# Determining a sensitive index to measure the allocation of visuospatial attention

**An Event-Related Lateralization study**

Peter Slijkhuis
s1327992
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Faculty of Behavioral, Management and Social Sciences
Cognitive Psychology and Ergonomics
University of Twente
First supervisor: Dr. Rob H.J. van der Lubbe
Second supervisor: MSc. Suzanne M. Vosslamber

UNIVERSITY OF TWENTE.

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## Abstract

Electroencephalographical (EEG) measurements played an important role in understanding the processes involved in directing, shifting and dividing attention. The present study aimed to find a sensitive index for EEG to measure visuospatial attention. Several studies used EEG in the Posner endogenous cueing paradigm to examine these processes. In this study, a variant of this paradigm was used, with two conditions. One condition in which cues were hundred percent valid and one condition where cues were sixty-six percent valid. The Stimulus Onset Asynchrony (SOA), the difference in time in which the stimuli were masked, was used to measure the relation between spatial attention and subliminal consciousness. EEG was measured from eighteen participants that took part in the experiment, the first five participants were part of a pre-test. Afterwards, behavioural data and EEG data were analysed using repeated measures ANOVAs and t-tests. The results showed that no differences and interactions were found between the lateralizations and the validity conditions. The conclusion was drawn that spatial attention does not have an effect on the performance in different validity conditions. It can even be argued that ERLs, gained with a double subtraction, are not the most sensitive index to measure the allocation of spatial attention.

## Samenvatting

Elektro-encefalografische (EEG) metingen spelen een belangrijke rol in het begrijpen van processen betrokken bij het richten, verplaatsen en verdelen van aandacht. De huidige studie heeft geprobeerd een sensitieve index te vinden voor EEG om visuele spatiale aandacht mee te meten. Een aantal onderzoeken hebben EEG toegepast in het ‘Posner endogenous cueing’ paradigma om deze processen te onderzoeken. In dit experiment werd een variant van dit paradigma gebruikt met twee condities. Een conditie waarin alle cues honderd procent valide waren en een conditie waarin de cues zesenzestig procent valide waren. De ‘Stimulus Onset Asynchrony’ (SOA), het verschil in tijd waarin de stimulus gemaskeerd wordt, was gebruikt om de relatie tussen het toewijzen van spatiale aandacht en subliminale bewustzijn te onderzoeken. EEG was gemeten bij achttien proefpersonen, waarvan de eerste vijf onderdeel waren van een pre-test. Na het onderzoek werd de gedrags- en EEG data geanalyseerd door gebruik te maken van repeated measure ANOVAs en t-tests. De resultaten laten zien dat geen verschillen of interacties waren gevonden tussen de lateralisaties en de validiteitscondities. De conclusie was dat spatiale aandacht niet de prestatie in verschillende validiteitscondities beïnvloed. Er kan zelfs gezegd worden dat ERLs, verkregen met een dubbele subtractie, niet de meest sensitieve index is om de toewijzing van spatiale aandacht te meten.

## Introduction

This paper focuses on the allocation of spatial attention measured with Electroencephalography (EEG). The present study aimed to find a sensitive EEG index to measure visuospatial attention.  The allocation of attention can be measured with multiple indices and methods. For example the alpha-band index with single subtraction used by Gould, Rushworth and Nobre (2011).

Visual spatial attention is directing attention to a location in space using the eyes. Spatial attention allows humans to selectively process visual information through prioritization of an area within the visual field. A region of space within the visual field is selected for attention and the information within this region then receives further processing. Research shows that when spatial attention is used, an observer is typically faster and more accurate at detecting a target that appears in an expected location compared to an unexpected location (Posner, 1980).

Several EEG study used the Posner endogenous cueing paradigm (Posner, 1980) to examine the allocation of spatial attention (e.g. Eckstein, Shimozaki & Abbey, 2002; Talsma, Slagter, Nieuwenhuis, Hage & Kok, 2005; Albares, Criaud, Wardak, Nguyen, Hamed & Boulinguez, 2011). An effective way to examine the allocation of spatial attention is by measuring participants EEG during the research to compute event-related potentials (ERPs) afterwards (Hayward & Ristic, 2013).

In the paradigm, observers are seated in front of a computer screen. They usually fixate at a central point on the screen. For a brief period, a cue is presented on the screen. After the cue is removed, a target stimulus, usually a shape, appears on either side of the screen. The observer must respond to the target after detecting it. It is then possible to assess participants' ability to carry out an attentional shift (Talsma et al., 2005; Gould, Rushworth & Nobre, 2011). To measure reaction time (RT), a response mechanism is placed in front of the observer, usually a computer keyboard which is pressed upon detection of a target. Following a set inter-trial interval the entire process is repeated for a set number of trials predetermined by the experimenter. Furthermore, the experimenter could program the cues that a difference in validity of the cues occurs. For example cues that always indicate the target location correctly with a validity of hundred percent, or cues that do not necessarily indicate the target location correctly, but with a lower validity.

The way cues are presented and acted upon is called endogenous cueing. Endogenous orienting is the intentional allocation of attentional resources to a predetermined location or space (Hodgsen & Muller, 1999). They stated that endogenous orienting occurs when attention is oriented according to an observer's goals or desires, allowing the focus of attention to be manipulated by the demands of a task. In order to have an effect, endogenous cues must be processed by the observer and acted upon purposefully.

In several studies, a result commonly found is that participants perform better and faster in valid trials than in invalid trials, the so-called cue validity effect (Petersen & Posner, 1990; Eckstein, Pham & Shimozaki, 2003; Giessing, Thiel, Stephan, Rösler & Fink, 2004). The reaction time decreases within conditions that used valid cues (Gould et al., 2011). However, the authors warned that this can also be the result of non-attentional processes, like automatic motor responses. It was found that more mechanisms are involved to measure reaction times, than the simple orienting of attention (Albares et al. 2011).

Furthermore, several studies in the past revealed that either the left or the right hemisphere is likely involved with carrying out a specific process (e.g., attentional orienting), activity can be extracted from the EEG that is specific to the relevant side: known as event-related lateralizations (ERLs; Wascher & Wauschkuhn, 1996). ERLs are difference waves that can be derived from event-related potentials (ERPs). Van der Lubbe and Utzerath (2013) did this by employing a double subtraction technique. By applying the ERL method to all available lateral electrodes, a contra-ipsilateral topographic map can be determined. An important feature of this method is that all activity unrelated to the focus of attention is cancelled out, making this index highly specific for changes in spatial attention. Application of this procedure, in most cases, reveals three lateralized components that are characterized by different topographies. The early directing attention negativity (EDAN) is a contralateral negativity with a maximum above occipito-parietal sites at approximately 200-400 ms after cue onset (van der Lubbe & Utzerath, 2013; Eimer, van Velzen & Driver, 2002; McDonald & Green, 2008). This component is thought to reflect the first stage of attentional orienting by selecting the relevant part of the attentional cue (Van Velzen & Eimer, 2003). The second component, the anterior directing attention negativity (ADAN), is above anterior sites around 400 ms after cue onset and is thought to reflect activity from premotor cortex and/or the frontal eye fields. The third component is the late directing attention positivity (LDAP), being above posterior sites around 500-700 ms after cue onset, which might reflect the final stage in which attention modulates activity (Hopf & Mangun, 2000).

