Does a contralateral decrease in alpha power during the orienting phase predict visual awareness?

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Abstract

The purpose of this study was to examine the relation between visuospatial attention and visual awareness. Dehaene, Changeux, Naccache, Sackur and Sergent (2006) claimed that there is a preconscious state of processing in which a given not too salient stimulus can only be noticed when attention is deliberately directed to it. This entails that attention has to be first directed before conscious perception can occur. In this study, it was tested whether the conscious perception of a stimulus that is near the threshold of being either detected or undetected can be predicted by the direction of attention. A variation of the Posner task (1980) was used to relate the distribution of neural oscillations in the α-band as measured by electroencephalography (EEG) that are thought to be related to visuospatial attention to the reported visual awareness of the target stimulus. The results showed high correlations of reported awareness of the target stimulus and correct responses. A predictive effect of lateralized α-activity between 40 ms and 0 ms before target presentation as measured in occipital regions of the human brain on the reported awareness of the target stimulus was found. The fact that highly salient stimuli were not detected when there was no lateralization of α-activity supports Dehaene, Changeux, Naccache, Sackur and Sergent's (2006) statement that attention is necessary for consciousness to arise.

Introduction

The purpose of this study was to further assess the relationship between attention and conscious awareness. A large number of studies has been conducted to gain more insight in the mechanisms that lead to conscious perception and different theories have been formulated to explain observed phenomena. In 2006, Dehaene, Changeux, Naccache, Sackur and Sergent proposed a model of perception that not only includes consciousness and the lack of conscious perception, but an intermediate state that was called preconscious processing. They classified stimuli by their salience and suggested that stimuli of low salience would most likely lead to no form of conscious perception, while stimuli of high salience would likely be perceived. The preconscious processing was thought to occur when a stimulus is near the threshold of being perceived or not. In this case, it would depend on the direction of attention whether conscious perception would occur or not. If this claim holds true, it would be possible to predict whether a visual near threshold stimulus will be consciously perceived or not based on knowing whether attention was directed on it or not.

In the following, working definitions of visual awareness and visuospatial attention will be given. While visual awareness can only be reported, the direction of visuospatial attention can be measured without relying on subjective reports. A literature review on how to assess attention will be conducted and different concepts that have to be taken into account when designing an experiment that may provide new relevant information on the relation between visuospatial attention and visual awareness will be discussed. A research question will be formulated and the literature will be used to make predictions.

First, the concepts in question had to be defined:

Visual awareness and visuospatial attention

Visual awareness. Visual awareness can be described as the subjective sensation of seeing something (Block, 2005). Lamme (2004) and Dehaene, Changeux, Naccache, Sackur and Sergent (2006) argued that it is necessary to process a stimulus in form of sensory input to actively perceive it. As indicated earlier, a stimulus has to be highly salient in order to be consciously perceived. Dehaene, Changeux, Naccache, Sackur and Sergent (2006) explained this with neural activity in the human brain, stating that a less salient stimulus may fail to elicit sufficient neural activation. If any predictions were to be made, the focus of this study had to lie on the preconscious processing state. Therefore, visual awareness was viewed as the active, conscious perception of a visual near threshold stimulus. This definition includes the ability to report whether or not a stimulus was perceived, thus the assessment of visual awareness is limited to subjective reports.

In earlier studies, researchers often compared their measurement variables for cases in which the participants were aware of the target stimulus and cases in which they were not. To collect enough data for both conditions, near threshold stimuli had to be used. Common ways to make these stimuli difficult to detect were low salience and short presentation time. If the latter was employed, backward masking was used to prevent the occurrence of afterimages of the target stimulus by replacing it with another image: the masking stimulus (Breitmeyer, Hoar, Randall, & Conte, 1984). The amounts of time until the target stimulus was shown as well as the amount of time it was shown until it was replaced by the masking stimulus were variable. This is called stimulus onset asynchrony (SOA).

Visuospatial attention. Visuospatial attention is the ability to select and process relevant information from the whole of the sensory input (Posner & Petersen, 1990). Posner, Snyder and Davidson (1980) described attention as a limited cognitive resource that is either directed top-down (endogenous attention) or drawn bottom-up (exogenous attention). It was compared to a spotlight that could be fixed on a certain stimulus without having the eyes to follow this movement (covert attention). There is some controversy on the precise role of attention: It is sometimes described as inducing sensory gain (Mishra, Martínez, Schroeder, &

Hillyard, 2012), and thought to increase neuronal firing rates as illustrated in monkeys by Luck, Chelazzi, Hillyard, & Desimone (1997). Recently, rather than being a means of highlighting the focus, attention is regarded as reducing distraction by inhibiting the processing of distracting stimuli (Banerjee, Frey, Molhom, & Foxe, 2015; Kastner & Ungerleider, 2001; Klimesch, 2012). Endogenous attention can be motivated by inner goals and wishes (Jonides, 1981), be elicited by the prospect of rewards or punishment (Ryan & Deci, 2000), verbal instructions, or the estimation that an awaited stimulus might appear on a certain location (Chica & Lupiáñez, 2009). Exogenous attention on the other hand may simply be drawn by highly salient stimuli. Although attention includes the selection and processing of all sorts of sensory information, this study was only focused on visuospatial attention.

