The relation between visuospatial attention and conscious visual perception examined by using lateralized power spectra.

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Content

Summary

The aim of the present study was to examine the relation between attention and conscious perception. We investigated whether individual differences in conscious perception can be predicted on the basis of ipsi-contralateral differences in the alpha bands. A visuospatial attention task in combination with backward masking was performed by participants while their EEG was measured. A special method of analysis, lateralized power spectra (LPS), was applied to the raw EEG of participants to examine individual differences in the allocation of attention. Results showed that there were individual differences in conscious perception. Besides, we found evidence that other factors than attention also influenced the performance index of the visuospatial attention task, which suggests that individual differences in conscious perception were also caused by other factors than attention. Furthermore, there was no convincing evidence that individual differences in conscious perception can be predicted on the basis of ipsi-contralateral differences in the alpha bands

Samenvatting

Doel van het huidige onderzoek was het onderzoeken van de relatie tussen aandacht en bewuste perceptie. Hierbij werd gekeken of individuele verschillen in bewuste perceptie te voorspellen zijn op basis van ipsi-contralaterale verschillen in de alfa banden. Een visuospatiële aandachtstaak in combinatie met een maskering is uitgevoerd door participanten terwijl hun EEG gemeten werd. Een speciale analysemethode, ‘lateralized power spectra (LPS)’, is toegepast op het ruwe EEG van de participanten om individuele verschillen in het richten van aandacht te onderzoeken. Uit de resultaten bleek dat er individuele verschillen in bewuste perceptie waren. Overigens werd er bewijs gevonden dat andere factoren dan aandacht de prestatie-index van de visuospatiële aandachtstaak ook beïnvloed hebben. Dit suggereert dat individuele verschillen in bewuste perceptie ook veroorzaakt werden door andere factoren dan aandacht. Daarnaast werd er geen overtuigend bewijs gevonden dat individuele verschillen in bewuste perceptie voorspeld kunnen worden op basis van ipsi-contralaterale verschillen in de alfa banden.

Introduction

We can perceive something consciously when we focus our attention on it. This suggests that there is a relationship between attention and conscious perception. In the current study, the interest lay in the relation between attention and conscious perception examined by focusing on individual differences in the covert orienting of attention. This is the situation in which people shift their attention towards a location without moving their head or eyes. Above all, the interest lay in the predictive degree of individual differences in conscious perception on the basis of differences in the allocation of attention. In the following section, we begin by describing individual differences in attention and awareness and describe the possible causes of these individual differences. Then, arguments for the relation between attention and awareness are described and how this relationship was examined in the current study.

Research showed individual differences in both attention and conscious perception (e.g., Chechlacz, Gillebert, Vangkilde, Petersen, & Humphreys, 2015; Sandberg, Barnes, Rees, & Overgaard, 2014). First, Chechlacz et al. (2015) analyzed individual differences in attention by using Bundesen’s theory of visual attention (TVA) (Bundesen, 1990). This is a quantitative analysis in which participants have to respond to stimuli that are shown for various time intervals, followed by a mask. Results showed individual differences in attentional functions, for example speed of information processing, visual short-term memory (VSTM) and spatial bias. Second, Sandberg et al. (2014) carried out a magnetoencephalography (MEG) study in which subjects were asked to respond to visual stimuli. Results showed that MEG signals and the accuracy of visual perception differed between individuals. Differences in neural activity were found in time windows which are associated with differences in conscious perception. These differences in neural activity suggested that there are individual differences in the neural correlates of conscious perception.

The above mentioned individual differences in attention can be linked to differences in brain structures (e.g., Chechlacz et al., 2015; De Schotten et al., 2011). First, individual differences in attention were examined in the previously mentioned MRI study (Chechlacz et al., 2015) by looking at differences in the microstructures of the superior longitudinal fasciculi (SLF) and the inferior fronto-occipital fasciculus (IFOF). Results showed that there was variability in the microstructure of the IFOF, the middle SLF II and the ventral SLF III in the right hemisphere. This variability was associated with individual differences in visual short-term memory and speed of information processing. Individual differences in spatial bias were linked to a variability in volume and microstructure of the middle SLF II in the right hemisphere. Second, research from De Schotten et al. (2011) examined individual differences in attention by looking at differences in the volume of the longitudinal parieto-frontal tracts. They performed virtual in vivo dissections by using diffusion imaging tractography. Results showed individual differences in hemispherical lateralization of the middle superior longitudinal fasciculus (SLF II). Furthermore, participants performed an attention task in which they had to respond as fast as possible to stimuli in their left or right visual field (Posner, 1980). Rapid detection of stimuli in the left hemifield correlated with a large SLF II tract in the right hemisphere. In short, structural differences in the IFOF, SLF II and SLF III in the frontoparietal networks seems to contribute to individual differences in focusing attention.

As mentioned above, there are differences in both attention and conscious perception. Differences in attention can be linked to structural differences in several fasciculi in the frontoparietal networks. Furthermore, research suggested that individual differences in attention and conscious perception can also be linked to each other (e.g., Dehaene, Changeux, Naccache, Sackur, & Sergent, 2006; Lamme, 2003). There are several theories that explain a relation between attention and awareness, but there is some debate about the precise relation between them. First, Dehaene et al. (2006) suggested that actively focusing attention on stimuli (top-down attention) and passive bottom-up stimulus strength is needed to consciously perceive a stimuli. When top-down attention and bottom-up stimulus strength were present, parieto-frontal networks were activated, which results in conscious perception. Second, Lamme (2003) suggested that focusing attention on stimuli does not determine whether the stimuli will be perceived consciously, but attention determines whether a person can consciously report about stimuli. A conscious experience can be acquired through different inputs, but to consciously report, attention is necessary. Third, Koivisto and Revonsuo (2010) mentioned that different types and forms of attention and awareness should be distinguished to gain insight in the relation between attention and consciousness. They suggested that after stimulus onset, posterior occipito-temporal networks and parietal networks activate which causes visual awareness. If the correlate of visual awareness, visual awareness negativity (VAN), emerges depends on the degree of spatial attention. In short, all the above mentioned studies suggest that there is a relation between attention and awareness. The exact relation between attention and awareness, however, remains unclear.