When examning the paper from Gould et al. (2011), it appears a single subtraction was used. When comparing this single subtraction to the double subtraction, mentioned above, used by van der Lubbe and Utzerath (2013), a major downside is found in using the single subtraction. The downside concerns the possibility that general hemispherical differences (Verleger, Migasiewicz & Möller, 2011) complicate the lateralization index. For example, the right hemisphere is thought to be actively involved (i.e., disinhibited) when attention has to be directed towards any location, which may increase hemispherical differences in the case of left cues and reduce these differences in the case of right cues. This issue can be solved by using a double subtraction rather than a single subtraction. Another point of attention on the paper from Gould et al. (2011) is that they used trial wise presentation of stimuli. The stimuli and validity conditions were presented to the participant in random order. When looking at this method, it can be argued that the previous trials can interfere with the present one. A different method is to present the stimuli in blocks. This way all the same validity conditions are placed in one block and randomized within that block. This way the participant knows that all the trials are with that validity effect, which negates the effect previous trials with a different validity could have had.

The version of the Posner task used in the present study used a difference between the validity of the cues. There were cues that always indicated the target location correctly with a validity of hundred percent. On the other hand are those that do not necessarily indicate the target location correctly, but with a validity of sixty-six percent.

When cue validity is presented with both hundred percent and sixty-six percent validity, it was found by a lot of researchers that the participants performed better and faster in valid trials (Gould et al., 2011). But is this the case when another variable is presented to the participants, the Stimuli Onset Asynchrony (SOA). These SOAs denote the amount of time between the start of one stimulus and the start of another stimulus. Here, the critical parameter is the time interval between the onset of the stimulus and the onset of the masking. In the present experiment three different durations between the stimulus and masking were used, in which the shorter duration is subliminal, the middle duration on the edge of sub- and supraliminal and the longer duration is supraliminal.

In the present paper the research question was 'Is ERL a sensitive EEG index to measure the allocation of visuospatial attention?' The allocation of spatial attention was measured in Event-Related Lateralizations (ERLs), gained from the Event-Related Potentials (ERPs) using a double subtraction. This particular index, to look at the allocation of visuospatial attention, was chosen for the high sensitivity and specificity to changes in spatial attention. The double subtraction was used to negate any hemispherical differences.

When examining the results from Gould et al. (2011) it is expected to find lower values in reaction time (RT) and higher values on correct given responses (PC), in hundred percent cue validity than in sixty-six percent cue validity. Based on the results from multiple studies (Petersen & Posner, 1990; Eckstein et al., 2003; Giessing et al., 2004) it is also expected to find the cue validity effect, the participants perform better on valid than on invalid ques. Furthermore, it is thought that the difference between SOAs in hundred percent cue validity is smaller than in the sixty-six percent cue validity. This expectation is thought to be found because of the effect of knowing where a stimulus is going to present itself and then better consciously noticing the stimulus. This should decrease the difference between the SOAs.

The presence of three components of lateralization (eg. van der Lubbe & Utzerath, 2013) are expected to be found, the presence of the EDAN (Early Directing Attention Negativity), the ADAN (Anterior Directing Attention Negativity) and the LDAP (Late Directing Attention Negativity). Also a higher lateralization in the hundred percent validity condition than in the sixty-six validity condition is expected to be found.

With regard to already existing studies, it is relevant to examine the used differences between the presentation and the masking of the stimuli, because so far there is no study found concerning this problem. Therefore, behavioural measures as reaction time (RT) and correct given responses (PC) were used in addition to examining ERLs.

# Method

## Participants

Eighteen participants took part in the experiment. Five  participants were used for a pre-test, to test the SOA lengths. From the remaining thirteen participants, seven were female and six male aged between 19 and 27, with an average age of 21 years (M = 21.23).  Of the thirteen participants eleven participants were right handed, one was left handed and one was ambidextrous, which was ascertained with Annett's Handedness Inventory (Annet, 1970). None of the participants were colorblind, this was one of the excluding criteria for the sign-up. All participants had normal or corrected to normal vision (glasses or lenses) and none of them had a neurological or psychiatric history or used any medication. All were students of the University of Twente. Before starting the experiment, the participants signed an informed consent form. The used procedures to complete the experiment, as well as the experiment itself were evaluated by the ethical committee of the University of Twente.

## Task and stimuli

During the experiment, a variation of the Posner endogenous cuing task (Posner, 1980) was used. Two tasks were used, including either 66% or 100% valid cues. All of the participants had to run one block with cues pointing to the target with a validity of 66% and with a validity of 100%. To control the order effects in this research, counterbalancing was used. The relevant color indicating the target location was predetermined for each of the participants. These were divided in two groups with each focusing to one color: yellow or blue. The relevant color per participant did not change over the whole experiment. The utilized cues were all presented at a black screen in a darkened room. In the center of the screen a white fixation point was placed. This point got enlarged after 700 ms to allude the participant that a cue was going to be presented. In the valid cued trials, the cue itself was shaped as a rhombus, consisting of two triangular sides, with each side of the triangle colored different (blue and yellow with one of these labeled relevant). Participants were instructed to direct their attention to the relevant side (dependent on the color they had to focus on). Two circles were placed at each side. Participants were asked to press a determined button as fast as possible if they saw either horizontal or vertical lines in the directed circle, before being covered by a mask after either 132 ms, 264ms or 396 ms and without making any eye movements. Participants had to press the left control key in the case of horizontal lines and the right control key in the case of vertical lines. If participants had no idea of what they actually saw, they were instructed to press the space bar. By handling a “no idea” response, the risk of gambling was reduced. The construction of the experiment demanded an as accurate as possible reaction as well as it was used to assess attention, rather than the ability of gambling. On average, each participant made 648 trials in total, divided into two blocks of 8 times 36 trials and two practice trials of 36 trials for both blocks.