In an effort to investigate the effects of the direction of visuospatial attention, Posner (1980) devised an experiment in which his participants were seated in front of a computer screen at eye-level. They were asked to focus on a dot in the middle of the screen which was surrounded by one empty box on the left and another empty box on the right side. In each trial, there was a cue used to instruct the participants on which of the empty boxes they had to focus their covert attention on. Depending on the condition, the cued side would actually feature the stimulus, or not. Next, one of the boxes was for a short period of time replaced by the target stimulus. The participants had to report as quickly as possible. By directing the participants' attention to different locations inside of their field of view and examining the reaction times, Posner could assess that visuospatial attention can be directed top-down.

Knowing that visuospatial attention can be directed, it is important to define a measure for this concept: While visual awareness can still only be measured in form of self-report, it is widely accepted that there is a relation between neural activity that oscillates at a frequency of roughly 8 and 13 Hz and visuospatial attention. These neural oscillations or waves are defined as the α-band (Berger, 1929).

The direction of visuospatial attention and α-activity

Foxe, Simpson and Ahlfors (1998) conducted an experiment with a stimulus with visual and auditory compounds. They observed an increase in α-activity over the visual cortex when participants were expecting the auditory part to be presented. In a later experiment Worden, Foxe, Wang & Simpson (2000) used the Posner cueing paradigm (1980) to partially relate α-activity to the participants' field of view: Two possible target locations were chosen, one was located on the right side and one on the left. A stimulus that is visible only to the right eye can only be processed in the contralateral posterior cortex. This division in left and right provided the opportunity to relate changes of α-activity on the respective sides to the cued target location. The authors found that the power of α-oscillations in the posterior cortex was increased on the side to be focused on (ipsilateral) and decreased on the side that was not focused on (contralateral). Given that the processing of visual information happens contralaterally with sensory input of the left eye being processed in the right posterior cortex, it is believed that α-power is related to the selection of relevant and suppression of irrelevant information with higher α-power correlating with higher suppression (Kelly, Lalor, Reilly & Foxe, 2006; Thut, Nietzel, Brandt & Pascual-Leone, 2006; Wyart & Tallon-Bauldry, 2009). The variable of interest in such a variation of the Posner cueing tasks is not the α-power on the respective sides but the degree of distribution of this power to the respective sides (lateralization).

Lamme, Supèr, Landman, Roelfsema and Spekreijse (2000) researched whether visual awareness is linked to the activity of neurons in a particular area (localist approach) or to the frequency of the oscillations (globalist approach), independent of the location. Like Rees and Lavie (2001), who stated that visuospatial attention could be linked to α-activity in the posterior cortex while awareness was not sufficiently explained by it, they concluded the latter one to be true. Similar to how visuospatial attention can be directed or drawn, actively increased ipsilateral α-activity can be found before the expected presentation of a stimulus (Haegens, Handel & Jensen, 2011), while stimulus presentation was found to evoke similar increases (Babiloni, Vecchio, Bultrini, Romani & Rossini, 2005). This is further supported by Romei, Gross and Thut (2010), who researched the relation between visual awareness and lateralized α-activity. They stimulated visual areas by applying transcranial magnetic stimulation of different frequencies and found that the relation between α-power and perception of visual stimuli indeed works in both ways.

The findings of visual awareness being linked to not only the posterior cortex were consistent with the research conducted by Weisz et al. (2014) although others deemed their conclusions controversial: Weisz et al. (2014) examined prestimulus α-activity and noticed an additional increase in activity in the frontoparietal network. They concluded that a combination of processes in different areas is necessary in order to perceive stimuli consciously. Although this is possible, van Rullen (2011) warned to draw these kinds of conclusions: In cases where experimental conditions are contingent on subjective responses, he claimed, there might be a bias that may favor one of the possible responses. In this case, this bias would lead to activity that is solely related to favoring one response being interpreted as a neural correlate of consciousness. He refers to the research of Busch et al. (2009) in which the authors were able to predict responses in a target detection task based on frontal α-activity. In conclusion, there seem to be additional instances of prestimulus lateralized α-activity that may not be related to visuospatial attention and visual awareness, but seem to correlate with giving responses on attention orienting tasks. Van Rullen (2011) suggested solving this problem by using two or more different target stimuli and asking the participants to not only report detection but also to differentiate between them. A response bias would in this case not lead to consistently correct or incorrect responses that correlate with a certain aspect of the measured activity, as there is no link between a certain response and the classification of correct or incorrect.