In the previous sections we have discussed that there are individual differences in attention and conscious perception and that these individual differences can be caused by structural differences in the brain. Furthermore, there seems to be a relation between attention and awareness. To examine individual differences in attention and conscious perception and the possible relation between attention and conscious perception, several paradigms can be used. First, a paradigm that can be used to examine individual differences in visuospatial attention is the Posner cuing paradigm (Posner, 1980). In this endogenous cueing paradigm, participants perform a visuospatial attention task in which they have to shift their attention to stimuli that were presented outside the fixation field without moving their head or eyes. Second, a paradigm that can be used to examine individual differences in conscious perception is a backward masking paradigm. Backward masking is the presentation of a stimulus immediately after a target stimulus. The intensity of the mask depends on the time interval between presenting the target and the mask, named the stimulus onset asynchrony (SOA). A SOA of 0 ms has the lowest target visibility, when the SOA increases the target visibility also increases. Studying the effects of backward masking is interesting because the backward mask can inhibit the visibility of the target (Breitmeyer, 2014). It is an important factor in the failure to detect stimuli, because due to the mask it is more difficult to clearly register the stimuli on the retina. Boyer and Ro (2007) examined the role of attention in a masking paradigm. Participants had to respond on a stimulus, that was presented after a cue, by pressing a button if they saw only the mask or both the target and the mask. Results showed that the visibility of the target stimulus increased if participants focused their attention to the stimulus and the efficiency of the mask decreased. By combining the Posner cuing paradigm with a backward masking paradigm, individual differences in both visuospatial attention and conscious perception can be examined.

In order to gain insight in the relation between attention and awareness, an endogenous cueing paradigm and a backward masking paradigm can be combined with EEG measurements. Earlier research showed that EEG measurements in combination with a visuospatial attention task can be used to examine the allocation of attention. The allocation of attention during the performance of a visuospatial attention task can be examined by looking at ipsi-contralateral differences in alpha bands. Worden, Foxe, Wang & Simpson (2000) examined differences in the alpha band EEG activity in participants who performed a visuospatial attention task. The occipital effect for the alpha band increases ipsilateral before target onset compared to a decrease in contralateral occipital areas, which is in line with research of Thut et al. (2006) and Van der Lubbe and Utzerath (2013). This implies an inhibition of the to-be-ignored stimulus and/or disinhibition of the to-be-attended stimulus (Worden et al., 2000). A method for the analysis of EEG measurement that can be used to study the allocation of attention is lateralized power spectra (LPS). LPS is a method in which lateralized activity is determined on the basis of wavelet analyses of the raw EEG . In LPS, not only evoked activity is taken into account but also induced activity, which can give a more detailed view of visuospatial attention and the processes involved (Van der Lubbe & Utzerath, 2013). In sum, a combination of the EEG analysis with LPS and the behavioral analysis of the visuospatial attention task can examine the relation between attention and conscious perception and the predictive degree of conscious perception on the basis of the allocation of attention.

In the current study, the interest lies in the extension of studies that examined the relation between attention and awareness (e.g., Mathewson, Gratton, Fabiani, Beck, & Ro, 2009). We are mainly interested in whether individual differences in concious perception are predictive by analysing the allocation of visuospatial attention. Research from Mathewson et al. (2009) showed variance in the performance on an attention orienting task including backward masking. They found differences in both brain activity and the visual detectability of stimuli, which seemed to be related to differences in visual awareness. Furthermore, the performance of participants on the attention task varied over time. They suggested that these variations correspond to different brain states. When these different brain states are known, we can predict visual awareness. This makes studying the relation between attention and awareness very interesting, because we can use the task to predict how well a person’s conscious visual perception is. This can for instance be used to select people for positions where they have to be good at directing attention and conscious perception. Research from Rippe (2016) already examined the predictive value of the allocation of attention on conscious perception. She also looked at the ipsi-contralateral differences in the alpha bands and compared them to the performance on a visuospatial attention task. Results of the study showed that there was a relation between the allocation of attention and conscious perception, but only in a few time intervals. By improving the limitations of the study of Rippe (2016), such as a short range in time intervals, we want to gain more insight into the predictive value of individual differences in conscious perception.

The present study will examine the relation between attention and conscious perception, with a visuospatial attention task in combination with backward masking, by analyzing lateralised power spectra. On the basis of earlier mentioned research of Cechlacz et al. (2015) and Sandberg et al. (2014) expectations are that there are individual differences in attention and conscious perception. Furthermore, on the basis of research from Rippe (2016) we expect that individual differences in conscious perception can be predicted by ipsi-contralateral differences in the alpha bands.

Method

Participants

In total, twenty-four participants (9 male and 15 female) took part in the experiment. One of them had to be taken out because of too high amplitudes in his EOG, which suggested that this participant moved his eyes too much. Participants were aged between 18 and 37 years (M = 21.6, SD = 3.8). All participants had normal or corrected-to-normal vision, which was assessed using the Freiburg Visual Acuity Test for both eyes individually (Bach, 1996). In this test, the criterion was that all participants should have a mean score on both eyes of 1 or higher. All participants met this criterion. Ishihara's color blindness test (1976) was used to determine proper color vision. To determine the handedness of participants, Annett's Handedness Inventory (1970) was used (1 ambidextrous, 3 left, 19 right). A standard test is used to determine eye dominance (14 left, 9 right). One partcipant reported a psychiatric history (depression), the other participants reported no psychiatric or neurological history. At the start of the experiment, participants signed informed consent. The study was approved by the ethical committee of the Faculty of Behavioural, Management and Social Sciences.