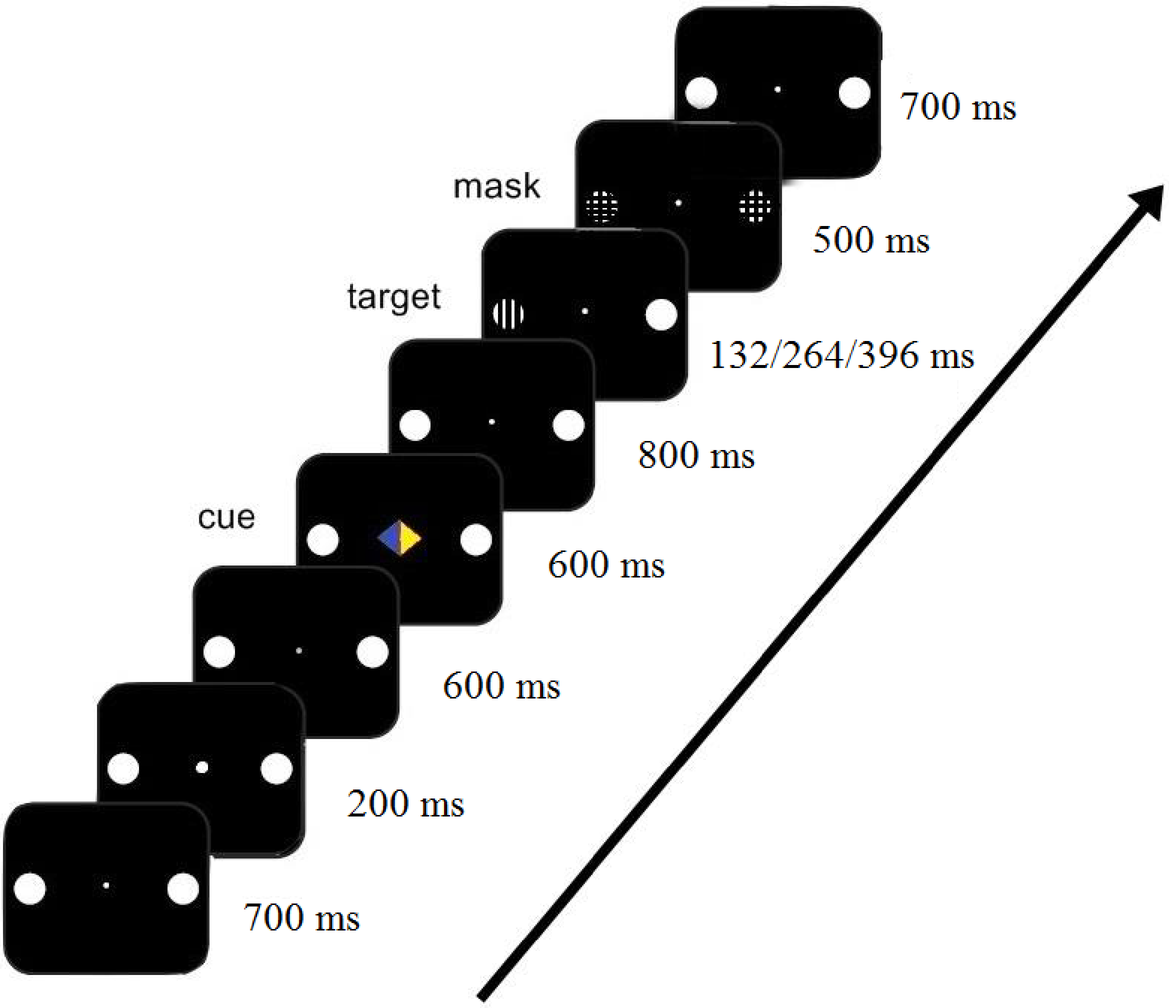



*Figure 1. Schematic representation of the setup of a 100% valid cued trial with blue as the relevant color inducing the target location.*

## Procedure and apparatus

After signing the informed consent and completing the handedness test, the participants were asked to sit down, approximately 80 cm  from their faces, in front of a computer screen. Stimuli were presented by using Presentation software (Neurobehavioral Systems, Inc., 2012) installed on a separate experimental computer. The participants were asked to place the ring fingers at the control keys and a thumb on the space bar on a standard QWERTY keyboard. Passive Ag/AgCl ring-electrodes were placed on an elastic cap (Braincap, Brainproducts GmbH). Electrode gel was applied and the standard procedures to improve conductivity were used. A 72-channels QuickAmp (Brain Products GmbH) amplifier was used to amplify the EEG and EOG. This amplifier has a built-in average reference. Together, EEG, EOG, and task-related events such as stimulus onset and responses were registered with BrainVision Recorder (Brain Products GmbH) installed on a separate acquisition computer.

## Recording

The EEG was recorded continuously, from the start until the end of the whole experiment. EEG was measured from 25 electrodes, which were located at: Fpz, Fz, F3, F4, F7, F8, FC5, FC6, Cz, C3, C4, T7, T8, CP5, CP6, Pz, P3, P4, P7, P8, PO3, PO4, PO7, PO8, Oz. Furthermore, the electro-oculogram (EOG) was measured to assess participants' eye movements to exclude trials, in which these were made between cue-onset and reaction, to focus only on attention related EEG data. Four electrodes were therefore placed near the participants' eyes. To measure horizontal eye movements (hEOG) two electrodes were placed left and right on the outer canthi. To measure vertical eye movements (vEOG) two electrodes were placed above and under the left eye. A ground electrode was placed at the stern. The resistance of the electrodes was kept below 10 kΩ. Signals were filtered with a low pass filter of 140 Hz, sampled at a rate of 200 Hz and a notch-filter of 50 Hz.

## Data analysis

EEG data was analyzed with BrainVision Analyzer 2.0 (Brain Products GmbH, 2012). The data were first partitioned in segments from -1000 to 3500 ms relative to cue onset, with a baseline set from -100 to 100 ms.  Horizontal movements of the eyes were marked when amplitudes on the hEOG channel exceeded the values of +/-60 μV. Vertical eye movements were corrected using the Gratton, Coles, Donchin (1983) gradient.  These procedures left on average 84% of the trials. This was carried out to exclude the possibility that the effects of cue validity on our behavioral measures may be due to overt rather than covert orienting.

Furthermore, this procedure controlled for the possibility that observed effects in the cue-target interval were unrelated to saccade execution.

**Behavioral measures**

Reaction times (RT) were determined relative to target onset. The proportion of correct responses was determined as well (PC). Responses that were faster than 100 ms and responses that were slower than 3000 ms were excluded from further analysis. Repeated measures ANOVAs were used on the variables RT, PC, PE and PNI for analyzing differences between all the used cues.

**EEG measures**

EEG data was processed in Brain Vision Analyzer. An interval was chosen from 1000 ms before until 3500 ms after cue onset. A correction to EOG and EEG artifacts was applied. The average amplitudes per participant were determined in windows with a size of respectively 50 ms, ranging from 200ms to 1400 ms. Paired samples t-tests were accomplished, using all the cues used in the experiment. This analysis included the following electrodes: F3, F7, T7, CP5, P3, P7, PO3 and PO7. The lateralization was significant when two or more consecutive time windows were significant. Because of the fact that several time windows were explored, a correction was necessary, thereby reducing the possibility of a Type I error. That is, two successive significant effects had to agree with a critical value for the ERLs of $p \leq 0.0104$. For a comparable procedure see the article from Talsma, Wijers, Klaver and Mulder (2001). Using this formula the significance level was ascertained.

$$p < \sqrt{\frac{0.05}{(timewindows - 1)(electrodes \times condition)}}$$

## Results

### Behavioral measures

Analyses on Reaction Time (RT) showed that there was no significant difference in validity between the sixty-six percent valid and the hundred percent valid conditions.
It showed that there was a significant difference in validity between the sixty-six percent valid and the sixty-six percent invalid conditions (resp. 1029.5ms vs. 1107.2ms), F (1, 12) = 8.52, p = 0.013. $\eta_p^2$ = 0.42.

Between the sixty-six percent valid and the hundred percent valid conditions, the RTs were lower for shorter SOAs than for longer SOAs (resp. 1037.6 vs. 1057.4ms vs. 1110.0ms), F (2, 24) = 9.84, p < 0.001. $\eta_p^2$ = 0.45. It also revealed a significance in the SOAs between the sixty-six percent valid and the sixty-six percent invalid conditions, it showed that the RTs were lower for shorter SOAs than for longer SOAs (resp. 1018.3 vs. 1031.2ms vs. 1084.1ms), F (2, 24) = 5.86, p = 0.008. $\eta_p^2$ = 0.33. No interactions were found in the RTs for all the validity conditions.