The implication of Dehaene, Changeux, Naccache, Sackur and Sergent's (2006) claim that there is a preconscious processing that only leads to conscious perception of a stimulus when attention is directed on it is that attention may be used to predict conscious perception. Based on the literature, it was concluded that conscious perception can only be measured via self report, but the direction of attention is suspected to be related to α-activity in the posterior regions of human brain. The next step was to design an experiment that can be used to relate visuospatial attention and visual awareness to ultimately test Dehaene, Changeux, Naccache, Sackur and Sergent's (2006) claim. Another literature review was conducted to put together the concepts that had to be addressed to achieve this goal.

Methodological aspects

A variation of the Posner task (1980) was used to further investigate the relation between visuospatial attention and visual awareness. In constructing the experiment, a number of design choices had to be made: At first, a measure for the lateralization of α-activity had to be found. Then, the Posner task (1980) had to be modified. The concepts that had to be addressed were to choose the degree to which the cueing stimulus predicted the correct target location, the duration of the target presentation, and the manner in which participants were to give responses.

As stated earlier, the variable of interest in a variation of the Posner task (1980) that is used to investigate the direction of visuospatial attention is the lateralization of α-activity as opposed to its simple occurrence on the respective sides. Van der Lubbe and Utzerath (2013) used a double subtraction method that results in a measure for lateralization that relates the power that is measured on both sides to the difference in power on the respective sides. This measure ranges from -1 to 1 and is independent of the side the cue is presented on.

In their experiment, Posner, Nissen and Ogden (1978) varied the cue validity, which is the chance that the cue correctly predicted the location of the target stimulus. They concluded that the reaction times were affected by the expected target location. Haegens, Handel and Jensen (2011) further investigated this effect and found that the degree of lateralization of the α-power depends on the cue validity with higher cue validity eliciting higher degrees of lateralization. When aiming to investigate a possible relation between lateralized α-power and visual awareness, cue validity should be kept at 100% to assure the most meaningful outcomes.

When trying to test Dehaene, Changeux, Naccache, Sackur and Sergent's (2006) claim, it is important that the target stimuli are hard to detect. To achieve this, a short presentation time, after which the possible target locations are masked, can be employed. Hanslmayr et al. (2005) stated that there are individual differences in target detection rates for equal presentation times. To take these differences into account and to try to produce roughly equal numbers of aware and unaware responses in an experiment, it might be appropriate to use an adaptive set of SOAs. For an experiment with two target stimuli, there is a 50% chance to guess the right answer. If the participants are aware of the target stimulus, they are expected to report correct answers. If the participants are not aware of the target stimulus, they are expected to guess the right answer in half of the cases. This would have them giving correct responses in roughly 75% of the time. If the participants score lower or higher, the SOAs could be adapted to keep the number of trials with correct responses roughly even to the number of trials with incorrect responses.

Finally, the manner in which participants give responses on visual detection or discrimination tasks had to be discussed, as it may introduce bias to the analysis: The intervals in which participants can report orientation or awareness of the target are fixed in a large number of studies (Thut, Nietzel, Brandt, & Pascual-Leone, 2006; Mathewson, Gratton, Fabiani, Beck &

Ro, 2009; Wyart & Tallon-Bauldry, 2009; Weisz et al., 2014). Exclusion of trials in which the participants needed more time to choose the response to be given could result in overlooking systematic effects. A forced response setting in which the next trial will only begin if the participant has given a response would give the participants more time to choose which response to give and therefore increase the accuracy.

The number of response buttons in the research of neural oscillations is an issue that has to be accounted for: Having only one response button that is pressed with either the left or the right hand can also increase the probability of introducing bias in the EEG measurement as the participant's response may in turn be influenced by certain decision making processes that are not related to the task at hand (van Rullen, 2011). Additionally, van der Lubbe and Utzerath (2013) suspected that giving responses with one hand might bring out lateralized motor and/or attentional activity related to this hand during the cue-target interval. They proposed to simply use tasks that require responses from both hands to eliminate these effects.

