppression

In many studies it is stated that alpha rhythm is one of the main EEG rhythms which has a well-defined physiological property, which is, as already mentioned, the suppression of amplitude in response to opening the eyes or increasing cognitive load. Therefore, some have used the amount of alpha suppression as an index of cortical activation (Bazanova & Vernon, 2013). Many studies examined the relation of alpha activity and different attentional mechanisms. In the review of Klimesch (2012), for instance, the focus was on alpha-band oscillations as the dominant oscillations in the human brain. He states that the argument for an involvement of alpha band activity in attention is given by findings which show that alpha-band activity desynchronizes in response to anticipatory attention in the absence of stimulation. Other studies show that following an attentional shift, there is a suppression of alpha activity and that this neuronal change might reflect an active neural area (Yamagishi, Callan, Anderson & Kawato, 2008). Many studies revealed that the gradient of occipital alpha desynchronization correlates with focusing of spatial attention and suppression of stimuli at ignored locations (Worden et al., 2000; Sauseng et al., 2005; Capostoto, Babiloni, Romani & Corbetta 2009).

Although alpha activity is a topic which many studies examined, the exact physiological mechanisms that generate alpha-band activity are not yet known well (Klimesch, 2012).

1.4 Alpha Lateralization

The first study demonstrating that the lateralization of alpha synchronization is linked to attention was the study of Worden et al. (2000), who made use of an endogenous orienting paradigm. They demonstrated that the activity of the alpha band depends on the cued side. Other studies found similar results making use of visuospatial attention tasks. They reveal that alpha exhibits greater amplitude over the parieto – occipital cortex ipsilateral to the relevant hemifield compared to the measure when the same hemifield is to be ignored. Increased alpha power was thus observed above ipsilateral occipital areas before visual target onset, whereas decreased alpha power was observed above contralateral occipital areas (Worden et al., 2000; Kelly, Lalor, Reilly & Foxe, 2006; Sauseng et al., 2005; Rihs et al., 2007; Van der Lubbe & Utzerath, 2013).

Gould et al. (2011) showed that previous studies demonstrated that small changes in the lateralization of alpha band activity are predictive of behavioral performance but these studies did not investigated how flexible alpha lateralization is linked to top- down attentional goals. In their own study, they investigated whether graded changes in alpha lateralization are associated with graded changes in the spatial allocation of voluntary attention. Participants had to discriminate the orientation of a target stimulus, which was preceded by a spatial cue. These cues indicated that the target stimulus would appear on the left or on the right side with a probability of 60%, 80% or 100%. Gould et al. (2011) found that manipulating spatial certainty led to graded changes in the lateralization of alpha during the cue- target interval and showed that desynchronization is greater when spatial certainty is higher and that alpha power progressively decreases as spatial certainty increases. Besides, they reported that spatial certainty has an influence on behavioral measures. Respondents responded faster and more accurate when spatial certainty was higher. In Gould's (2011) study, respondents only answered with one hand which could be a problem because it could have an influence on the lateralization of alpha oscillations. Besides, there is a possibility that general hemispherical differences have an influence on the lateralization index. This problem is also described by Van der Lubbe and Utzerath (2013), who state that the right hemisphere is thought to be actively involved when attention has to be directed towards any location. This may increase hemispherical differences in the case of left cues and reduce these differences in the case of right cues. To avoid those effects, it is expedient to make use of double subtraction rather than single subtraction. A second aspect of the study of Gould et al. (2011) which could be a problem is the presentation of the cue. The cues were presented randomly and the participant had to concentrate per stimulus where he or she had to focus on.

Alpha phase plays also a role in predicting visual awareness. Mathewson et al. (2009) state that we often fail to see something, which is at other times detectable. This variability in conscious awareness is likely related to changes in the brain, because the visual stimulus itself remains unchanged. They therefore searched for a pre-stimulus alpha phase, which predicts visual awareness. Their results demonstrate that alpha power as well as phase differences contribute to conscious target detection.

The current study is based on the ideas of the study of Gould et al. (2011) and Mathewson et al. (2009), described above. We wanted examine whether the results of Gould et al. (2011) can be replicated, after adjusting the method to avoid problems mentioned above. In the current study compared to the study of Gould et al. (2011), double subtraction was applied (Van der Lubbe & Utzerath, 2013). Making use of the LPS (lateralized power spectra) method, differences between the hemispheres were evaluated. This method enables to isolate the effects of attention, to determine the involvement of internally generated lateralized processes which are not bound to an event and to get information of the raw EEG itself (Van der Lubbe & Utzerath, 2013). Besides, we made use of blocks, rather than presenting the stimuli randomly to reduce variability due to interference from previous trials. The second question is based on the ideas of Mathewson et al. (2009). We wanted to examine whether there is a relation between the performance measures of the respondent with the index of lateralization of alpha synchronization. In contrast to Mathewson et al. (2009), we focused on differences between individuals rather than differences within individuals.

To examine these questions, we made use of an endogenous orienting task. Two blocks with two different spatial certainties were presented to each of the participants, one with cues of a spatial certainty of 100% and one with a spatial certainty of 66%. We also made use of subliminal and supraliminal stimuli. A mask covered the target after three different periods (132 ms, 264 ms, 396 ms). Our expectations are that respondents respond faster and more accurate when spatial certainty is higher and that there is a greater desynchronization when spatial certainty is higher. For the second question, we expect that there is a relationship between performance and the lateralization of alpha synchronization.

2. Method

2.1 Participants

In total, there were 13 participants, who took part in the experiment, whereof seven participants were female and six were male aged between 19 and 27 with an average age of 21 (*M* = 21.23). Making use of the Annett's Handedness Inventory (Annett, 1970), we ascertain the handedness. Eleven participants were right-handed, one participant was left-handed and one was ambidextrous. All participants had normal or corrected-to-normal vision, were not color-blind, and had no history of neurological diseases, which could have an influence on the data. All participants were students of the University of Twente, who signed an informed consent before starting with the experiment. The experiment and its procedures were approved by the ethical committee of the University of Twente.

2.2 Task and stimuli

At the beginning, the participants were asked to read the informed consent and to fill in the questionnaire (Appendix A) and the Annett's Handedness Inventory (Annett, 1970). While preparing the electrodes, the participant had the opportunity to practice do a demo – version of the experiment. The Posner (1980) endogenous cueing task was employed with one block with 66% valid cues and one block with 100% valid cues. At a display a white fixation point was presented on a black background. The onset of a trial was marked by an enlargement of the fixation dot for 200 ms. The participants were instructed to direct their eyes towards the fixation point. After presenting the display for another 400 ms, a diamond-shaped cue, consisting of two colored triangles (blue and yellow, with one color defined as relevant) pointing to the left and right circles, was displayed for 600 ms, indicating the location of the target. This cue was replaced by a fixation point 800 ms. At 1,400 ms after cue onset, a target was presented in either the left or the right circle. The target was either a vertically or a horizontally striped circle. Horizontally striped targets required a left button response, and vertically striped targets required a right button response. To make use of subliminal and supraliminal stimuli, a mask covered the target after three different SOAs (132 ms, 264 ms, 396 ms). The participants were instructed to press the key as fast as possible before the stimulus was covered by the mask. There was a clear instruction to press the space-bar if the participant did not see anything. They were also instructed not to guess. After target-offset, the default display was presented for another until a new trial began. The relevant color (the yellow or the blue triangular part of the diamond) stayed the same per participant. All respondents took part in two blocks, one block with cues pointing to the target with a validity of 66% and one block with cues pointing to the target with a validity of 100%. The relevant color and the type of block (cue validity) were counterbalanced. Making use of different variants which were counterbalanced between participants, sequence effects should be avoided. Each participant was presented with 630 trials in total, divided across two blocks. The experiment took approximately 150 minutes in total. The setting was adjusted based on a pre-test with five persons.