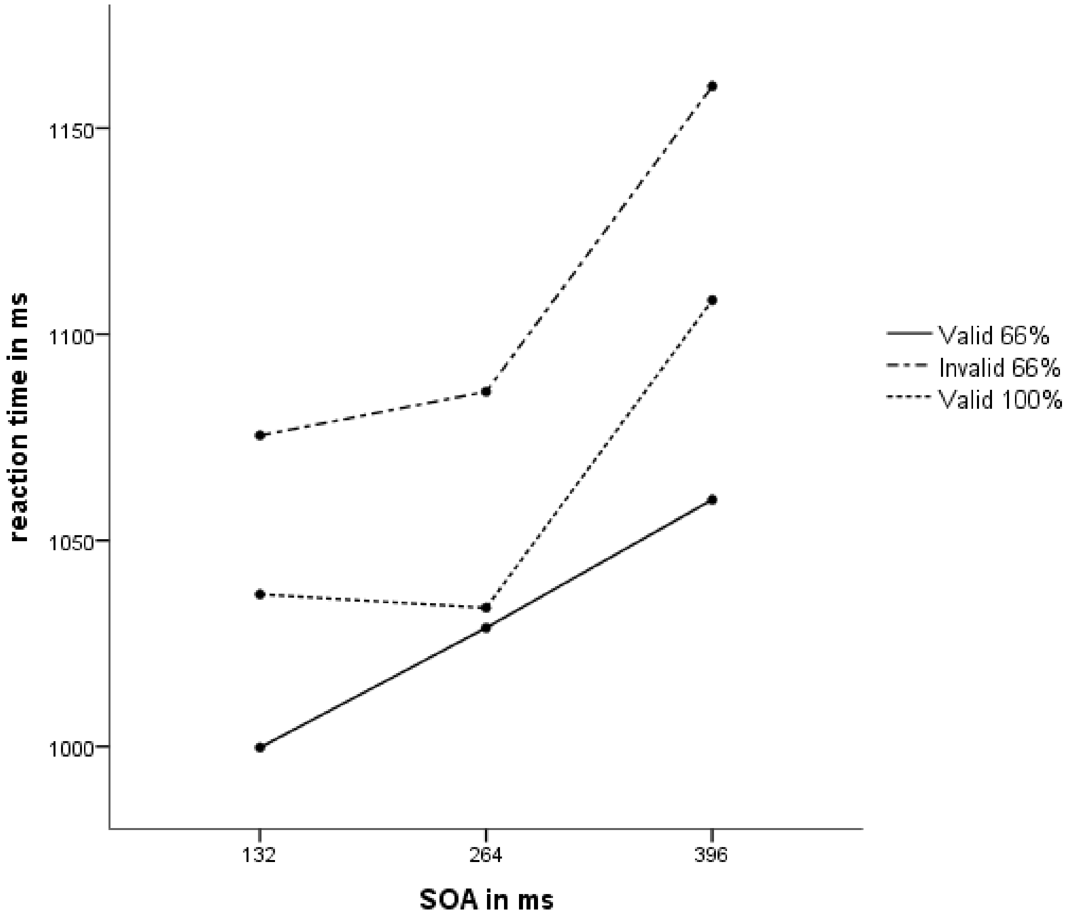
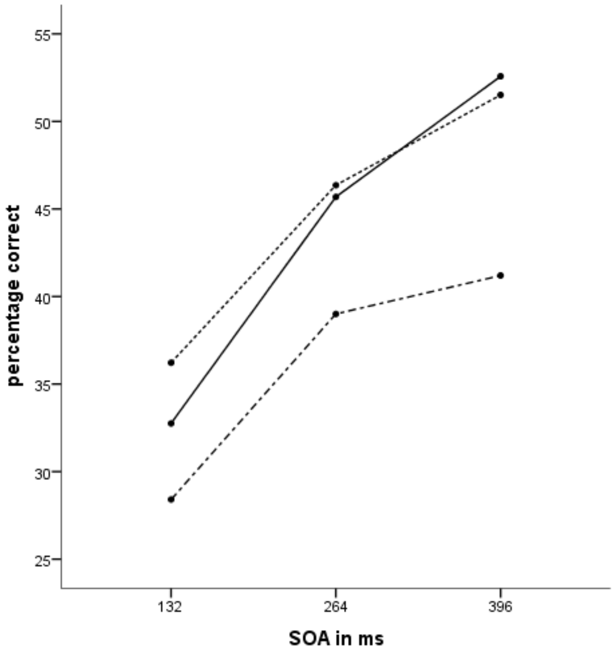


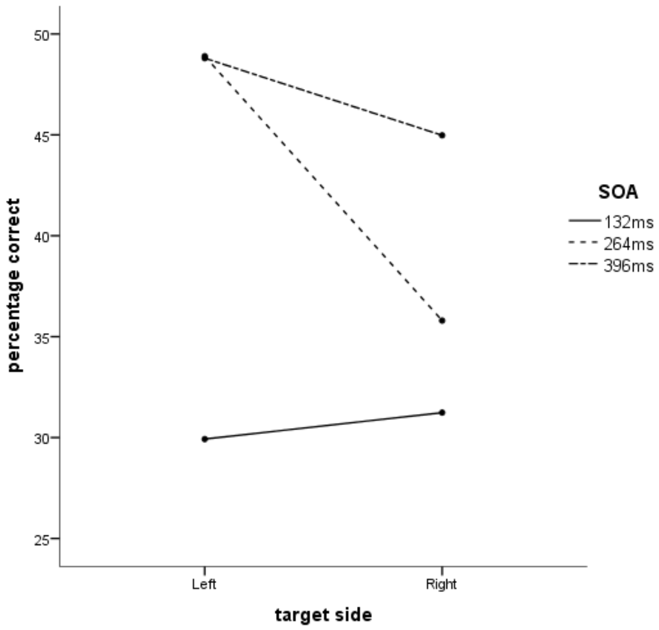

*Figure 2. The reaction times(in milliseconds) for all the validity conditions and Stimulus Onset Asynchrony (in milliseconds).*

Analyses on the accuracy of responses, the Percentage Correct (PC), showed that there was no significant difference in validity between the sixty-six valid condition and hundred percent valid condition (resp. 43.67% vs. 44.70%), F (1, 12) = 0.18, p > 0.65. $\eta_p^2$ = 0.02. The PCs in the sixty-six percent valid trials were not significantly higher than in the sixty-six percent invalid trials (resp. 43.67% vs. 37.34%), F (1, 12) = 3.96, p > 0.05. $\eta_p^2$ = 0.25.

Between the sixty-six percent valid and the hundred percent valid conditions, the PCs were lower for shorter SOAs than for longer SOAs (34.49% vs. 46.02% vs. 52.04%), F (2, 24) = 18.22, p < 0.001. $\eta_p^2$ = 0.60. It also revealed a significance in the SOAs between the sixty-six percent valid and the sixty-six percent invalid conditions, it showed that the PCs were lower for shorter SOAs than for longer SOAs (30.58% vs. 42.35% vs. 46.89%), F (2, 24) = 17.89, p < 0.001. $\eta_p^2$ = 0.60.

No interactions were found in PCs between the sixty-six valid condition and hundred percent valid condition. An interaction was found in PCs between the sixty-six valid condition and sixty-six invalid condition. This interaction is between the target side and the SOAs, where the 264ms and 396ms SOAs are nearly the same on the left side but differ a lot on the right side (resp. 48.9% and 48.8% vs. 35.8% and 44.98%), F (2, 24) = 5.14, p = 0.014. $\eta_p^2$ = 0.30.