Task and procedure

A variant of the Posner endogenous cuing paradigm was used (Posner, 1980). The sequence of events in one trial started with a default display (see Figure 1). The default display consisted of a black background with a centrally presented white fixation point (d = .3 cm) and two open circles at the left and right side of the screen (d = 1.5 cm) at 7.5 cm distance from the fixation point. At the start of the experiment participants were instructed to direct their eyes towards the fixation point during the task. The default display was presented for 700 ms, then the fixation point was enlarged for 200 ms. After presenting the default display again for 600 ms, a romb with two colored triangles (blue and yellow) pointed to the left or right circle. Participants were told to focus on one color which functioned as a cue of the to-be-attended side. These colors were counterbalanced over participants. The romb was displayed for 600 ms, then the target was presented in the circle on the left or right side. The target cue was either a vertically striped circle or a horizontally striped circle. Participants had to press the left "Ctrl" key as a response to a horizontally striped circle and the right "Ctrl" key as a response to a vertically striped circle on a QWERTY keyboard. Afterwards, a mask (500 ms) replaced the target cue at varying time intervals (7, 13.9, 20.8, 27.8, 34.7, 41.6, 48.6, 62.5, 83.4, 111.1, 138.8, 173.6, 208.3, and 277.8 ms). After responding to the stimulus, feedback was given to the participant by showing a red fixation point for a wrong answer (500 ms) and a white fixation point for a correct answer.

The task consisted of 910 trials, which were divided into one practice block of 14 trials and eight blocks of 112 trials each. There was a one-minute break between the blocks. The whole experiment took approximately 3 hours, while the execution of the task took approximately 90 minutes.