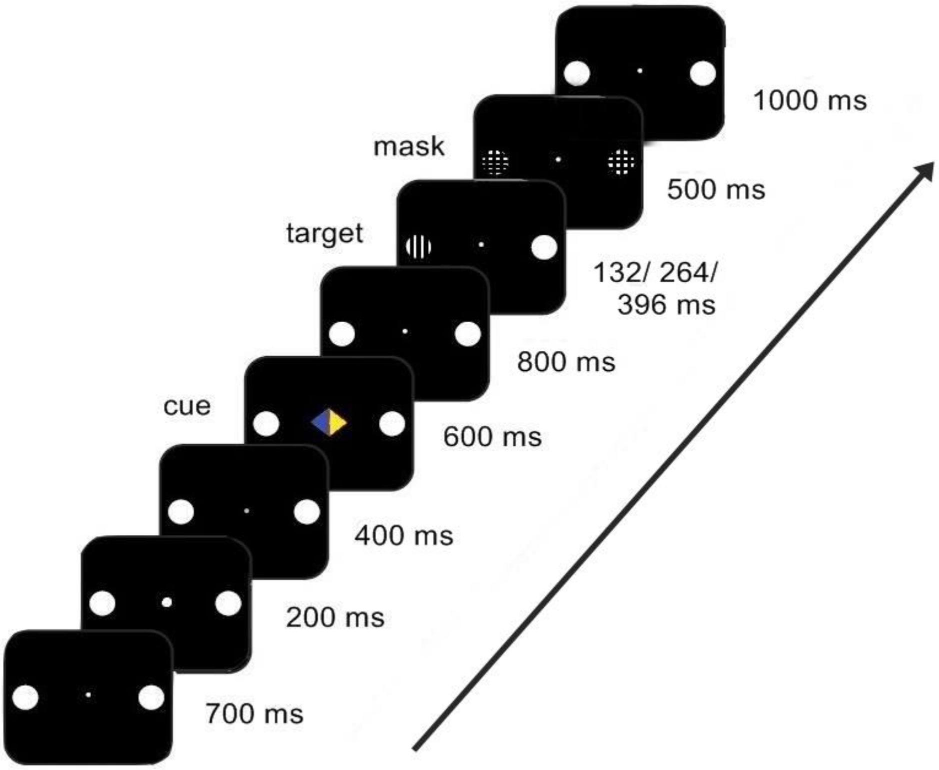

Figure 1. Schematic representation of the sequence of events in a trial. It is the set – up 100% valid cue with blue as relevant color with a target of vertical stripes.

2.3 Apparatus and EEG recordings

During the experiment, the participants sat on a comfortable chair approximately 80 cm in front of the monitor in a darkened room. The stimuli, described above, were presented with Presentation Software (Neurobehavioral Systems, Inc., 2012). To indicate whether the lines in the target stimuli were filled with horizontal or vertical stripes, the participants made use of the left or right “Ctrl” key placing the index fingers on a standard QWERTY keyboard. During the whole experiment, the EEG of the participant was recorded with Brain Vision Recorder, making use of 30 electrodes. 25 electrodes were mounted in an elastic cap on following locations: Fpz, F7, F3, Fz, F4,F8, FC5, FC6, T7, C3, Cz, C4, T8, CP5, CP6, P7, P3, Pz, P4, P8, PO7, PO3, PO4, PO8, Oz , one was the ground electrode, which was placed at the forehead and four electrodes were placed near the participant’s eye to record the electrooculogram (EOG). With the EOG, horizontal (hEOG) as well as vertical eye movements (vEOG) were measured. Only 25 electrodes on the scalp were recorded, because the results of previous studies revealed that this is sufficient for this experiment. To enable conduction between the electrodes and the scalp, conductive gel was used. The resistance of the electrodes was kept below 10 kΩ. To amplify the EEG and EOG, a 72-channels QuickAmp (Brain Products GmbH) amplifier was used. EEG, EOG, as well as task-related events such as stimulus onset and responses were registered with BrainVision Recorder (BrainProducts GmbH), which was installed on a separate computer. Signals were sampled at a rate of 500 Hz with the following online filters: low cut-off of 0.3 Hz and a high cut-off of 20 Hz, notch-filter 50 Hz.

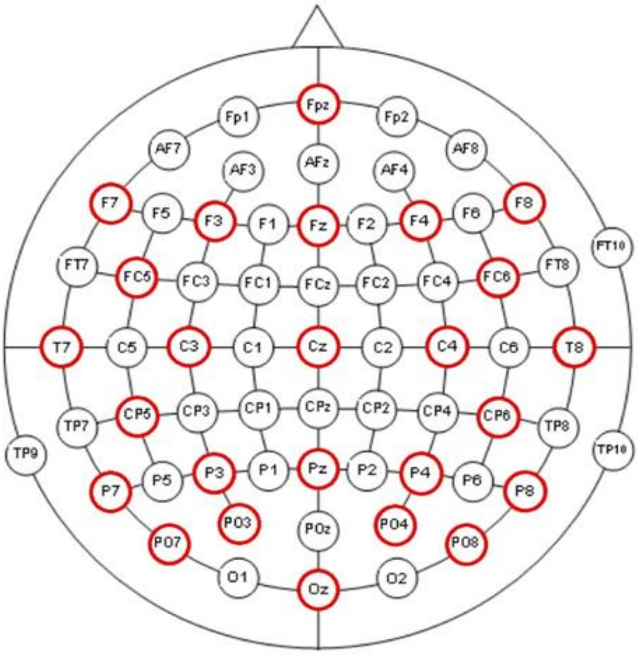

Figure 2. Representation of the electrodes measured during the experiment.

2.4 Data Processing and Analysis

Data was processed with Brain Vision Analyzer 2.0 (Brain Products GmbH, 2012). The data were first subdivided into segments from -1,000 to 3500 ms relative to cue onset, with a baseline set from -100 to 100 ms. To be able to make adequate analyses, only trials without eye-movements were used for the measurement to make sure that effects measured, can be ascribes to attention, not to eye-movements. Trials with horizontal eye movements within the cue-target interval, showing a value above values of +/-60 μV were thus excluded. Additionally, vertical eye movements were corrected by the Gratton, Coles, Donchin (1983) gradient. These procedure were carried out to exclude the possibility that the effects of cue validity on our behavioral measures may be due to overt rather than covert attention and left on average 84% of the trials.

Behavioral measures

The reaction times (RT) were compared as well as the proportion of correct (PC) and incorrect responses (PE). We also determined the proportion of the responses, the participants indicated that the target was not identifiable (PNI). An ANOVA was run with these factors, comparing validly cued trials in the 66% condition with the invalidly cued trials of the 66% conditions and the validly cued trials in the 100% condition.

Responses that were faster than 100 ms and responses that were slower than 3000 ms were excluded from further analysis. In the case that there were too much responses which were excluded in one condition because, there was no reaction at all, or the responses were too slow or too fast, the mean of the reaction times of all conditions of the respondent was used for further analysis.

EEG analyses of the cue-target interval

In the cue-target interval, EEG segments which contained artefacts were removed. The following criteria were used (gradient criterion: max. 50 μV, min-max criterion: -/+ 150 μV, low activity criterion: 0.5 μV).

The lateralized activity was determined based on the outcome of a wavelet analysis on the raw EEG. This was denoted as LPS (lateralized power spectra). The power within a frequency band is determined for the hemispheres contralateral and ipsilateral to the direction of the cues. The ipsi-contralateral difference in alpha power for each cue direction was scaled by the sum of activation of both hemispheres. This calculation is performed and averaged across both cue directions. Values of the LPS vary from -1 to +1, where a negative value indicates that the power within a specific frequency band was larger above the hemisphere contralateral to the cued side than ipsilateral, while a positive value indicates the opposite pattern. A value of zero indicates an absence of hemispherical differences (Van der Lubbe & Utzerath, 2013). The lower alpha band was analyzed as well as the higher. Alpha^1 ranges from 7.2 to 10.7 Hz with a central frequency of 8.9 Hz, and alpha^2 ranges from 9.4 to 14 Hz with a central frequency of 11.7 Hz.