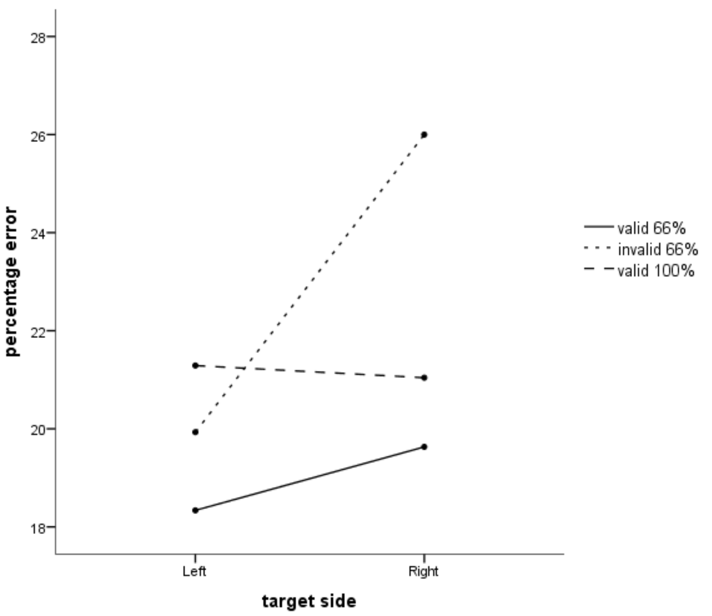


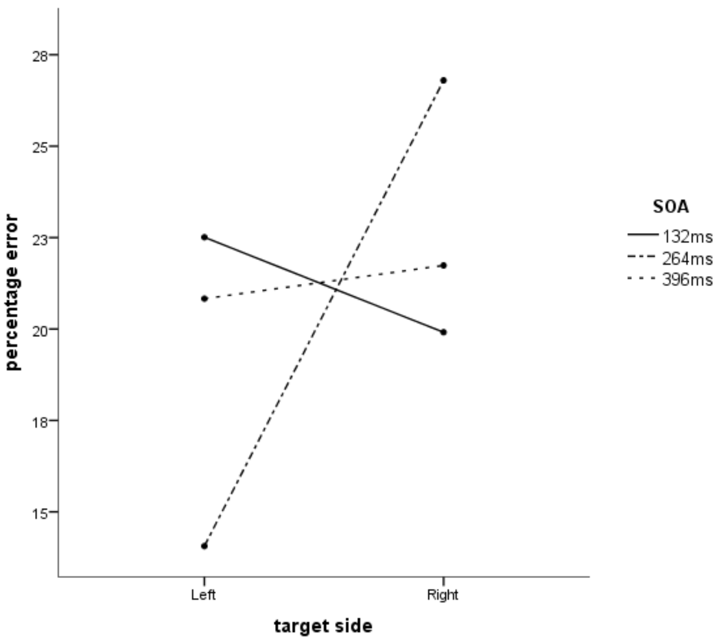



*Figures 3 and 4. Respectively correct given response(in percentage) for all the validity conditions and Stimulus Onset Asynchrony (in milliseconds) and correct given response (in percentage) for target side and Stimulus Onset Asynchrony (in milliseconds).*

Analyses on the Percentage Error (PE) showed no significance in validity, target side and SOAs between the sixty-six percent valid and hundred percent valid conditions.

It did reveal a significance in validity between the sixty-six percent valid trials and the sixty-six percent invalid trials (resp. 18.98% vs. 22.97%), F (1, 12) = 5.04, p = 0.044. $\eta_p^2$ = 0.30. Furthermore, it was found that, in the sixty-six percent valid and invalid trials, the PEs were significantly lower on the left side than on the right (resp. 19.13% vs. 22.82%), F (1, 12) = 5.18, p = 0.042. $\eta_p^2$ = 0.30. An interaction was found in PEs between the sixty-six valid condition and sixty-six invalid condition. This interaction is between the target side and the SOAs, where the 264ms SOAs are much less incorrect on the left side than the right side (14.06 vs. 26.8), F (2, 24) = 6.03, p < 0.01. $\eta_p^2$ = 0.33.



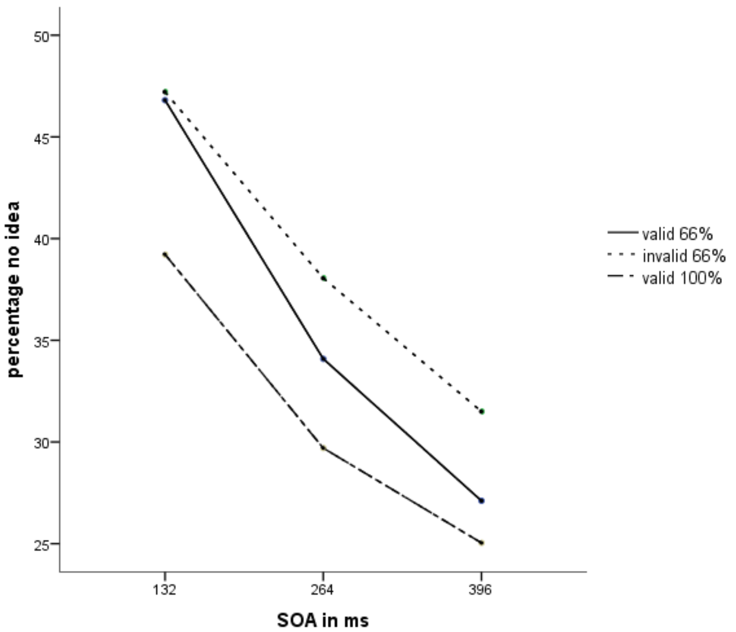



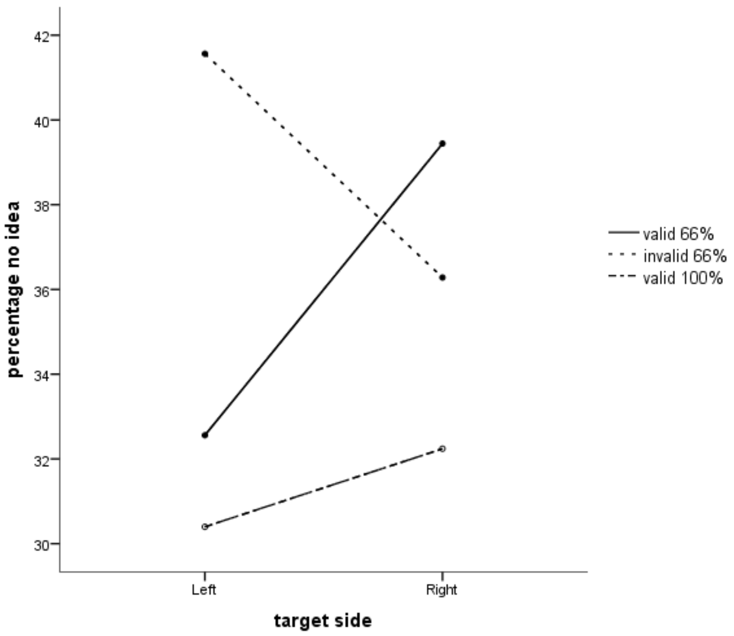

*Figures 5 and 6. Respectively incorrect given response (in percentage) for all the validity conditions and target side and incorrect given response (in percentage) for target side and Stimulus Onset Asynchrony (in milliseconds).*

Analyses on the Percentage No Idea (PNI) showed that there was no significant difference in validity between the sixty-six valid condition and hundred percent valid condition. No significant difference was found for the sixty-six percent valid and sixty-six invalid trials.