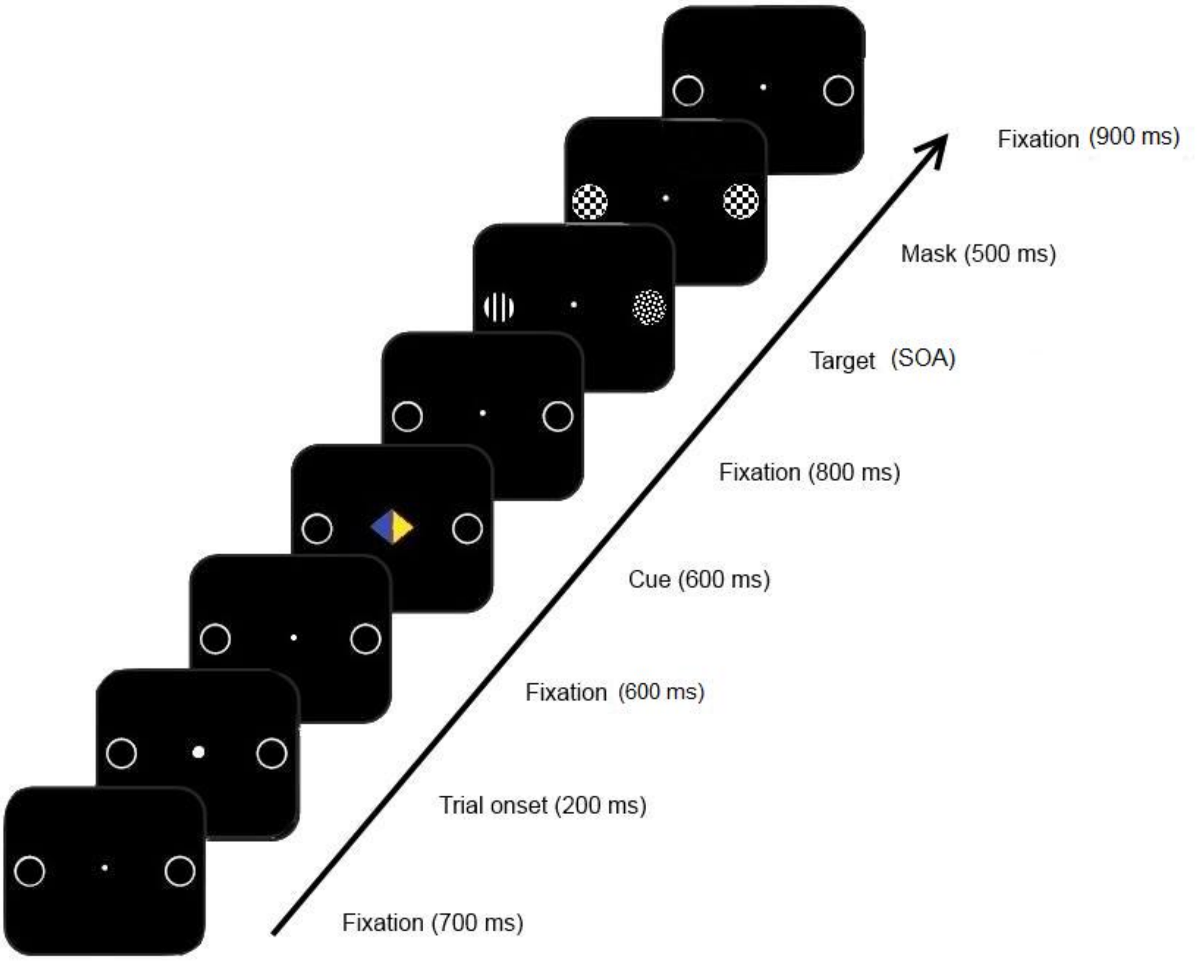

Figure 1. Sequence of events in one trial

Apparatus and EEG recordings

Participants sat on a comfortable chair, at a distance of approximately 85 cm in front of a 24 inch monitor in a dark room. The stimuli on the screen were presented with Presentation software (Neurobehavioral Systems, Inc., 2012). There were used two computers, one computer for the visuospatial attention task and another for the EEG measurements. Brain Vision Recorder was used for the measurement of EEG activity. Active Ag/AgCl electrodes were placed on a cap (actiCAP, Brainproducts GmbH) according to a 10-20 system at the following locations: AFz, AF7, AF8, F7, F3, Fz, F4, F8, FC5, FC1, FC2, FC6, T7, C3, Cz, C4, T8, CP1, CP2, P7, P3, Pz, P4, P8, PO7, PO3, POz, PO4, PO8, O1, Oz, O2 (see Figure 2). Four electrodes around the eyes were placed to record horizontal and vertical electro-oculogram (hEOG and vEOG). The horizontal electrodes were placed at the outer canthi of both eyes and the vertical electrodes below and above the left eye. Electrode gel was used to improve conductivity, the resistance was kept below 10 kΩ expect for one participant which resistance was kept below 20 kΩ. A 64-channels actiCHamp (Brainproducts, GmbH) amplifier was used to amplify the EEG and EOG. BrainVision Recorder (BrainProducts GmBh) registered EEG, EOG and task-related events such as stimulus onset and responses. Signals were sampled at a rate of 500 Hz with the following online filters: a high cutoff filter of 200 Hz (24 dB) and a notch-filter of 50 Hz.

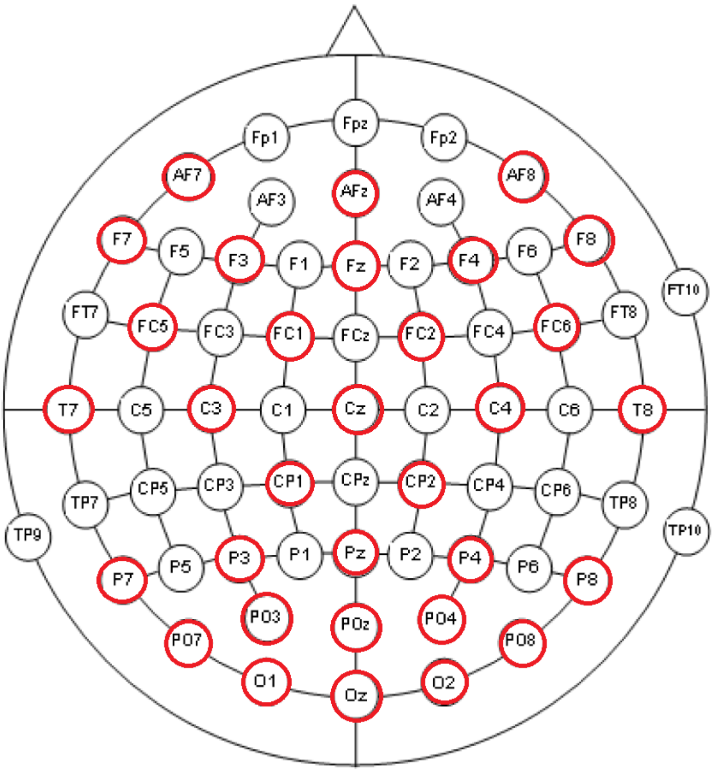

Figure 2. Schematic presentation of electrodes (red) used for EEG measurements

Data processing and analysis

Behavioral data processing and analysis

The extent to which participants were able to consciously perceive stimuli was determined for each SOA and denoted by the proportion of correct (PC). The average PC over the visuospatial attention task was also determined for each participant. To examine whether PCs increases when the time between the presentation of the target and the mask (SOA) increases, we plotted PCs against the different SOAs. The time interval (SOA) in which participants scored 75% correctly was refered as the visual awareness threshold. These time intervals were determined for each participants by means of linear interpolation with the following formula (see Figure 3 for the interpretation of the formula):

$$\text{Time interval 75\% correct responses (ms)} = \frac{(x - x_0)(y_1 - y_0)}{(x_1 - x_0)} + y_1$$

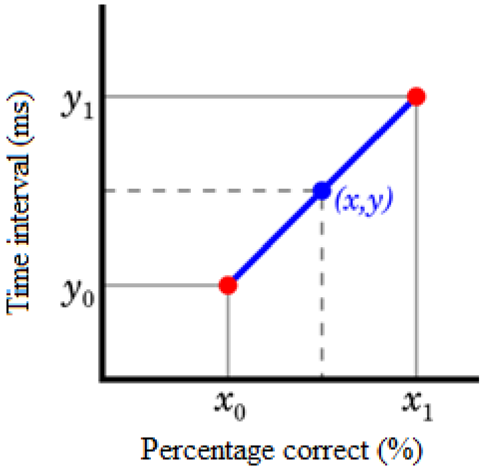

Figure 3. Illustrates the way time intervals can be determined by means of linear interpolation

EEG data processing and analysis

Data processing of 34 channels (32 EEG, 2 EOG) was carried out with Brain Vision Analyzer 2.1 (Brain Products GmbH, 2012). The raw data was filtered with a low cutoff filter of .016 Hz, a high cutoff filter of 32 Hz and a notch filter of 50 Hz. For further analysis, the EEG signals ranging from -1000 ms before cue ontset to 3400 ms after cue onset were taken out. Responses slower than 2 seconds after target onset were removed. Amplitudes on the hEOG and vEOG channels in the cue-target interval from 0 ms to 1400 ms that were too high were marked. Trials with marks were removed and not included in the analysis. In the cue-target interval, segments that contained no responses were selected and EEG channels with artifacts were removed from further analyses.