The average power was determined for each person for intervals of 50 ms after the cue onset, ranging from 200 to 1400 ms, resulting in 24 time windows. *T*-tests were performed for respectively each of the 24 time windows. A correction was carried out to reduce the possibility of a Type I error. In the used method two successive significant effects had to agree with $p < \surd$ (0.05/23 x 2 x 10 x 2) < 0.007 ($p < \surd$ (0.05/(windows – 1) x condition x electrode pairs x band). The significance criterion had to cross for at least two successive time windows. The tests were performed to make a pre-selection of significant lateralization of alpha synchronization.

To answer the first question, whether the manipulation of cue validity has an influence on the lateralization of alpha synchronization, a paired-sample *t*-test was applied. Based on the pre-test, the condition of the 66% validly cued trials and the condition of the 100% validly cued trials were compared for the time windows identified as significant.

To answer the second question, whether there is a correlation between the lateralization and the performance of the respondent, a ranking order had to be built of the respondents. To build this ranking order of performance, the factors percentage correct, percentage incorrect and reaction time were considered (for a detailed explanation see Appendix). First, the percentage error was subtracted from the percentage correct. With this calculation, the influence of guesses is controlled. After that, reaction time was considered. Based on these factors, a ranking order was built which is an indicator for performance. A Spearman’s rank correlation was applied to the performance and the lateralization of alpha synchronization.

3. Results

3.1 Behavioral measures

3.1.1 Reaction time

Comparing the reaction time in the three conditions of cue validity (validly cued of the 66% condition, validly cued trials of the 100% condition, and validly cued trials of the 100% condition), analyses show that there is no significant difference found in reaction time $F(2, 24) = 1.31$, $p = 0.287$, $\eta_p^2 = 0.1$. Pairwise comparison however shows, that responses were faster on validly cued than on invalidly cued trials of the 66% condition ($p < 0.013$), while there was no significant difference in reaction time between the validly cued targets of the 66% condition and of the 100% condition. A significant difference in reaction time was found for SOA. Responses were faster for targets with the shorter SOA, than for targets with a longer SOA, $F(2, 24) = 8.5$, $p < 0.002$, $\eta_p^2 = 0.42$. No effects were found for side $F(1, 12) = 1.88$, $p < 0.195$, $\eta_p^2 = 0.14$.

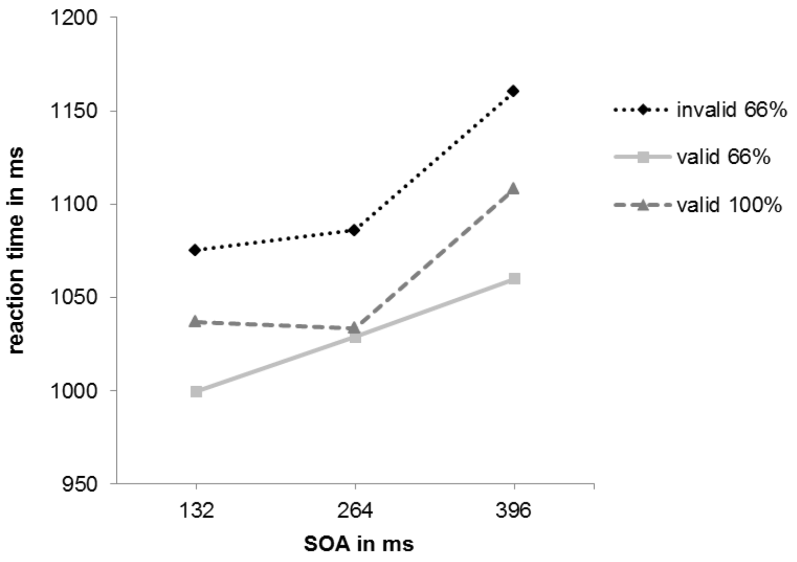

Figure 3. Representation of the difference in reaction time between the three different SOAs (stimulus onset asynchrony). A difference was made between the validly and invalidly cued trials of the three target conditions (66% validly cued, 66% invalidly cued, 100% validly cued).

3.1.2 Accuracy

Percentage correct

A significant difference in the percentage of correct responses was found for the three conditions of cue validity, $F(2, 24) = 3.77$, $p < 0.038$, $\eta_p^2 = 0.24$. Pairwise comparisons however, reveal that there is only no significant difference between the validly and invalidly cued trials of the 66% condition ($p = 0.07$) and no significant difference between the validly cued trials of the 66% and 100% ($p = 0.677$). Also an effect of SOA was found, $F(2, 24) = 20.83$, $p < 0.00$, $\eta_p^2 = 0.63$. The percentage of correct responses was higher for targets with a long SOA, than for targets with a short SOA. No difference in the percentage of correct responses was found for side, $F(1, 12) = 1.9$, $p < 0.193$, $\eta_p^2 = 0.14$. A significant interaction was found for side and SOA, $F(2, 24) = 4.97$, $p < 0.016$, $\eta_p^2 = 0.29$.

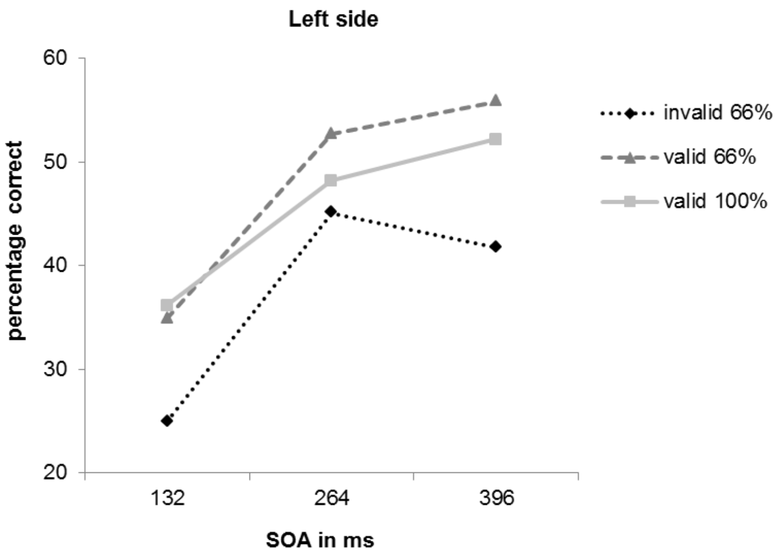

Figure 4. Representation of the difference in the percentage of correct responses between the three different SOAs (stimulus onset asynchrony) for targets presented at the left side. A difference was made between the validly and invalidly cued trials of the three target conditions (66% validly cued, 66% invalidly cued trials, 100% validly cued).

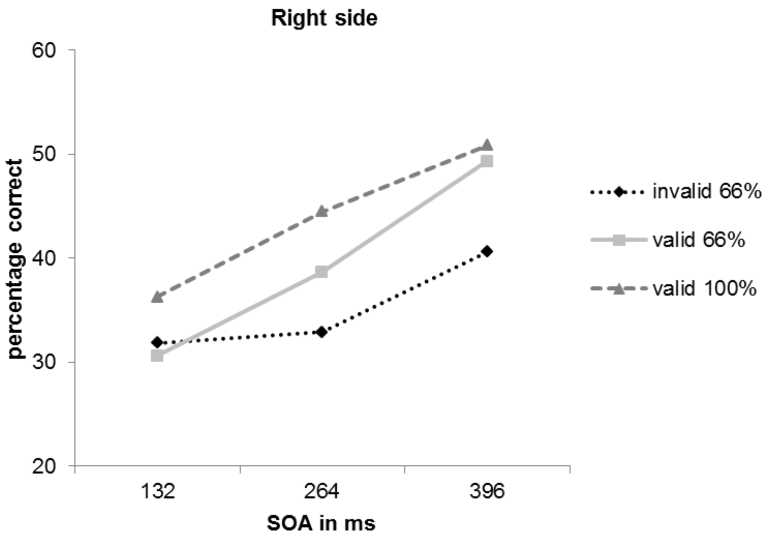

Figure 5. Representation of the difference in the percentage of correct responses between the three different SOAs (stimulus onset asynchrony) for targets presented at the right side. A difference was made between the validly and invalidly cued trials of the three target conditions (66% validly cued, 66% invalidly cued trials, 100% validly cued).