When assessing visual awareness in a target discrimination task, it is necessary that the participants report whether they were aware of seeing the target stimulus that was presented. Still, they would have to report whether they had seen target 1 or target 2, because, otherwise, there would not be any way to control the accuracy of their responses. Thus, there were four different answers. Babiloni, Vecchio, Bultrini, Romani and Rossini (2005) chose to approach this matter by having the participant give a motor response on target location and then saying aloud 'seen' or 'not seen' depending on whether they were aware of the target stimulus. Szumska, van der Lubbe, Grzeczkowski and Herzog (2016) investigated whether the channel on which a response was given in a binary choice task influences of that response. They concluded that there were differences in reaction time, but none in accuracy. A possible issue however is the order of responses that are given: If participants have to first decide what they have seen and then whether they were aware of it, it is possible that the first decision will introduce bias to the second one. This problem could be solved by using four possible responses: Target 1-aware, target 2-aware, target 1-unaware, and target 2-unaware. By asking the participant to give both answers simultaneously, no decision should influence the other. This method might introduce some difficulty to giving the desired answer, but in combination with a forced response setting, no effect of this kind was expected. Still, the reports of awareness could be related to the correctness of the discrimination between the two targets to examine this possibility: a positive correlation of aware and correct responses would indicate the participants' capability of correctly reporting target and awareness.

Research question

The purpose of this study is to test Dehaene, Changeux, Naccache, Sackur and Sergent's (2006) claim that there is a preconscious processing state in which awareness of a stimulus can only be achieved by directing attention to it. The relation between visuospatial attention and visual awareness was investigated; if the claim holds true, it might be possible to predict the reported awareness of a stimulus based on the direction of the attention. The research question was therefore:

'Can visual awareness of a near threshold stimulus be predicted by the direction of visual attention?'

An experiment was designed to answer this question. Based on the literature, it was a variation of the Posner task with two different targets, two possible target locations and a cue that validly predicts the target location on each trial. The target locations were chosen to be presented at the same height, one to the right and one to the left of the cueing stimulus. No distracter stimulus was used because the moment of target presentation was irrelevant for the analysis. Backward masking was used to hide near threshold stimuli. To account for individual differences in detection rates and assure comparable numbers of trials for each condition, SOAs were adapted to each participant's performance. A forced-response setting was employed to avoid bias; all responses were given by pressing buttons that were equally distributed to the right and the left hands. If the direction of visuospatial attention would elicit a lateralization of α-activity, it would be discernible whether the location to be attended to would be related to the area above which the α-activity was measured.

The literature review suggested that visuospatial attention can be directed at will, and that visual awareness of a target stimulus can be reported reliably. If these assumptions are correct, then the proposed experiment could be used to test whether visual awareness can be predicted by prestimulus direction of visuospatial attention as measured in form of lateralization of α-power. The hypothesis to be tested is:

'A decrease in contralateral α-activiy over the posterior regions of the human brain increases the reported awareness of a near threshold stimulus in a binary choice target detection task.'

Method

Participants

The 26 participants' visual acuity was tested with the Freiburg Visual Acuity Test (Bach, 1996), and possible color blindness was assessed with Ishihara's test (1976). To pass for visual acuity with normal or corrected to normal sight, a decimal acuity (dec. VA) of 1.0 had to be reached. To pass as non- colorblind, the participants had to complete the test without errors. The target detection rates for each participant were calculated. As described earlier, participants were expected to score a proportion of roughly 75% correct answers in total. Out of the 26 participants, four were used to conduct a pilot study, six were excluded from the testing for scoring low on visual acuity, six were excluded from the analysis for scoring less than 75% on target detection, one due to errors in the measurement, and finally, one participant complained about drowsiness which lead to an early termination of the experiment. This left a total of eight participants for analysis.

Six out of the remaining eight participants were female, the average age was 20.5 years (s=2.45; range: 18– 25). All participants reported to be undergraduate students at the University of Twente, three of them were enrolled in communication science, while the other five studied psychology. Three participants were wearing glasses, one wore contact lenses. Annett's Handedness Inventory (1970) was used to determine that all of them were right handed.

The study was approved by the ethics committee of the Faculty for Behavioral, Management and Social Sciences at University of Twente. All participants signed a form to give informed consent. For students of the University of Twente, participating was compensated with study credits; the remaining participants took part on a voluntary basis.

Task and Stimuli

A variation of the Posner task (1980) was chosen. The sequence of events on a trial is depicted in Figure 1 and further described in the following:

A black screen with one white dot (r=0.164°) in the center, and two rings (6.03° to each side with r=0.614°) as possible locations for the target stimulus was presented. This screen was used for fixation periods. To mark the beginning of a trial, a bigger white dot (r=0.246°) was shortly presented at the center location. After a fixation period of 600ms, the white dot was replaced with a half blue and half yellow rhombus. By pointing to either the left or the right, the yellow half cued the target location for each trial. After another fixation period, the target stimulus was presented. This target stimulus consisted of the ring on the indicated side being filled with either horizontal stripes or with vertical ones, while the other side featured an empty ring. After a variable amount of time (SOA), both locations were filled with masking stimuli: A ring that is filled with crossing diagonal stripes. The following fixation period had an indefinite duration; it could only be ended by the participants giving a response. At the end of each trial, a big dot in the center location, green for correctly and red for incorrectly reported targets, was used to provide feedback. The measurement variables in this target discrimination task were the reported orientation of the stripes of the target stimulus, and the reported awareness of the target stimulus.