Between the sixty-six percent valid and the hundred percent valid conditions, the PNIs were higher in the short SOAs and decreased with medium and long SOAs (resp. 43.01 vs. 31.89 vs. 26.07), F (2, 24) = 15.53, p < 0.001. $\eta_p^2$ = 0.56. The sixty-six percent valid and sixty-six percent invalid trials also showed a significance in SOAs, the PNIs were higher in the short SOAs and decreased with medium and long SOAs (resp. 47.01 vs. 36.07 vs. 29.30), F (2, 24) = 20.13, p < 0.001. $\eta_p^2$ = 0.63.

An interaction was found in PNIs between the sixty-six valid condition and sixty-six invalid condition. This interaction is between validity and target side, the sixty-six percent valid trials have lower PNIs on the left side than on the right side (32.56% vs. 39.44%) and the sixty-six percent invalid trials have higher PNIs on the left side than on the right (41.56% vs. 36.28%), F (2, 24) = 5.93, p < 0.05. $\eta_p^2$ = 0.33.




*Figures 7 and 8. Respectively percentage no idea for all the validity conditions and Stimulus Onset Asynchrony (in milliseconds) and percentage no idea for all validity conditions and target side.*

**EEG analyses of the cue-target interval**

One sample T-tests were performed on the data for each of the twenty-four time windows, ranging from 200ms to 1400ms in intervals of 50ms. A summary of the most relevant findings for the ERLs is presented in Table 1 (for the entire Table see appendix 1).

The presence of the EDAN (Early Directing Attention Negativity ) was not significant, but still visible in figures 9 and 10. The criterion used was of multiple windows significant in sequence and thus a significance level of $p < 0.01$, derived from a procedure used in Talsma, Wijers, Klaver and Mulder (2001). When using a criterion of one window and thus a significance level of $p < 0.05$, the EDAN would have been significant on more than one electrode in multiple time windows. The ADAN (Anterior Directing Attention Negativity) was not found to be significant and was not seen in the figures. A highly pronounced LDAP (Late Directing Attention Negativity) was visible from 450 until at least 650 for both the hundred percent and the sixty-six percent conditions. As shown in figure 9 and 10, the LDAP for the hundred and sixty-six percent validity is very noticeable. The effects seem slightly more pronounced on the Occipital-Parietal sites than the other sites. The T7 electrode in the hundred percent condition showed a high significance in the window 250ms to 350ms. The F7 electrode in the hundred percent condition was significant in the window from 400ms to 500ms, as was the F3 in the sixty-six percent condition.

For all observed effects it was examined whether there was a possible relation with small eye movements related to the cued side. Almost all correlations between hEOG and the relevant EEG channels were non-significant, only in the window from 450ms to 500ms the F7 electrode in the hundred percent condition and the P3 electrode in the sixty-six condition were significant in correlation to hEOG (resp. $p = 0.048$ and $p = 0.028$). Although all but one window for the P3 electrode were not significant, it came to the attention that the P3 channel was  a lot closer to the significance level than the other relevant channels in more than one time window. This observation suggests that the parietal focus may partially reflect the execution of very small below threshold saccades. Nevertheless, almost all of the observed effects appear to have an attentional nature.

**ERLs**

| Component | Condition | Window | Maxima | p |
|---|---|---|---|---|
| | 100% | 250-350 | T7 | $p < 0.003$ |
| | | 400-500 | F7 | $p < 0.003$ |
| LDAP | | 450-650 | P3 | $p < 0.003$ |
| | | 450-850 | P7 | $p < 0.008$ |
| | | 450-850 | PO3 | $p < 0.002$ |
| | | 450-700 | PO7 | $p < 0.001$ |
| | | 750-850 | PO7 | $p < 0.001$ |
| | 66% | 400-500 | F3 | $p = 0.004$ |
| LDAP | | 450-800 | CP5 | $p < 0.005$ |
| | | 450-700 | P3 | $p < 0.003$ |
| | | 450-900 | P7 | $p < 0.008$ |
| | | 450-700 | PO3 | $p < 0.01$ |
| | | 450-700 | PO7 | $p < 0.002$ |
| | | 750-850 | PO7 | $p < 0.008$ |

*Table 1. A summary of effects observed on the Event-Related Lateralizations.*

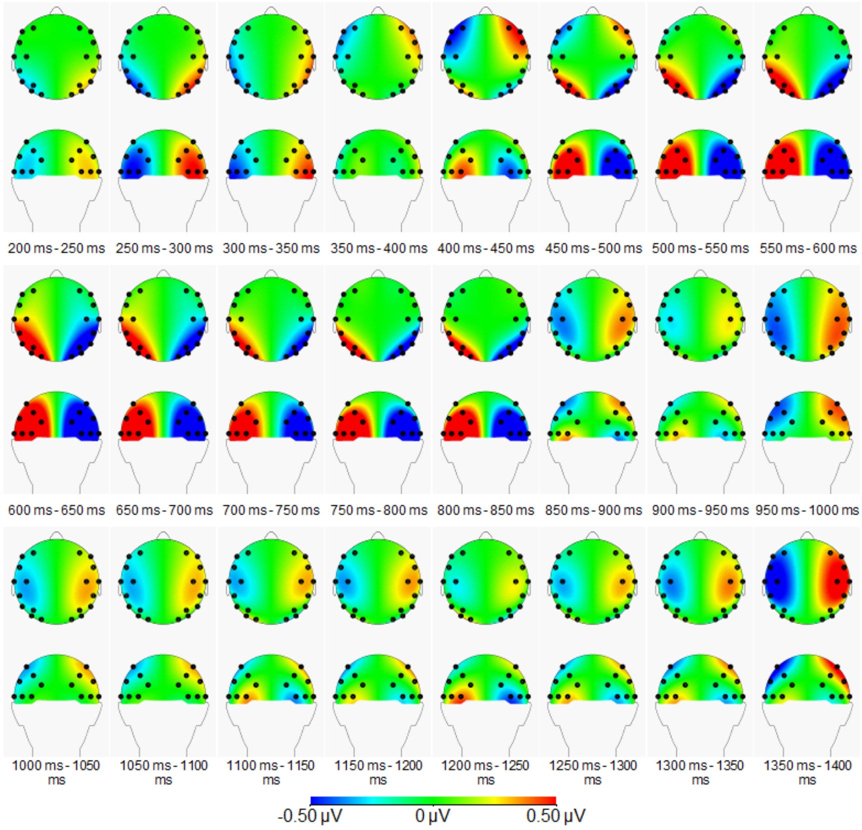



*Figure 9. Topographical map of the averaged Event-Related Lateralizations elicited by a 100% valid cue on the left side, contra-ipsi lateral, in the time window from 200 ms – 1400 ms.*