Percentage error

No significant effect in the percentage of incorrect responses was found for validity $F(2,24) = 1.65$, $p < 0.212$, $\eta_p^2 = 0.12$. However, pairwise comparisons reveal that the percentage of incorrect responses on validly and invalidly cued trials of the 66% condition differs significantly ($p < 0.044$). The percentage of incorrect responses was higher on invalidly cued trials than on validly cued trials. No effects were found for side ($F(1,12) = 3.4$, $p < 0.09$, $\eta_p^2 = 0.24$) and SOA ($F(2, 24) = 0.25$, $p < 0.778$, $\eta_p^2 = 002$). An interaction was found for side and SOA, $F(2, 24) = 5.61$, $p < 0.01$, $\eta_p^2 = 0.32$. For targets presented on the left side, the percentage of incorrect responses was lowest for the medium SOA. For targets presented on the right side the percentage of incorrect responses was highest for the medium SOA.

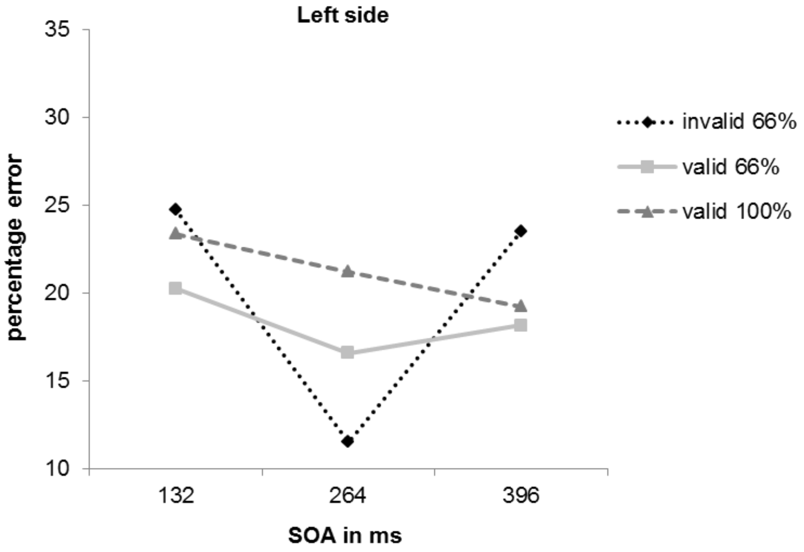

Figure 6. Representation of the difference in the percentage of incorrect responses between the three different SOAs (stimulus onset asynchrony) for targets presented at the left side. A difference was made between the validly and invalidly cued trials of the three target conditions (66% validly cued, 66% invalidly cued, 100% validly cued).

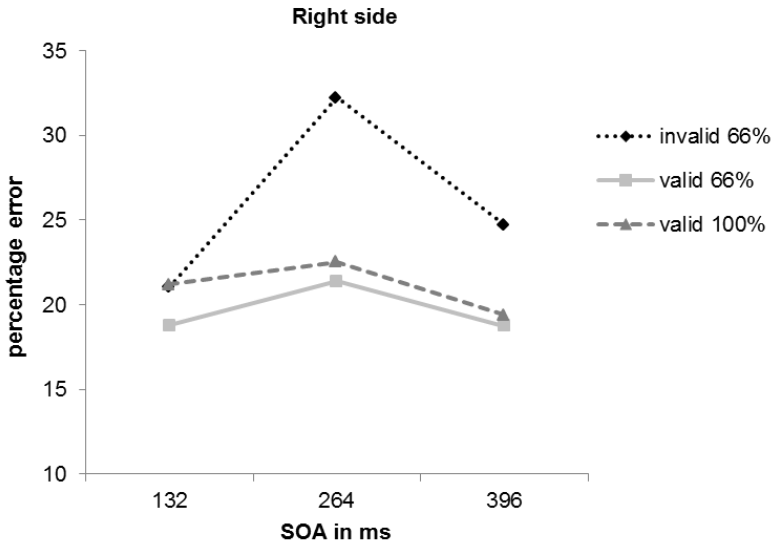

Figure 7. Representation of the difference in the percentage of incorrect responses between the three different SOAs (stimulus onset asynchrony) for targets presented at the right side. A difference was made between the validly and invalidly cued trials of the three target conditions (66% validly cued, 66% invalidly cued, 100% validly cued).

Percentage “not identifiable”

Analyzing the percentage of targets, respondents indicated as “not identifiable”, no significant effect was found between the three conditions of cue validity, $F(2,24) = 2.65$, $p < 0.092$, $\eta_p^2 = 0.18$. No significant effects of side were found for the percentage of not identifiable targets, $F(1, 12) = 0.16$, $p < 0.697$, $\eta_p^2 = 0.01$. An effect for SOA was found, $F(2, 24) = 20.65$, $p < 0.00$, $\eta_p^2 = 0.63$. The percentage of targets indicated as “not identifiable” was longer for targets with a high SOA than for targets with a short SOA. Additionally, an interaction was found for side and validity, $F(2, 24) = 4.53$, $p < 0.022$, $\eta_p^2 = 0.27$. For targets presented on the left side, the percentage of targets indicated as “not identifiable” was highest for invalidly cued trials of the 66% valid condition. For targets presented on the right side the percentage of targets indicated as “not identifiable” was highest for the validly cued trials of the 66% valid condition.

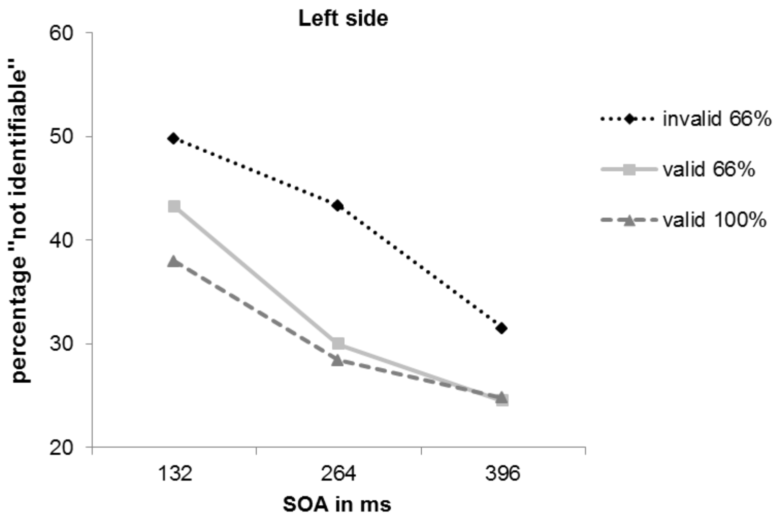

Figure 8. Representation of the difference in the percentage of correct responses between the three different SOAs (stimulus onset asynchrony) for targets presented at the left side. A difference was made between the validly and invalidly cued trials of the three target conditions (66% validly cued, 66% invalidly cued, 100% validly cued).