The testing consisted of one practice session with 36 trials and eight blocks with 112 trials each, thus 932 trials in total. Variable values in the uneven blocks were target and target location, orientation of the stripes and SOA. For even blocks, the moment of target presentation was roughly 45 ms (half the length of an average α wave) earlier for half of the trials.

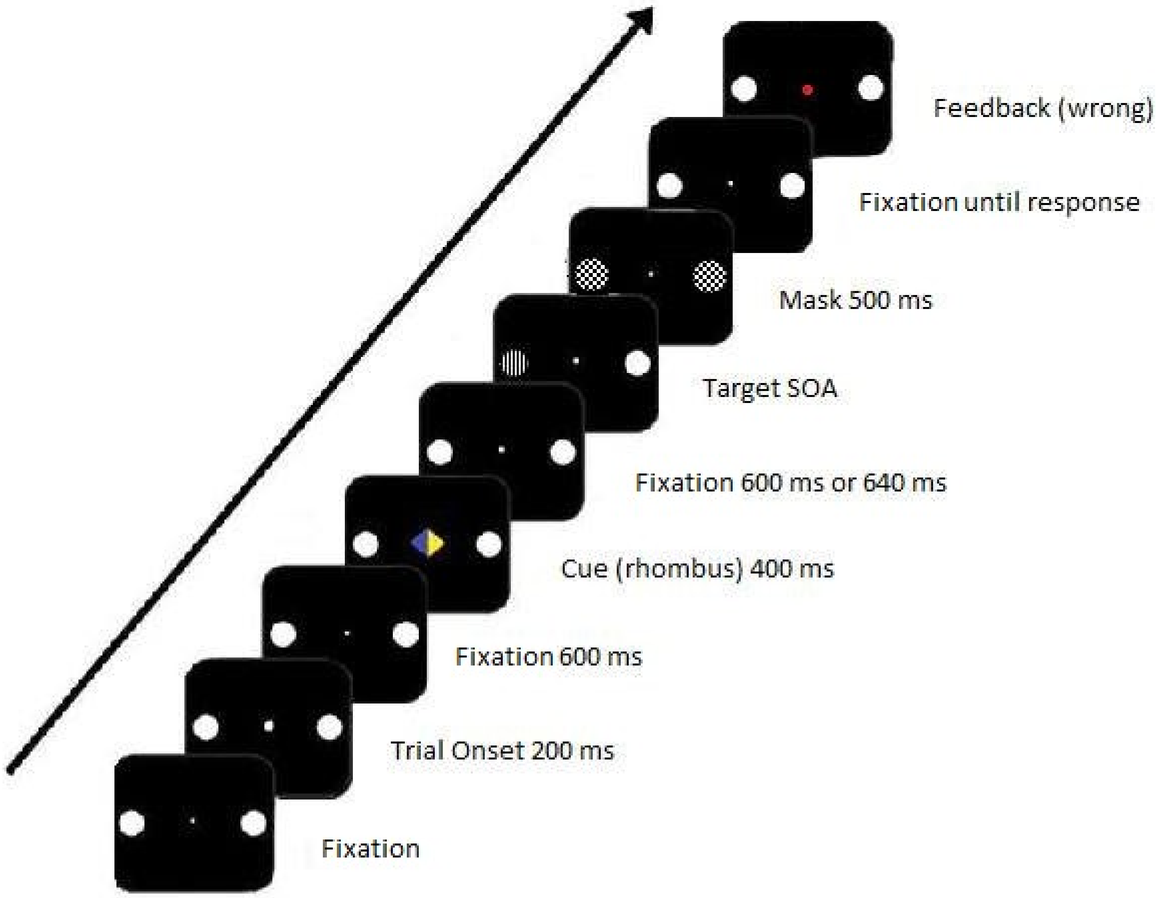

Figure 1. Sequence of events on a trial. The beginning of each trial is indicated with a big white dot. After a fixation period of 600ms, a blue and yellow rhombus cued on which side the target stimulus was going to appear for 400ms. Following another fixation period of either 600ms or 640 ms, the target stimulus (a circle filled with vertical stripes) was shown for a variable amount of time and subsequently masked for 500ms. In order for the next trial to begin, a response had to be given.