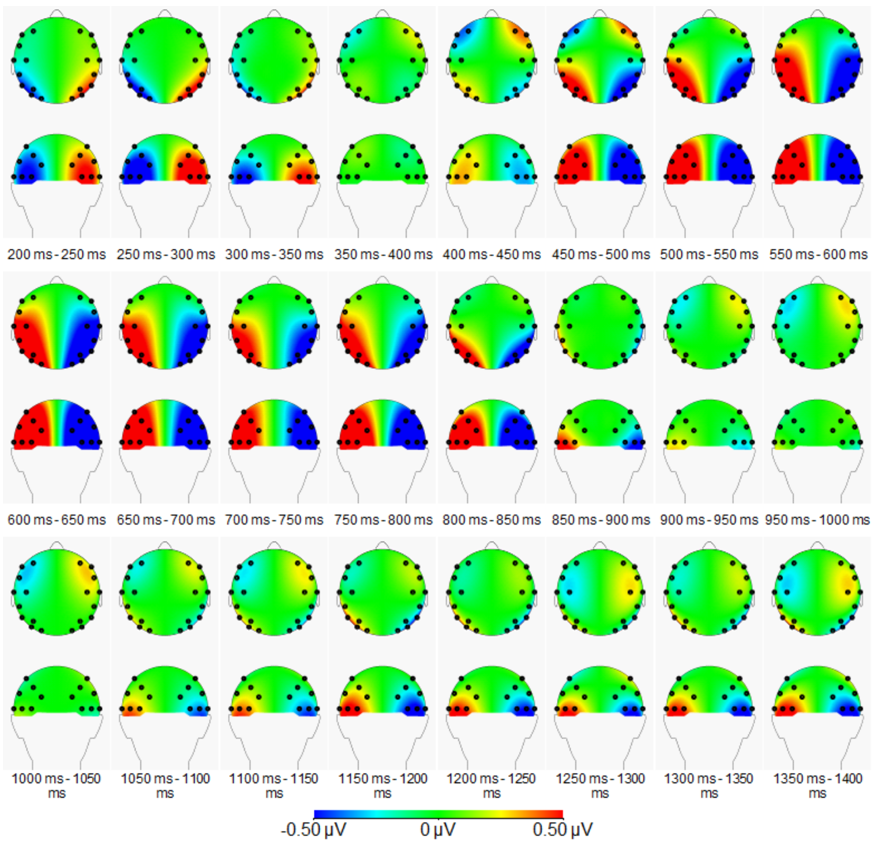



*Figure 10. Topographical map of the averaged Event-Related Lateralizations elicited by a 66% valid cue on the left side, contra-ipsi lateral, in the time window from 200 ms – 1400 ms.*

To determine differences between the hundred and sixty-six conditions, paired sample t-tests were performed on the relevant electrodes and corresponding time windows found in the earlier one sample t-tests. Only the lateralizations of which at least one of the two validity conditions was significant (Table 1) were used, so the difference between the two conditions could be analysed. These analyses showed no significant differences between the hundred and sixty-six conditions using the significance level, $p < 0.05$.

## Discussion

The main focus and research question of this paper, as mentioned in the introduction, were that the present study aimed to find a sensitive EEG index to measure visuospatial attention using the research question 'Is ERL a sensitive EEG index to measure the allocation of visuospatial attention?'

When examining the results from Gould et al. (2011) it is expected to find lower values in reaction time (RT) and higher values on correct given responses (PC), in hundred percent cue validity than in sixty-six percent cue validity. This research shows that the reaction time was not significantly lower in the hundred percent condition than in the sixty-six percent condition. This is not in accordance with what Gould et al. (2011) report. A reason for this could be that the researchers explained to the participants that the correctness of a response was more important to them than the quickness of the response. The participants should then have reacted slower not to compromise the correctness of the responses. Also the PCs were not significantly higher in the hundred percent condition than in the sixty-six percent condition, which was very unexpected.

Based on the results from multiple studies (eg. Petersen & Posner, 1990) it is also expected to find the cue validity effect, the participants perform better on valid than on invalid ques. The results of percentage correct show that the participants showed no significant better performance on the sixty-six percent valid condition than on the sixty-six percent invalid condition.. This was also a not expected find, because multiple researchers reported this to happen (Petersen & Posner, 1990; Eckstein et al., 2003; Giessing et al., 2004).

Furthermore, it was thought that the difference between SOAs in hundred percent cue validity was smaller than in the sixty-six percent cue validity. This was also not found, however, the difference for PCs between the medium and long SOA for the sixty-six percent valid condition were more than the difference for the hundred percent condition. This was not significant, but it can be seen in figure 3.

It was also expected to find the presence of three components, mentioned in earlier research (van der Lubbe & Utzerath, 2013; Eimer, van Velzen & Driver, 2002; McDonald & Green, 2008; Hopf & Mangun, 2000), the EDAN, the ADAN and the LDAP. The EDAN was not significant, but still visible in figures 9 and 10. The criterion used was of multiple windows significant in sequence and thus a significance level of $p < 0.01$, derived from a procedure used in Talsma, Wijers, Klaver and Mulder (2001). Because of this it can be discussed that the criterion is too rigorous. When using a criterion of one window and thus a significance level of $p < 0.05$, the EDAN would have been significant on more than one electrode in multiple time windows. Furthermore, unlike a previous study (van der Lubbe, Neggers, Verleger & Kenemans, 2006), no ADAN was visible in the ERL data. It might be that the process reflected by the ADAN has a more induced nature than the EDAN and therefore does not necessarily show up in ERLs. A highly pronounced LDAP was found in this experiment, it was observed from 450ms until approximately 700ms after cue onset which roughly resembles findings from several previous studies (van der Lubbe & Utzerath, 2013). Most likely, the LDAP reflects the top-down influence of frontal and parietal areas on occipital areas. Furthermore, this effect seems to concern either inhibition of the unattended visual field and/or disinhibition of the attended field.

A higher lateralization in the hundred percent validity condition than in the sixty-six condition was expected to be found. But the analysis showed no significant findings regarding this notion, which means that no differences were found between the two validity conditions regarding the allocation of spatial attention. This could have been expected, because the behavioural data showed little difference between the validity conditions, so how high are the odds that there would have been significant lateralizations later on in the analysis.

When comparing this analysis to the analysis of Aldiek (2015), which she performed concerning the same matter with the same data, but only using alpha-bands as an index, differences were found between the conditions. These were significant on the PO4 and P8 electrodes in several time windows, so only on the parietal and parietal-occipital cortices. What this suggests is that the measurement of the allocation of spatial attention is more sensitive when using alpha-bands than the ERLs method. This is somewhat predictable, because the onset of a process like attentional orienting probably varies over trials, and in the case of higher spectra this varying activity will be subtracted out by the standard averaging technique. An alpha band analysis is a wavelet analysis that does incorporate the trial-to-trial variation.

What may be interesting for future research is the length of the time windows. In this paper an interval of 50ms was used, while van der Lubbe and Utzerath (2013) used an interval of 20ms. When examining the results of both papers, it was found that the intervals of 20ms were more precise when determining the components of the ERLs. When using the 50ms intervals, the LDAP started at 450ms after the cue onset. When using the 20ms intervals, the LDAP started at 540ms. Although the experimental data varies, 540ms is too accurate when using 50ms intervals and cannot be distinguished from 550ms. A downside of using 20ms interval is the data to analyse. When using an interval of 50ms for 200-1400ms, that is 24 windows. When using 20ms intervals, that is 60 intervals. It can be argued that the rise in data does not weigh against the gain in accuracy of the data.