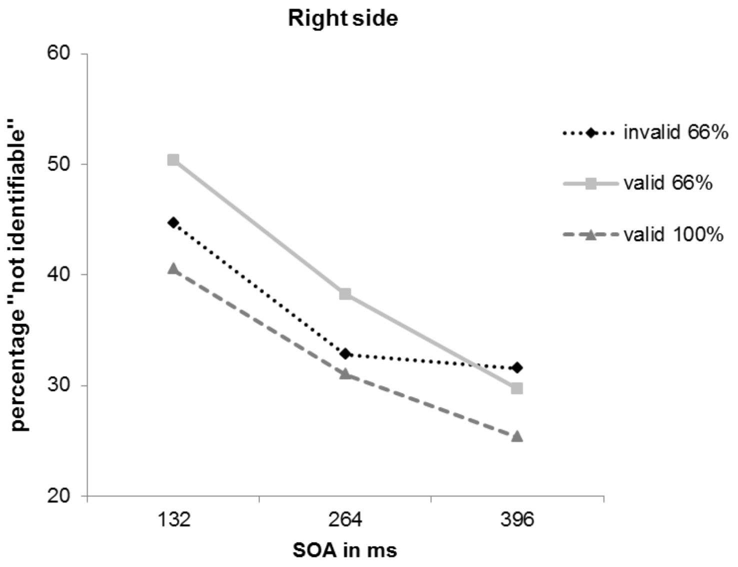

Figure 9. Representation of the difference in the percentage of correct responses between the three different SOAs (stimulus onset asynchrony) for targets presented at the right side. A difference was made between the validly and invalidly cued trials of the three target conditions (66% validly cued, 66% invalidly cued, 100% validly cued).

3.2 EEG results

T-tests tests were performed to make a pre-selection of significant lateralization of alpha synchronization, which are listed in table 1 and 2 (for a graphical representation, see Appendix D & E).

Table 1.

A Summary of Effects Observed for Alpha[1] (7.2 Hz – 10.7 Hz) when the Significance Criterion was Crossed for at Least Two Successive Time Windows ($p < 0.007$).

window (in ms)	electrode	condition	p < p
400 – 500	F4	100%	0.002 < 0.005
400 – 550	PO8		0.002 < 0.007
700 – 850	P8		0.00 < 0.005
950 – 1200	P4		0.001 < 0.004
950 – 1250	PO8		0.001 < 0.007
1000 – 1400	PO4		0.002 < 0.006
1100 – 1400	P8		0.00 < 0.008
400 – 700	PO4	66%	0.00 < 0.002
450 – 650	PO8		0.002 < 0.006
550 – 650	P4		0.004 < 0.005
900 – 1100	PO4		0.001 < 0.004
1150 – 1400	P8		0.00 < 0.007

Note. The effects are described in terms of ipsi – contralateral differences (therefore CP6, PO8, PO4, etc).

Table 2

A Summary of Effects Observed for Alpha^2 *(9.4 Hz – 14 Hz), when the Significance Criterion was Crossed for at Least Two successive Time Windows (*$p < 0.007$*).*

window (in ms)	electrode	condition	p < p
300 - 850	CP6	100%	$0.00 < 0.005$
400 - 500	PO8		$0.004 < 0.005$
700 - 800	T8		$0.001 < 0.004$
950 - 1100	PO4		$0.004 < 0.007$
1200 - 1400	P4		$0.002 < 0.007$
400 - 1400	PO4	66%	$0.00 < 0.009$
500 - 650	CP6		$0.000 < 0.004$
600 - 700	P4		$0.004 < 0.005$
850 - 1400	P8		$0.00 < 0.008$
1150 - 1400	CP6		$0.00 < 0.004$
1250 – 1400	PO8		$0.003 < 0.005$

Note. The effects are described in terms of ipsi – contralateral differences (therefore CP6, PO8, PO4, etc).

The analysis of the *t*-test of the hEOG revealed that there are effects for several time windows of the 100% condition. To be able to exclude that eye movements caused the lateralization effects, we examined for all observed effects, whether there was a correlation between eye movements and lateralization. Nearly all correlations between hEOG and the relevant EEG channels were not significant ($p > 0.05$). The only significant correlation found was the correlation between T8 of alpha 2 in the 100% condition and hEOG was observed from 700-750 ms.

EEG analysis of spatial certainty

Paired sampled t-tests were used to analyze the difference of lateralization of alpha synchronization in the 66% valid condition and the 100% valid condition. These t-tests were only applied to the electrodes and time windows identified as significant based on the pre-test.

Alpha1

For alpha^1 (7.2 Hz – 10.7 Hz) significant differences in alpha lateralization between the condition of 66% validly cued trials and 100% validly cued trials was found for PO4 in the

time window of 950 - 1000 ms, $t(12) = 2.25$, $p < 0.044$ (see figure 10).
(see figure 10).

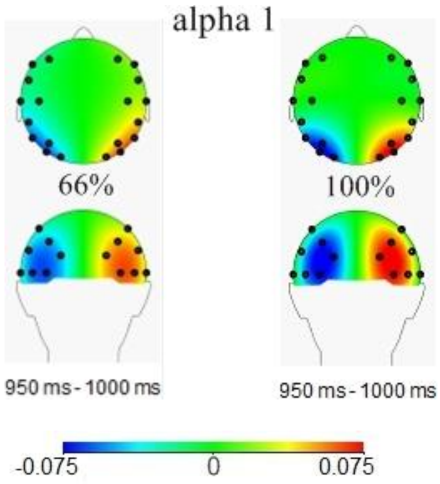

Figure 10. Topographical maps for alpha1 for the time windows where a significant difference between the 100% condition and the 66% condition was found for PO4. In the left hemisphere the contra – ipsilateral power difference is presented, whereas the right hemisphere reflects the ipsi-contralateral power difference. LPS = lateralized power spectra.

<u>Alpha2</u>

For alpha^2 (9.4 Hz – 11.7 Hz) significant differences in alpha lateralization between the condition of 66% validly cued trials and 100% validly cued trials was found for PO4 in the time window of 650 – 800 ms, with the greatest difference found between 700 – 750 ms, $t(12) = 3.78$, $p < 0.003$ (see figure 11).

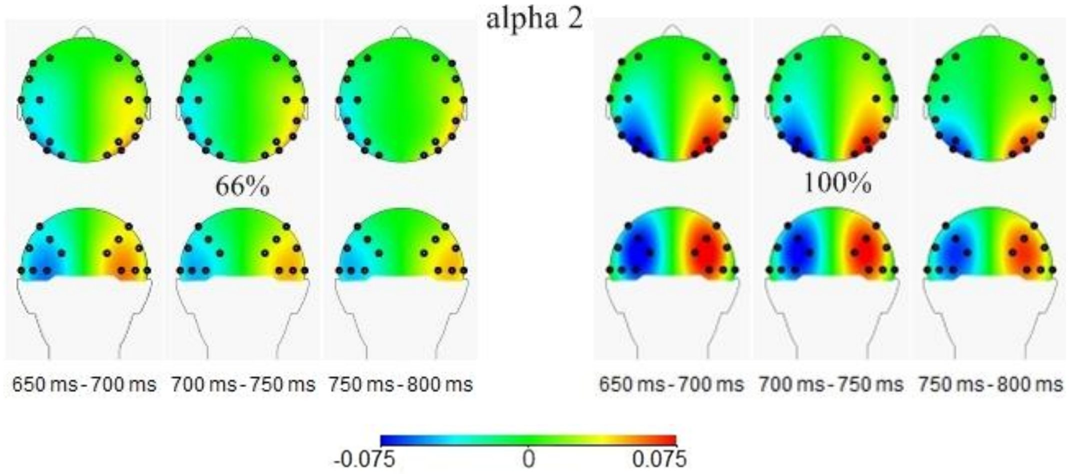

Figure 11. Topographical maps for alpha2 for the time windows where a significant difference was found for PO4 between the 100% condition and the 66% condition. In the left hemisphere the contra – ipsilateral power difference is presented, whereas the right hemisphere reflects the ipsi-contralateral power difference. LPS = lateralized power spectra.

Additionally, significant differences were found for PO4 in the time window of 900 – 1000 ms, with the greatest difference found between 900 – 950 ms, $t(12) = 3.46$, $p < 0.005$ (see figure 12).