During pilot testing, three of four participants reported that the target stimulus was masked too quickly. When asked about how they felt about the test, they reported to be frustrated and that they had to guess in most trials. The number of different SOAs was therefore increased to provide an easier start in the practice session. The different SOAs were 7 ms, 21 ms, 35 ms, 49 ms, 63 ms, 76 ms, 90 ms, 104 ms, 118 ms, 132 ms, 146 ms, 160 ms, 174ms, 188 ms, 201 ms, 215 ms, 229 ms, 243 ms, 257 ms, 270 ms, 285 ms, 299 ms, 313 ms, 326 ms, 340 ms, and

354 ms. These durations were chosen with respect to the frame rate of the used screen of 144 Hz and are therefore of 1, 3, 5, 7, …, 51 frames.

The test was programmed to assess the number of correct responses in predefined sets of trials and to adapt the used SOAs to the participant's performance. This was achieved by sorting the SOAs into 20 different sets. For the practice session of 36 trials, each of the different sets contained 12 trials (3 SOAs x 2 target locations x 2 target stimuli). Starting at set number nine, which contains trials with the SOAs 188 ms, 201 ms, and 215 ms, the set of used SOAs was evaluated every 12 trials. If the participants gave less than seven correct answers, set number eight would have provided the next 12 trials (SOAs: 201 ms, 215 ms, 229 ms), if seven to nine correct answers were given, the set would not have changed, and if more than nine correct answers were given, the participant would have moved up to set number ten (SOAs: 174 ms, 188 ms, 201 ms). The four chances to change the group provided an opportunity to start the test at an appropriate speed.

After completion of the practice session, eight blocks with 112 trials each were presented. The chosen set of SOAs was kept adaptive by dividing each block into four sets of 28 trials each. After each set of trials, the set of SOAs to be used for the next 28 trials was assessed in a manner that is similar to the practice session. The sets for the actual tests contained seven different SOAs and required 21 correct responses not move down to a set of longer SOAs, and 24 ones to move up. The SOAs in each set are listed in Appendix A.

Procedure

After the participants passed the tests for visual acuity, ability to see color, and dexterity, the computer assisted testing begun. The participants were asked to sit down and face a computer screen, which featured the following instructions: The participants should place their left index and middle fingers on the "F" and "D" keys and their right index and middle fingers on the "J" and "K" keys of a QWERTY keyboard. It was explained that two hard to detect stimuli, namely rings that were filled with either horizontal or vertical stripes, would be presented and then quickly be covered by a mask. The participants were instructed to report the orientation of the stripes that filled the ring at the target location and also whether they were sure to have seen the stimulus or not. The orientation of the stripes was reported by clicking with the left hand for horizontal stripes and the right hand for vertical ones. When reporting to be aware of the target stimulus, the participants should press the keys their index fingers are placed on, when in doubt or even guessing, they were told to use their middle fingers. It was explained that the target stimuli could appear on one of two possible target locations and that the yellow side if the cue validly predicted the target location for each trial. The participants were instructed to fixate at the white dot in the middle of the screen, while shifting their focus of attention to the cued target location. It was noted that reaction time would not be measured in this experiment and that the participants should focus on reporting as accurately as possible. After the participants had read these instructions, the experimenter asked if there were any questions regarding the experiment.

Prior to starting the test, each participant was asked to first focus on the dot in the middle of the screen and then, while not moving their head, to shift their view to the left and right edges of the screen several times. These eye movements were later used as a reference to exclude trials in which the participants shifted their view and looked directly at the cued target location.

A second opportunity to ask questions was given after completion of the practice session. There were breaks with one minute duration after each block of 112 trials. After finishing all eight blocks, a short debriefing was conducted and the experiment ended.

Apparatus and EEG Recordings

The test was presented on a 25 inch screen with a refresh rate of 144 Hz and the test was programmed and presented using Presentation software (Neurobehavioral Systems, Inc., 2012). The distance between the participants' eyes and the screen was set to 85 cm and the height of the chair was adjusted so that the participants' eyes were 45 cm above the desk. Brain Products' ActiCHamp was used to amplify the EEG and EOG signals, which were in turn recorded with Brain Vision Recorder (Brain Products GmbH) with a sample rate of 1,000 Hz. Presentation software sent task related events and responses were sent as markers.

A total of 33 active and 5 passive Ag/AgCl electrodes were used in the measurement. The active electrodes were placed in the Braincap (Brain Products GmbH), an elastic cap with slots, at the following positions: AFz, AF7, F7, F3, Fz, FC5, FC1, T7, C3, Cz, CP1, P7, P3, Pz, PO7, PO3, POz, O1, Oz, O2, PO8, PO4, P4, P8, CP2, C4, T8, FC2, FC6, F4, F8, AF8, and FPz for the ground. The positions of the active electrodes can be seen in figure 2. The passive electrodes were used to measure the EOG. Electrodes for the horizontal EOG were placed at the outer canthi of both eyes, electrodes for the vertical EOG were placed above and below the left eye. Additionally a ground electrode for the EOG was placed on the forehead. Electrically conducting gel was used to lower the resistance below 10 kΩ for each electrode.