To examine individual differences in the allocation of attention, we used LPS on the raw EEG of participants. The EEG segments from -1000 ms to 2000 ms were taken for further analyses, segments with artifacts were removed. The gradient criterion that was applied was 100 µV per ms, the mimima and maxima criterion ranged from -250 µV to +250 µV and the low activity criterion was .1 µV. If these criteria were not met, EEG segments were removed. An independent component analysis (ICA) was applied to remove activity that had a non-cortical source. The applied baseline was set from -100 ms to 0 ms. Furthermore, fine artifacts were removed with the minima and maxima criterion from -150 µV to +150 µV.

For further analysis we focussed on activity in the P8/P7, PO4/PO3, PO8/PO7 and O2/O1 electrode pairs. The bands used for analysis were the alpha-1 band ranging from 7.2 to 10.4 Hz and the alpha-2 band ranging from 9.4 to 14.0 Hz. Lateralized activity was measured by separating the average power of each participant for time intervals of 100 ms after cue onset, from 400 ms to 1400 ms, in 10 time windows. A double suctraction technique was used to examine ipsi-contralateral differences in the alpha bands. The power within the alpha frequency band (ωp) at time point (t) was determined for the ipsi-conontralateral differences with the following formula:

$$LPS\left(\omega_p\right)_t = \left(\left(left\ cues\ \frac{\omega_p(PO7) - \omega_p(PO8)}{\omega_p(PO7) + \omega_p(PO8)}\right) + \left(right\ cues\ \frac{\omega_p(PO7) - \omega_p(PO8)}{\omega_p(PO7) + \omega_p(PO8)}\right)\right) \times \frac{1}{2}$$

A value that was positive indicates that the power in a specific alpha band was larger above the hemisphere that was ipsilateral to the cued side than the contralateral hemisphere.

Various t-tests were performed per cue condition to determine whether lateralization deviated from zero. Due to the large number of to-be-performed t-tests, there is a risk for Type-I errors. In order to avoid these Type-I errors, a correctionmethod was used. The formula that was used here is p < √.05 ÷ (windows − 1) × electrodes x bands). The new critical value we used in the current study was p < .026. This critical value had to be crossed for two successive time windows. Furthermore, we examined whether there was a correlation between the performance index of the visuospatial attention task and the hemispherical lateralization for both the dataset with all participants and the dataset in which an outlier was removed.

Results

Behavioral measures

The average percentage correct responses (PC) of each participant was determined and showed in Table 1. Mean PC over all participants was 76.2% (SD = 8.7). Criterion values that indicate the time interval that participants needed for 75% correct responses had a wide range with a minimum of 14.3 ms and a maximum of 187.6 ms. The average time participants needed to respond 75% correct is 59.2 ms (SD = 39.1). One participant had a criterion value that deviated more than 2.5 SD from the average time. An one-way repeated measures analysis of variance (ANOVA) was performed to examine significant differences in PC on the diferent time intervals between presenting the target and the mask.

A significant effect between PC and SOA has been found, *F*(13, 286) = 93.2, *p* < .001. As can be seen in Figure 4, an increase in SOA led to a decrease in PC.

Table 1.

Overview of the performance of participants in the visuospatial attention task.

Parctipant number	SOA for 75% correct (ms)	Average percentage correct
1	130.9	60.7
2	54.9	75.0
3	30.9	81.8
4	40.9	79.3
5	187.6	59.5
6	44.4	81.0
7	31.0	86.3
8	45.4	77.4
9	28.6	88.0
10	77.2	65.6
11	59.2	67.8
12	55.4	78.6
13	49.0	74.1
14	19.4	88.1
15	14.3	92.3
16	54.0	78.6
18	113.0	69.1
19	54.9	75.0
20	41.4	77.7
21	25.4	84.7
22	65.9	68.1
23	76.0	73.2
25	55.0	74.4

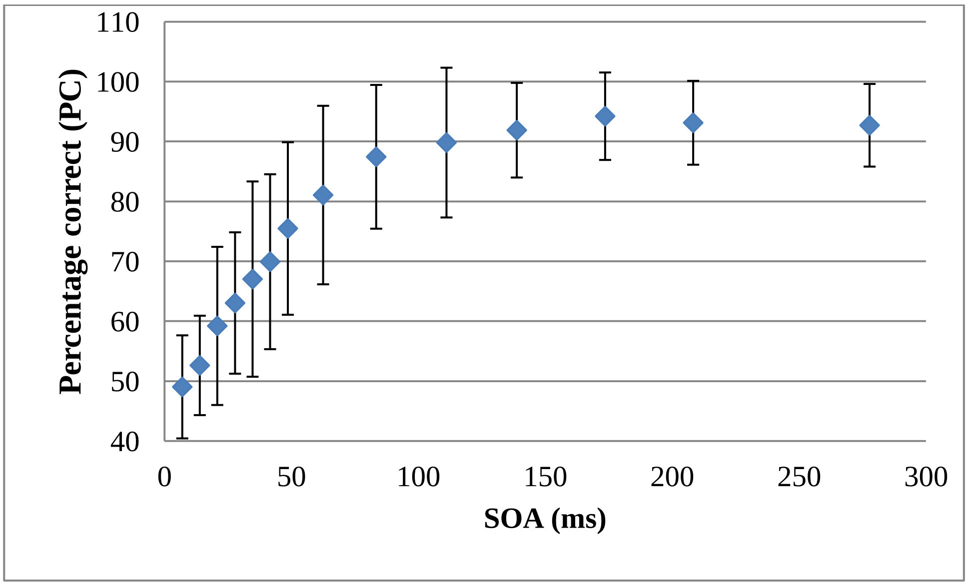

Figure 4. Mean percentage correct responses and standard deviations at each SOA in milliseconds.