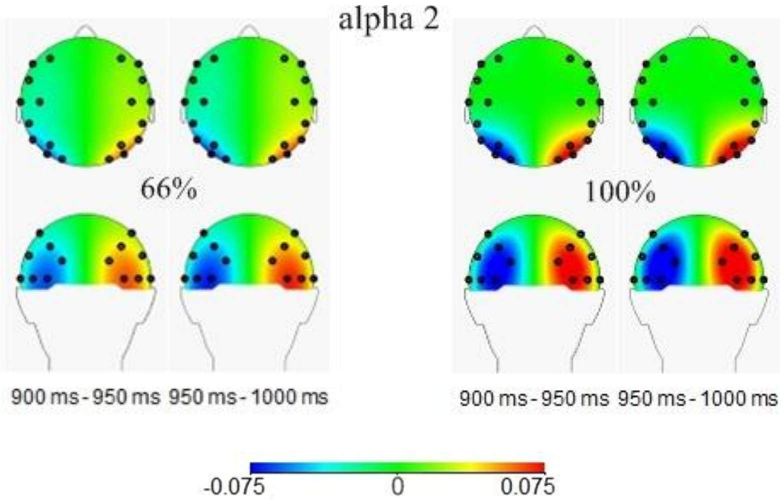

Figure 12. Topographical maps for alpha2 band for the time windows where a significant difference between the 100% condition and the 66% condition was found for PO4. For further descriptions, see figure 10. LPS = lateralized power spectra

Analysis of the correlation of the lateralization of alpha synchronization and performance

Applying a Spearman’s rank correlation to the performance and the lateralization of alpha synchronization, significant correlations were found (results are presented in table 3).

Table 1.

A Summary of the Correlation between Performance and Lateralization of Alpha when the Significance Criterion was Crossed for at Least Two Successive Time Windows (p < 0.007).

Band	window (in ms)	electrode	condition	< p <
alpha1	350 – 900	PO4	100%	0.00 < 0.007
alpha1	700 – 900	P4		0.001 < 0.005
alpha2	650 – 800	P4		0.003 < 0.007

Note. The effects are described in terms of ipsi – contralateral differences (therefore CP6, PO8, PO4, etc).

Significant correlations were only found for the condition with 100% validly cued targets. All correlations found were positive. A strong positive correlation between the lateralization of alpha1 synchronization and performance was found for PO4 in the time windows from 350 ms until 900 ms ($p \leq 0.007$, r_s ,< 0.71, see figure 14). For alpha2, a correlation was found for the time window from 650 – 800 ms ($p \leq 0.007$, r_s<0.7, see figure 15).

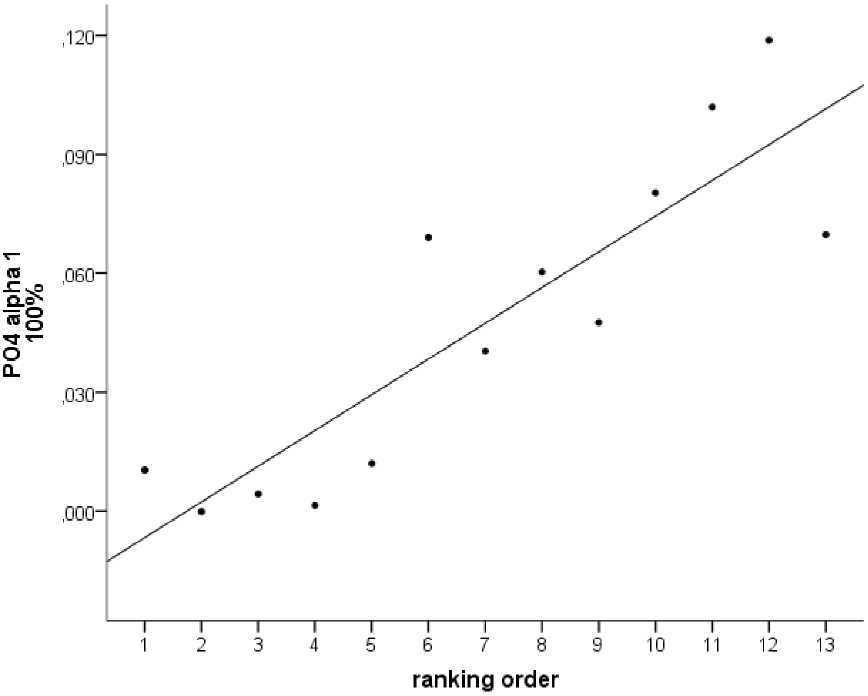

Figure 14. Relation between alpha lateralization and performance in the time window with the highest correlation (400 – 450 ms, $p < 0.00$, $r_s = 0.89$). A positive relation was found between PO4 and alpha1 synchronization in the condition of 100% validly cued trials.

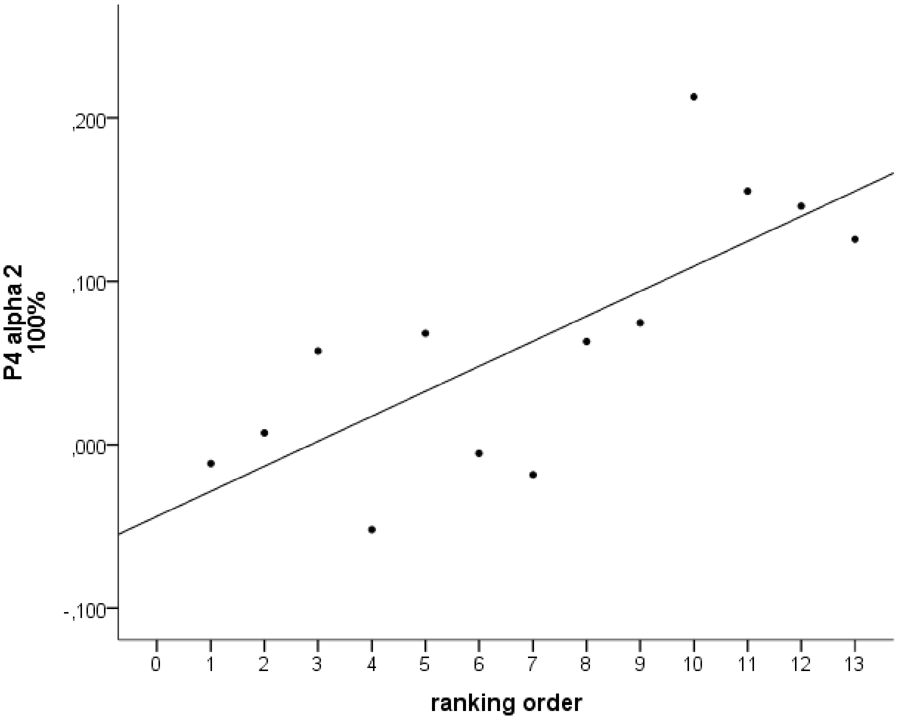

Figure 15. Relation between alpha lateralization and performance in the time window with the highest correlation (700 – 750 ms, $p < 0.003$, $r_s = 0.75$). A positive relation was found between P4 and alpha synchronization in the condition of 100% validly cued trials.

4. Discussion

The aim of this study was to examine whether the results of Gould et al. (2011) can be replicated after adjusting the method. In contrast to the study of Gould et al. (2011) double subtraction was applied (Van der Lubbe & Utzerath, 2013). Making use of the LPS (lateralized power spectra) method, differences between the hemispheres were evaluated. We also made use of blocks, rather than presenting the stimuli randomly to reduce variability due to interference from previous trials. The second question whether predictions regarding to performance can be made based on alpha synchronization is based on the ideas of Mathewson et al. (2009).