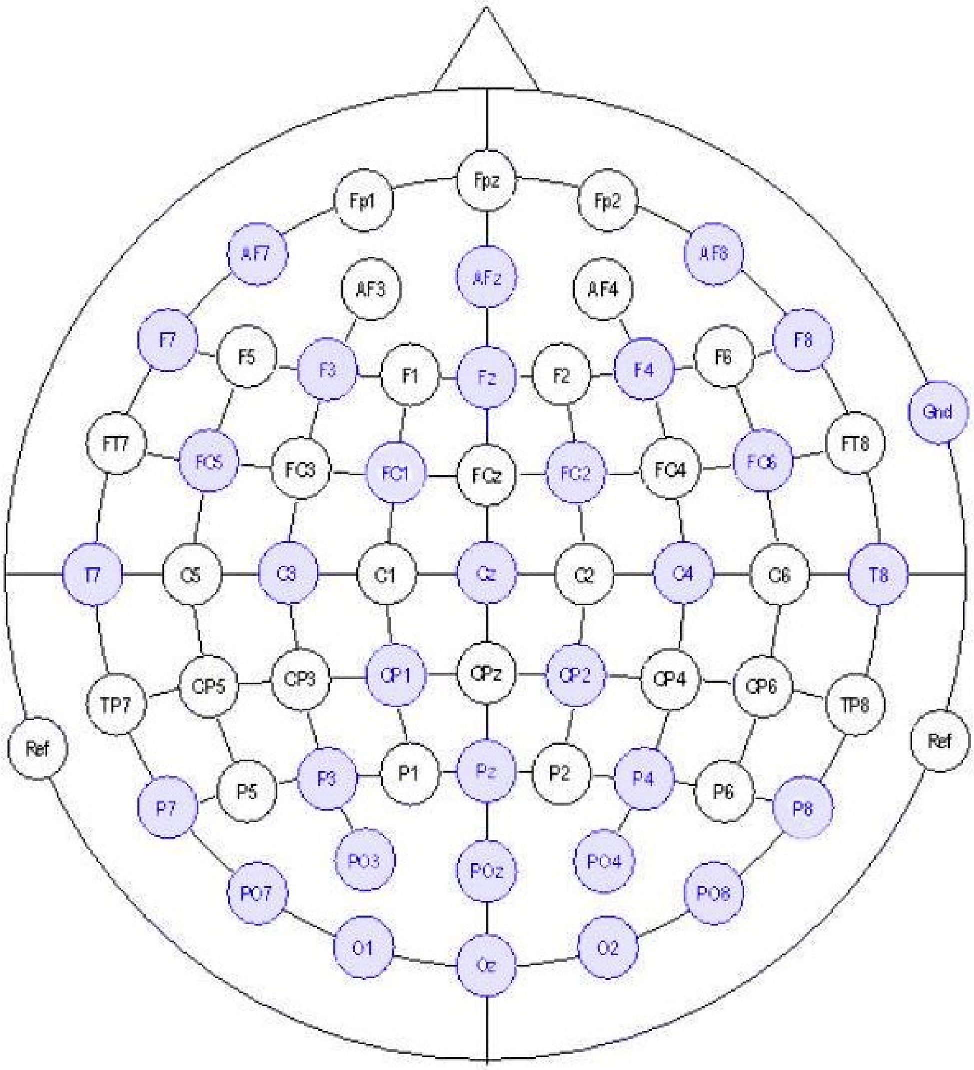

Figure 2. Positions of used EEG-electrodes

Data processing and analysis

Behavioral data. The behavioral data was processed by first using the given responses to determine whether the target stimulus was correctly identified and whether the participants reported being aware of it on single trial basis. This information was used to calculate the percentages of correct and aware, incorrect and aware, correct and unaware, and incorrect and unaware responses per SOA per participant.

Due to the large range of SOAs per participant the difficulty of identifying the target varied significantly across the trials. The ranges of SOAs and the number of trials per SOA differed between participants, so it was not possible to compare trials that were just sorted by SOA.

The trials of each participant were, therefore, split into trials with short SOAs, and trials with long SOAs. The cut-off value was the median encountered SOA which is the SOA with 50% of the trials having a shorter and 50% of the trials having a longer SOA.