EEG measures

For each window, one-sample t-tests were performed to test for ipsi-contralateral differences in the alpha frequency band lateralizations. The significance criterion was crossed for at least two time windows in both the alpha-1 frequency band and the alpha-2 frequency band for all eletrodes above the parieto-occipital areas. The time windows in which significant ipsi-contralateral differences were found, is shown in Table 2 (alpha-1 frequency band) and Table 3 (alpha-2 frequency band). This indicates that ipsi-contralateral differences were present. Positive t-values shown in Table 2 and Table 3 and the red colors in Figure 5 and Figure 6 indicates that the alpha power was higher more ipsilateral to the cued side.

Table 2.

Effects that were observed for the alpha-1 frequency band in which the significance criterion was crossed for at least two successive time windows (p < .026)

Band	Electrode pair	Window (ms)	t(22)	min. p < max. p
Alpha 1	P8/P7	400-900	2.6 - 3.7	.001 < .02
		1000-1400	2.9 – 3.9	.001 < .008
	PO4/PO3	400-1400	2.9 – 4.9	.0001 < .007
	PO8/PO7	400-1400	3.0 - 4.9	.0001 < .006
	O2/O1	400-1400	2.4 – 5.0	.0001 < .03

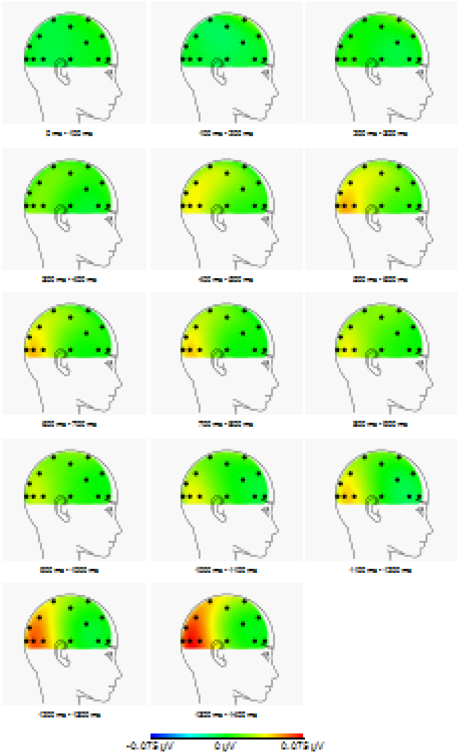

Figure 5. Topographical maps for the alpha-1 frequency band for the time windows 0 - 1400 ms. The red color represents more ipsilateral power than contralateral power.

Table 3.

Effects that were observed for the alpha-2 frequency band in which the significance criterion was crossed for at least two successive time windows (p < .026)

Band	Electrode	Window (ms)	t(22)	Min. p < max. p
Alpha 2	P8/P7	400-1400	3.0 - 6.6	.0001 <.007
	PO4/PO3	400-1400	2.7 – 5.5	.0001 < .01
	PO8/PO7	400-1400	2.6 - 6.6	.0001 < .02
	O2/O1	400- 800	2.4 - 3.1	.005 < .02
		1000-1400	4.1 - 4.6	< .0001

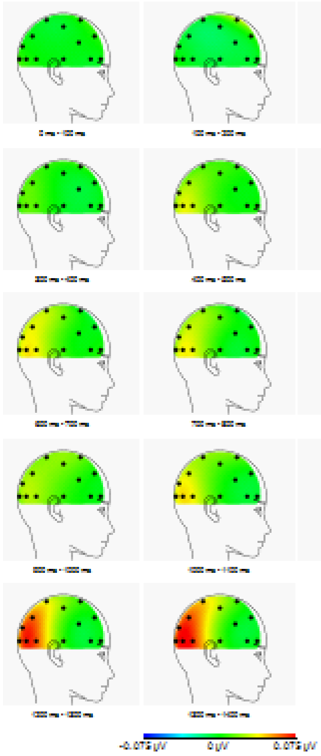

Figure 6. Topographical maps for the alpha-2 frequency band for the time windows 0-1400 ms. The red color represents more ipsilateral power than contralateral power.

A Pearson’s correlation was measured for the performance of individuals on the visuospatial attention task and lateralization. Significant correlations were found in only the alpha-2 frequency band (see Table 3). The strongest correlation was found in time window 900-1000 ms above the PO4/PO3 electrode pair ($r = -.608$, $p = .002$). The explained variance ($r^2 = .37$) in this relation is 37%. The negative values of the correlation coefficients (see Table 3) and Figure 7 show that an increase in the time interval for 75% correct responses led to a decrease in power in the alpha-2 frequency band.

Table 3.

Correlations between the SOAs and the alpha-2 frequency bands (criterion value = 75%)

Band	Electrode pair	Window (ms)	r	r^2	p
Alpha 2	PO4/PO3	900-1000	-.608	.37	.002
	PO8/PO7	400-500	-.474	.22	.02
		1000-1200	-.490	.24 < .23	.018 < .02
	O2/O1	500-600	-.483	.23	.02
		900-1000	-.519	.27	.01
		1300-1400	-.496	.25	.02