To answer the first question, an endogenous orienting paradigm was used with two conditions. In the first condition, cues predicted the location of the target with a special certainty of 66% while there was special certainty of 100% in the second condition. To see whether there is a difference between the invalidly and validly cued trials of the 66% condition and the trials of the 100% condition, behavioral data was analyzed. Responses were faster on valid trials than on invalid trials and the reaction time rose with the SOA, which was also reported by other studies (Posner & Cohen, 1984). In this study, we found that respondents had a higher percentage of correct responses if the SOA was higher, which is consistent with earlier findings (Posner & Cohen, 1980). It is interesting to note that respondents had more problems with the detection of targets on the right side than targets on the left side. This is a phenomenon, found in other studies as well (Verleger & Śmigasiewicz, 2015). Results inconsistent with our expectations were especially found regarding the different cueing conditions. While Gould et al. (2011) reported differences in reaction time between the validly cued trials of different spatial certainties, there was no effect found in this study between the validly cued trials of the 100% and 66% condition. They also reported that there were significant differences in accuracy between targets of different spatial certainty. However, in the current study, we did not find the same results. Differences in accuracy were only found between invalidly and validly cued trials of the condition with spatial predictability of 66%.

Analyzing EEG data, diverse results were found for the different time windows, different electrodes, alpha1 and alpha2. For alpha1 the difference between the two conditions of spatial predictability was at its highest 950 – 1000 ms after cue onset. A difference in lateralization between the two conditions of spatial certainty was only found for PO4. Overall, greater effects were found for alpha2. For this band, differences in lateralization between the conditions were also only found for PO4, in the time windows prior to the targets (650 – 800 ms & 900 – 1000 ms). Gould et al. (2011) reported that the degree with which alpha-band desynchronization was lateralized increased linearly with spatial certainty for the electrodes O1/O2 and PO7/PO8 and that this desynchronization got greater when spatial certainty was higher. In the current study we did not find significant differences between the two conditions of spatial certainty for PO7/PO8, the activity in O1/O2 was not measured in the current study. We only found effects for PO4 in specific time windows. Differences in the lateralization of alpha synchronization between the 66% valid condition and the 100% valid condition were not found immediate before the target occurs. This could be an indicator for the fact, that no behavioral differences were found between the validly cued trials of the 66% valid condition and the 100% valid condition.

The results of the behavioral measurements as well as of the EEG analyses differ from the results found in Gould et al. (2011). This can partly be explained by differences in the methods explained above. Besides, in the current study, we subdivided the whole range from 200 till 1400 ms of the cue onset into intervals of 50 ms. With this method it was possible to see graded changes in alpha lateralization and to determine when lateralization was its highest. Based on pre-tests we selected electrodes and time windows where significant lateralization was found for at least one condition. Differences between the conditions could probably be found in other electrodes as well, but we focused on lateralization. In Gould's study (2011) there were no analyses based on pretests and they did not analyze data based on different time windows. There are thus differences in results between the results, but the main outcome is the same. As in Gould's study (2011) we also found that there was greater lateralization in the condition with higher spatial certainty compared to the condition with lower spatial certainty and that the alpha band desynchronization was higher at contralateral than on ipsilateral electrodes. These findings are also consistent with results of other studies (Kelly et al., 2006; Sauseng et al., 2005; Rihs et al., 2007). The approach that Gould et al. (2011) took was not as precise as the approach took in the current study.

The second question examined in the current study is based on the idea of Mathewson et al. (2009). The question was whether there is a correlation between the performance of the respondent and the lateralization of the alpha synchronization. Compared to Mathewson et al. (2009), we were searching for differences between participants rather than for differences within participants. A relation was found for the parietal and parieto – occipital cortex for the electrodes P4/P3 and PO4/PO3. Effects were found only for the condition with a spatial certainty of 100%. Our results show that there is an especially strong relation of the lateralization of alpha synchronization and the performance of participants in PO4/PO3. This correlation was found during a remarkably long interval (350 - 900 ms). These results indicate that it is possible to predict performance differences on the basis of the LPS index. To our knowledge, these results provide the first demonstration that individual performance differences can be predicted by the LPS index of the electrodes PO4/PO3. These findings could have implications for the diagnostics of attention disorders, as for example ADHD. EEG measurements seem to be a good tool to determine how good people are in directing behavior, but additional research with more respondents is necessary to examine whether these results can be replicated.

To sum up, the results found by Gould et al. (2011) are similar to the findings of the current study. There was greater lateralization in the condition with higher spatial certainty compared to the condition with lower spatial certainty and that the alpha band desynchronization was higher at contralateral than on ipsilateral electrodes. An additional finding we can report, is the significance PO4/PO3 plays in focusing visual attention. This can be found in the lateralization of alpha synchronization as well as in the correlation with individual performance. It seems that individual performance differences can be predicted by the LPS index of the electrodes and that alpha lateralization is an adequate dimension to examine attention.

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Appendix A

Informed Consent

Ik verklaar hierbij op voor mij duidelijke wijze te zijn ingelicht over de aard en methode van het onderzoek `Cue validiteit`. Mijn vragen zijn naar tevredenheid beantwoord. Ik stem geheel vrijwillig in met deelname aan dit onderzoek waar EEG en oogbewegingen afgenomen worden. Ik behoud daarbij het recht deze instemming weer in te trekken zonder dat ik daarvoor een reden hoef op te geven en besef dat ik op elk moment mag stoppen met het experiment. Indien mijn onderzoeks-resultaten gebruikt zullen worden in wetenschappelijke publicaties, dan wel op een andere manier openbaar worden gemaakt, zal dit volledig geanonimiseerd gebeuren. Mijn persoonsgegevens zullen niet door derden worden ingezien zonder mijn uitdrukkelijke toestemming.

Als ik nog verdere informatie over het onderzoek zou willen krijgen, nu of in de toekomst, kan ik me wenden tot Peter Slijkhuis (e-mail: p.j.h.slijkhuis@student.utwente.nl) en tot Lisa Aldiek (e-mail: l.aldiek@student.utwente.nl).

Voor eventuele klachten over dit onderzoek kunt u zich wenden tot de secretaris van de Commissie Ethiek van de faculteit Gedragswetenschappen van de Universiteit Twente, mevr. J. Rademaker (telefoon: 053-4894591; e-mail: j.rademaker@utwente.nl, Postbus 217, 7500 AE Enschede).

Aldus in tweevoud getekend:

…………………………… ……………………………

Naam proefpersoon Handtekening

Place:

Date:

Ik heb toelichting verstrekt op het onderzoek. Ik verklaar mij bereid nog opkomende vragen over het onderzoek naar vermogen te beantwoorden.’

…………………………… ……………………………

Naam onderzoeker Handtekening

Appendix B

Participant Registration Form

Name:

SONA-number:

Day of birth:

Gender:

Glasses/lenses, no eye correction:

Colorblind:

Handedness:

Medication:

Neurological/Psychiatric history:

Date of participation:

Experiment:

EEG files:

Remarks:

Appendix C

Annett Handedness Inventory

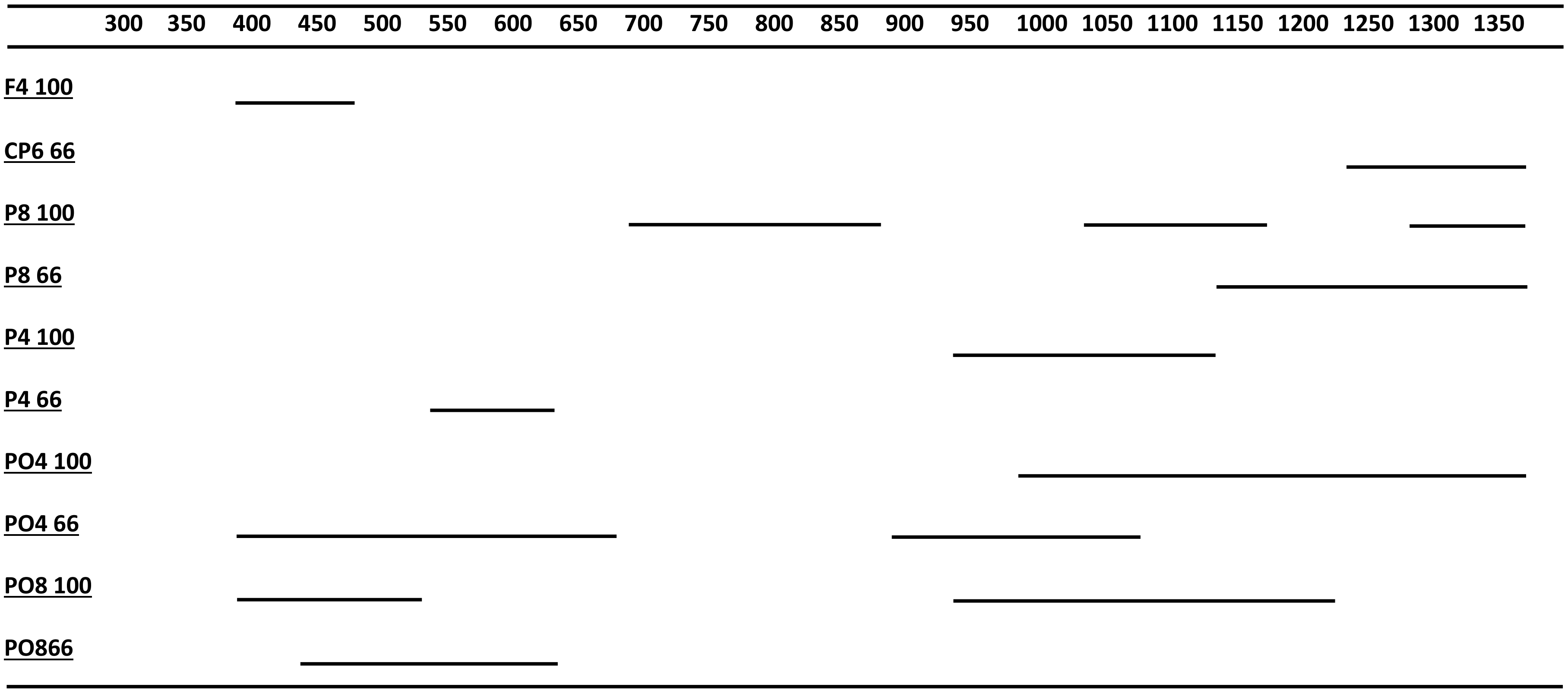
	Always left	Mostly left	No preference	Mostly right	Always right
Writing a letter					
Throw a ball to hit a target					
To play a racket in tennis, squash, etc.					
What hand is up to handle a broom removing dust from the floor					
What hand is up to manipulate a shovel					
Lighting matches					
Scissors when cutting paper					
To hold a wire to move it through the eye of a needle					
To distribute playing cards					
To hit a nail on the head					
To hold your toothbrush					
To remove the cover from a jar					
	-2	-1	0	+1	+2

-24 to -9	left handed
-8 to +8	ambidexter
+9 to +24	right handed

Annett, M. (1970). A classification of hand preference by association analysis. British Journal of Psychology, 61, 303-321.

Appendix D

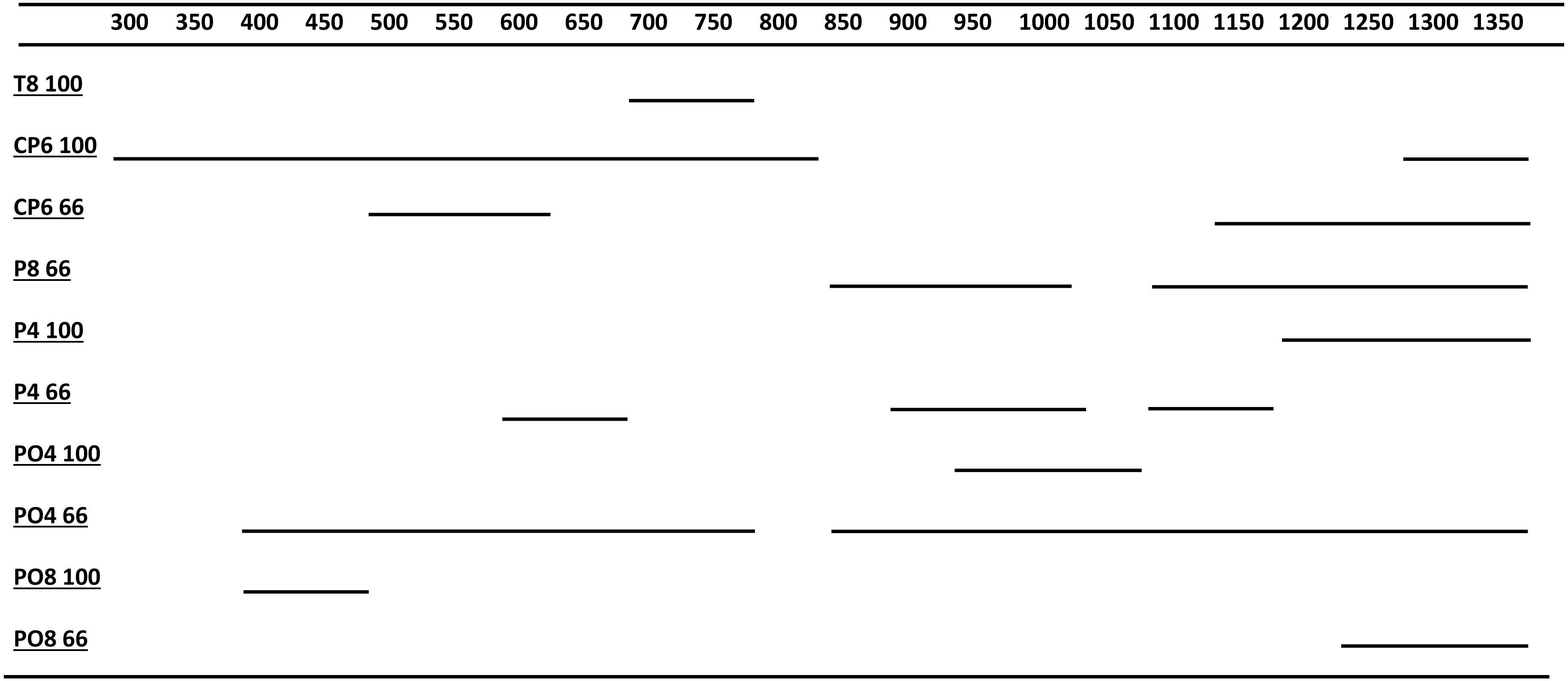
Alpha 1



Note: Representation of the results for the LPS on the raw EEG for alpha 1, when the significance criterion was crossed for at least two successive time windows ($p < 0.007$). Effects are described in terms of ipsi – contralateral differences (therefore F4, CP6, P8, etc.). LPS = lateralized power spectra.

Appendix E

Alpha 2



Note: Representation of the results for the LPS on the raw EEG for alpha 1, when the significance criterion was crossed for at least two successive time windows ($p < 0.007$). Effects are described in terms of ipsi – contralateral differences (therefore T8, CP6, P8, etc.). LPS = lateralized power spectra.

Appendix F

Ranking order

Respondent	Ranking order PC - PE	Ranking order reaction time
1	7	12
2	11	13
3	9	11
4	12	10
5	1	8
6	4	1
7	2	7
8	10	6
9	5	2
10	3	3
11	6	5
12	8	4
13	13	9

Note. Ranking order from 1 to 13. A low number corresponds with a high performance.
PC = percentage correct. PE = percentage error.

Taking the ranking order of PC-PE and the ranking order of reaction time together, the following ranking order, which is used for the analysis, evolves:

Respondent	Ranking order used for analysis (includes PC, PE and reaction time)
1	9
2	13
3	10
4	12
5	4
6	1
7	5
8	8
9	3
10	2
11	6
12	7
13	11

Note. Ranking order from 1 to 13. A low number corresponds with a high performance.
PC = percentage correct. PE = percentage error.