A recommendation for future researchers is the usage of the double subtraction method, as used in this paper. This method negates the general hemispherical differences (Verleger, Migasiewicz & Möller, 2011) that complicate the lateralization index, which will be present in a single subtraction.

Another recommendation for future research with the Posner task is the use of block wise stimulus presentation instead of a trial wise presentation (Gould et al, 2011). This way all the same validity conditions are placed in one block and randomized within that block. This way the participant knows that all the trials are with that validity effect, which negates the effect previous trials with a different validity could have had.

## Conclusions

Coming back to the research question, if ERLs are a sensitive EEG index to measure the allocation of visuospatial attention. The ERL method is not the most sensitive EEG index to measure this, it can show the three components from EEG lateralization and the LDAP was highly pronounced, but no differences in lateralization were found between the sixty-six and hundred percent validity conditions.

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# Appendices

| ERL overview of the performed t-tests | 200-250 ms | 250-300 ms | 300-350 ms | 350-400 ms | 400-450 ms | 450-500 ms | 500-550 ms | 550-600 ms | 600-650 ms | 650-700 ms | 700-750 ms | 750-800 ms | 800-850 ms | 850-900 ms | 900-950 ms | 950-1000 ms | 1000-1050 ms | 1050-1100 ms | 1100-1150 ms | 1150-1200 ms | 1200-1250 ms | 1250-1300 ms | 1300-1350 ms | 1350-1400 ms |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| F3-100% | .933 | .647 | .473 | .067 | .020 | .054 | .685 | .553 | .430 | .399 | .743 | .633 | .781 | .373 | .419 | .220 | .444 | .368 | .459 | .580 | .711 | .606 | .365 | .097 |
| F3-66% | .376 | .911 | .391 | .033 | .004 | .004 | .393 | .467 | .187 | .387 | .955 | .426 | .372 | .435 | .063 | .088 | .103 | .119 | .161 | .283 | .407 | .339 | .398 | .387 |
| F7-100% | .276 | .075 | .038 | .027 | .002 | .003 | .020 | .651 | .965 | .949 | .616 | .874 | .652 | .144 | .401 | .072 | .230 | .240 | .227 | .346 | .493 | .354 | .508 | .123 |
| F7-66% | .593 | .762 | .819 | .140 | .113 | .024 | .401 | .904 | .869 | .696 | .543 | .337 | .907 | .384 | .646 | .776 | .537 | .807 | .833 | .888 | .643 | .928 | .884 | .814 |
| FC5-100% | .931 | .083 | .001 | .020 | .001 | .012 | .339 | .934 | .783 | .672 | .955 | .757 | .788 | .044 | .188 | .000 | .048 | .053 | .086 | .227 | .497 | .266 | .282 | .042 |
| FC5-66% | .325 | .461 | .186 | .127 | .189 | .162 | .932 | .266 | .151 | .350 | .485 | .198 | .846 | .714 | .255 | .181 | .094 | .356 | .275 | .389 | .691 | .343 | .535 | .367 |
| C3-100% | .250 | .056 | .031 | .109 | .024 | .738 | .238 | .181 | .097 | .232 | .244 | .605 | .837 | .011 | .030 | .001 | .034 | .041 | .075 | .136 | .243 | .099 | .050 | .013 |
| C3-66% | .144 | .247 | .463 | .904 | ,843 | .068 | .026 | .001 | .002 | .002 | .013 | .010 | .319 | .572 | .519 | .368 | .309 | .635 | .360 | .700 | .618 | .130 | .482 | .185 |
| T7-100% | .061 | .003 | .001 | .032 | .101 | .688 | .365 | .192 | .141 | .123 | .151 | .140 | .223 | .151 | .413 | .025 | .139 | .393 | .124 | .383 | .845 | .352 | .713 | .150 |
| T7-66% | .503 | .078 | .360 | .834 | .662 | .264 | .022 | .008 | .004 | .022 | .033 | .021 | .090 | .072 | .687 | .605 | .866 | .302 | .525 | .444 | .397 | .835 | .612 | .657 |
| CP5-100% | .099 | .011 | .007 | .208 | .759 | .108 | .047 | .034 | .031 | .082 | .113 | .052 | .160 | .199 | .473 | .013 | .210 | .328 | .304 | .444 | .724 | .431 | .456 | .144 |
| CP5-66% | .040 | .027 | .166 | .822 | .589 | .002 | .001 | .001 | .001 | .002 | .005 | .005 | .012 | .140 | .952 | .655 | .590 | .623 | .801 | .420 | .764 | .810 | .925 | .971 |
| P3-100% | .076 | .004 | .119 | .785 | .602 | .002 | .000 | .003 | .002 | .012 | .061 | .014 | .051 | .168 | .552 | .003 | .052 | .078 | .620 | .608 | .778 | .475 | .347 | .170 |
| P3-66% | .053 | .044 | .349 | .247 | .228 | .000 | .001 | .001 | .001 | .003 | .018 | .015 | .022 | .454 | .770 | .925 | .958 | .465 | .556 | .348 | .539 | .902 | .681 | .667 |
| P7-100% | .136 | .024 | .037 | .613 | .234 | .001 | .002 | .003 | .000 | .002 | .008 | .000 | .001 | .497 | .963 | .120 | .368 | .682 | .691 | .701 | .195 | .416 | .568 | .870 |
| P7-66% | .018 | .009 | .047 | .861 | .236 | .000 | .000 | .000 | .000 | .000 | .000 | .001 | .000 | .008 | .288 | .681 | .596 | .148 | .105 | .012 | .038 | .071 | .099 | .082 |
| PO3-100% | .113 | .016 | .371 | .210 | .049 | .000 | .000 | .001 | .000 | .002 | .023 | .005 | .004 | .643 | .496 | .129 | .830 | .728 | .410 | .683 | .335 | .541 | .613 | .809 |
| PO3-66% | .022 | .017 | .219 | .511 | .151 | .000 | .001 | .001 | .003 | .010 | .128 | .071 | .037 | .690 | .851 | .647 | .952 | .663 | .620 | .504 | .610 | .707 | .683 | .469 |
| PO7-100% | .274 | .026 | .155 | .595 | .016 | .000 | .000 | .000 | .000 | .001 | .012 | .000 | .000 | .174 | .099 | .771 | .655 | .706 | .124 | .203 | .055 | .149 | .245 | .448 |
| PO7-66% | .019 | .017 | .039 | .837 | .241 | .000 | .002 | .001 | .001 | .002 | .024 | .008 | .003 | .225 | .489 | .983 | .929 | .282 | .223 | .084 | .186 | .254 | .253 | .180 |
| hEOG-100% | .878 | .442 | .024 | .008 | .004 | .004 | .003 | .008 | .001 | .002 | .004 | .003 | .010 | .009 | .015 | .014 | .008 | .046 | .060 | .107 | .148 | .143 | .196 | .124 |
| hEOG-66% | .628 | .267 | .054 | .020 | .024 | .014 | .013 | .016 | .021 | .029 | .041 | .048 | .046 | .047 | .032 | .050 | .055 | .061 | .037 | .029 | .044 | .047 | .042 | .135 |

*Appendix 1. An overview of significance levels from the data gathered using one sample t-tests on the acquired EEG data*