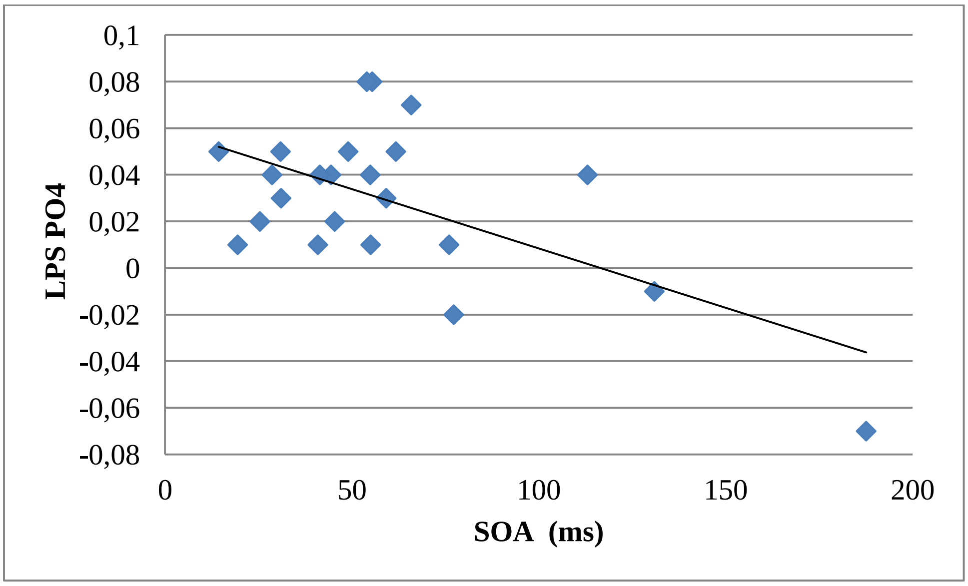

Figure 7. Relation between alpha-2 lateralization in PO4 and SOA criterion values in time window 900-1000 milliseconds (r = -.608, p = .002)

Correlations between the performance of individuals on the visuospatial attention task and lateralization were also calculated when outliers were removed. One participant, whose SOA was more than 2.5 SD above the average SOA when 75% correct, was excluded from analysis. Results then showed no significant correlation between performance and lateralization. Correlation coefficients after removing a outlier are shown in Table 4 (Appendix A) for alpha-1 frequency bands and in Table 5 (Appendix B) for alpha-2 frequency bands. For example, removing the outlier in time window 900-1000 ms for electrode pair PO4/PO3 resulted in no significant correlation (r = -.272, p = .002) while this relation had the strongest correlation in the dataset without the removal of the outlier. This suggests that after the removal of the outlier, there was no relation between the time interval for 75% correct responses and lateralization.

Discussion

The goal of the study was to gain insight in the relation between visuospatial attention and conscious perception, examined by focusing on individual differences in alpha bands and the performance on a visuospatial attention task. In de following section, we will answer the research question if individual differences in conscious perception are predictive on the basis of ipsi-contralateral differences in alpha bands. First, results of the behavioral measurements will be discussed. Then, we will discuss whether ipsi-contralateral differences were found. Next, the main question if individual differences in conscious perception were predictive by using ipsi-contralateral differences in the alpha bands will be discussed. Lastly, we will discuss some limitations and recommendations for further research.

To examine individual differences in conscious perception, a backward masking paradigm was used. Results of the behavioral measurements showed that when the time (ms) between the presentation of the target and the mask enlarged, the percentage correct increases. This suggests that, when the mask is presented later, the visibility of the stimuli increases. As earlier mentioned, longer SOAs lead to an increase in the visibility of the target (Breitmeyer, 2014). In sum, the findings are in line with earlier research which suggests that the backward mask was successful in changing the visibility of the stimuli.

Furthermore, the current study examined whether ipsi-contralateral differences were present in the alpha bands. Results of the EEG measurements showed significant ipsi-contralateral differences in almost all time windows above all electrode pairs. Significant t-values were positive, which indicates that the power in the alpha bands was larger above the hemisphere ipsilateral to the cued side than contralateral. As above mentioned, Worden et al. (2000) suggested that activity in the alpha bands ipsilateral to the cued side corresponded with an inhibition of the to-be-ignored stimulus and/or disinhibition of the to-be-attended visual field (Worden et al., 2000). The findings of Worden et al. (2000) and our findings are in line with earlier research, Rippe (2016) found ipsilateral to the cued side more alpha power than contralateral. On the basis of the results of the studies of Worden et al. (2000) and Rippe (2016), there can be suggested that participants in the current study focused their attention on the to-be-attended visual field in almost all time windows.

Finally, we examined whether individual differences in conscious perception could be predicted by analyzing the allocation of attention. The relationship between attention and conscious perception was examined by looking for correlations between the lateralization in the alpha bands above parieto-occipital networks and the performance index of the visuospatial attention task. We found significant correlations between performance and lateralization in the alpha-2 frequency band for different electrode pairs above the parieto-occipital networks. Longer SOAs were associated with lower alpha power in the alpha-2 frequency band above the parieto-occipital networks in certain time windows. This is in line with earlier research from Rippe (2016), they found correlations between the performance on a visuospatial attention task and lateralization above occipito-parietal areas. This suggests that conscious perception can be predicted on the basis of the allocation of attention.

In sum, significant correlations between SOAs and LPS were found for occipito-parietal areas in some time windows, which suggests that the allocation of attention can predict individual differences in conscious perception. However, this was only the case if the entire data set, including an outlier, was used for the analysis. In contrast to earlier research from Rippe (2016), the current study also examined the relationship between the allocation of attention and conscious perception when one outlier was removed from the dataset. After the removal of the outlier, no significant correlations were found between the performance on the visuospatial attention task and lateralization in the alpha bands. This suggests that the above mentioned relationship between the performance index of the visuospatial attention task and lateralization in the alpha bands was based on an outlier. The predictive value of the correlation coefficients does not truly describe the relationship between SOA en LPS, which suggests that these values were not reliable. In short, this means that there is no convincing evidence that individual differences in conscious perception can be predicted by differences in the allocation of attention. This puts a different perspective on the results of previous studies (e.g., Rippe, 2016), which can be seen as a strength of the current study. In the study of Rippe (2016) an outlier that deviated more than 2.5 standard deviation from the average SOA criterium was not taken out. In short, whether differences in the allocation can predict individual differences in conscious perception remains unclear.

As mentioned above, there is no convincing evidence that there is a relationship between attention and conscious perception after the removal of the outlier. However, even when the outlier was not removed from the dataset, attention does not seems to be the only factor that plays a role in conscious perception. Besides correlations, explained variances were determined. Explained variances can value from 0 to 1. A variance of 1 is equivalent to an explanatory rate of 100%. When this is the case, this means that the linear relationship between x and y explains 100% of the variance in y-values (Moore & McCabe, 2006). In the current study, the highest explained variance (r^2) for the relation between performance and lateralization in alpha bands was 37 percent above the PO4/PO3 electrode pair in time window 900-1000 ms. Other explained variances were around 25 percent. This suggests that the linear relationship between SOAs and the lateralization in alpha bands cannot explain the variance in lateralization for 100%. This means that, in the current study, other factors than attention also played a role in conscious perception. Furthermore, we found that an increase in time between the target and the mask (SOA) led to an increase in the visibility of the stimuli. As mentioned above, this suggests that the backward masking was successful in adapting the visual detectability of the stimuli. According to Dehaene et al. (2006) attention is necessary to consciously perceive stimuli. Attention can be necessary for conscious perception but not sufficient because stimuli were often not detected in the shortest SOAs even though participants focused their attention on it. This also suggests that there might be other factors than attention that played a role in conscious perception.

It appears that other factors than attention have played a role in the conscious perception of stimuli. This can be seen as a limitation of the study. When other factors than attention play a role in the performance on a visuospatial attention task, the performance index does not represent individual differences in conscious perception. An example of a factor which may have played a role in the performance on the visuospatial attention task is the time when participants were measured. A study of Matchock and Mordkoff (2009) examined the influence of the time-of-day on various aspects of attention. Results showed that participants were less well in the performance of tests that measures the executive functions of attention, such as inhibitory control, in the middle of the day (12.00 and 16.00 hours). In the current study, participants were measured in the morning (9.00 to 12.00) and in the afternoon (13.30 to 16.30). This suggests that differences in the performance on the visuospatial attention task can also be caused by the effect that time-of-day had on executive functions. For further research, it is important to gain insight in the factors besides attention that can play a role in the performance on a visuospatial attention task. These factors should be excluded so they cannot influence the execution of the visuospatial attention task, and therefore the index for conscious perception.

Results of the current study showed no convincing evidence that individual differences in conscious perception can be predicted by ipsi-contralateral differences in the alpha bands. However, earlier research showed a relation between attention and conscious perception. This suggests that further research into the role of attention on conscious perception is recommended. Earlier research showed that attention plays a role in perceptual sensitivity (d'). Research from Hawkins et al. (1990) showed that focusing attention on stimuli facilitated the sensory processing of stimuli during detection. This was associated with better and faster perception of attended stimuli. This suggests that visuospatial attention plays a role in the perceptual sensitivity which is important for the conscious perception of stimuli. Furthermore, research from Mathewson, Fabiani, Gratton, Beck & Lleras (2010) showed evidence for a mechanism which suggests that temporal attention is tuned to visual sensitivity. Temporal attention can cause peaks in visual sensitivity whereby the processing of visual stimuli can be optimized. By processing visual stimuli, visual stimuli can be consciously perceived. This suggests that attention plays a role in stimuli processing and thus in conscious perception. However, this doesn't reveal the predictive value of the allocation of attention on consciousness, which is interesting to investigate for further research. Examining if the allocation of attention has a predictive value on perceptual sensitivity can also reveal information about the conscious perception of stimuli.

In sum, the interest of the present study was the relationship between attention and conscious perception. To examine this relationship, performance on a visuospatial attention task with backward masking was combined with lateralized EEG measurements in alpha bands. Results showed no clear evidence that the allocation of visuospatial attention can predict individual differences in conscious perception. After the removal of outliers, results showed no relation between the allocation of attention and the performance on the visuospatial attention task. Without the removal of outliers, there were some relations found, but it is plausible that these relations were caused by an outlier. That no effect was found can be caused by other factors than attention that influenced the performance on the visuospatial attention task. For further research it is important to filter these factors out, so that individual differences in the performance index represent individual differences in conscious perception. Furthermore, earlier research showed that there is a link between perceptual sensitivity and attention and that perceptual sensitivity is important for the conscious perception of stimuli. Investigating the predictive value of attention on perceptual sensitivity can therefore also reveal information about individual differences in conscious perception.

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Appendix

Appendix A

Table 4.

Correlations between the SOAs and the alpha-1 frequency band (criterion value = 75%)

Electrode pair	Window (ms)	Min. r < max. r	Min. p <max. p
P8/P7	400-1400	-.244 < -.015	.274 < .946
PO4/PO3	400-1400	-.261 < .069	.240 < .999
PO8/PO7	400-1400	-.301 < -.072	.174 < .751
O2/O1	400-1400	-.333 < .016	.130 < .992

Appendix B

Table 5.

Correlations between the SOAs and the alpha-2 frequency band (criterion value = 75%)

Electrode pair	Window (ms)	Min. r < max. r	Min. p < max. p
P8/P7	400-1400	-.415 < -.097	.055 < .667
PO4/PO3	400-1400	-.305 < .047	.167 < .957
PO8/PO7	400-1400	-.379 < -.178	.082 < .429
O2/O1	400-1400	-.384 < .056	.077 < .937