EEG-measurement. The raw EEG data were processed using Brain Vision Analyzer (Brain Products GmbH). The data was segmented, with each segment centered at the marker for the mask and ranging from -2080ms to 2800ms, to divide the datasets into individual trials. To remove noise a Zero phase shift IIR Butterworth Filter with a high cut-off of 32 Hz and a low cut-off of 0.53 Hz was used to decrease the interference of higher and very low frequencies. For each participant the horizontal (h) EOG data that was obtained prior to starting the practice session was used to determine the trials that had to be excluded due to eye-movement. It was expected that the potentials in the hEOG would correlate linearly with how far the participants shifted their views to the sides. The difference in angle between the fixation point and the left and right edges of the screen was roughly three times the difference between fixation point and possible target locations. Therefore, a third of the potential while fixating on the edges of the screen was set as cut-off value for eye-movement. Markers were set on each trial that showed too much horizontal eye movement from the beginning of each trial to the presentation of the mask and were in turn used to exclude these trials from the analysis. After artifact rejection, ocular correction for blinking with Gratton and Coles' method and baseline correction, several segmentations were used to divide the data with respect to SOA, reported sureness and actual correctness of the answer. The SOAs were divided into the categories slow and fast. The cut-off value for this was the median encountered SOA per participant. From here on out, a last segmentation was used to divide the trials that had the target stimulus on left side from the ones that showed the target stimulus on the right side. A continuous wavelet transformation with seven steps from 4 Hz to 20 Hz and a wavelet extraction of the fifth layer were applied to extract the power of the upper α-band of around 11.7 Hz. For each condition, the average power was calculated from the segments. A double subtraction was used to calculate a measure for the lateralization α-power: If the target is presented on the right side, the change in α-activity in the parietal and occipital regions is expected contralateral, i.e. at the left side. The difference of the power on the left side and the right side was divided by their sum to relate the allocation of the absolute power that is measured in the symmetrical pairs of electrodes to total power measured with each pair. The following formula shows this process for the electrodes PO7 and PO8:

$$PO7/8(\omega_p)_t = (\left(left\ cues \frac{\omega_p(PO7) - \omega_p(PO8)}{\omega_p(PO7) + \omega_p(PO8)}\right) + \left(right\ cues \frac{\omega_p(PO8) - \omega_p(PO7)}{\omega_p(PO8) + \omega_p(PO7)}\right)) \times \frac{1}{2}$$

If calculated like this, positive values indicate an increase in lateralized α-power ipsilateral to the side that was to be attended, and a decrease in contralateral α-power. A value of zero would suggest that the activity did not depend on the to be attended side. The average degree of lateralization was calculated for 40ms intervals from the moment the cue showed on which side target would appear until the target is masked and then exported to IBM SPSS Statistics 23 for further analysis.

Statistical analysis. The first question to be addressed is whether there is a positive correlation between the reports of awareness of the target stimulus and the correct responses. A Pearson correlation was calculated; a positive correlation would indicate that visual awareness was reported reliably.

Further, it had to be assessed whether there were prestimulus lateralizations of α-power in the posterior cortex of the brain. A topographical view of the degree of lateralization of α-power during the orienting phase was plotted, so that intervals with lateralized α-power could be read out of it. The data was then examined by first dividing the trials by reported awareness and length of the SOA and then comparing the degree of lateralization of α-power at PO7/8 with 0 by using t-tests. Based on the reviewed literature, a contralateral decrease in α-power was expected. Therefore, one-tailed t-tests were conducted.

The chance of committing a Type-1 error increases with the number of tests that are conducted. Therefore it was possible that the use of the standard significance level of α=0.05 would not be possible. To deal with this family wise error problem, a critical p-value was calculated and used for two consecutive time windows at a time. Van der Lubbe, Bundt and Abrahamse (2014) suggested calculating p_{crit} as dependent on the chosen significance level, the number of time windows and the number of used electrodes:

$$p_{crit} = \sqrt[2]{\alpha / (n_{intervals} - 1) \times n_{electrodes}}$$

Finally the hypothesis that a contralateral decrease of prestimulus lateralizations of α-power in the posterior cortex of the brain predicts awareness of the target stimulus was tested. For each of the intervals that showed significant degrees of lateralization of α-activity, an ANOVA analysis with the average of the degree of lateralization of α-activity as dependent variable and length of SOA and reported awareness as predicting factors was conducted. Any significant effect of awareness on the lateralized α-activity will be interpreted as supporting the alternative hypothesis, if higher awareness leads to a higher degree of lateralization.

Results

Behavioral data

For each participant, the median SOA was determined and used as cut-off value to divide trials per participant into trials with long SOAs and trials with short SOAs. Table 1 depicts the range and median of encountered SOAs per participant.

Table 1
Shortest, longest and median SOA per participant in ms

Participant	Shortest SOA	Longest SOA	Median SOA
1	90	215	146
2	35	201	132
3	49	215	132
4	76	215	146
5	21	104	63
6	7	215	90
7	21	160	76
8	76	215	146

Plots of reported awareness of the target stimulus and correct answers for trials with long and short SOAs in Figure 3 show a decrease in reported awareness and correctness in trials with short SOAs when compared to trials with long SOAs. The reports of awareness and the correctness of the responses are correlated with $r=0.86$ ($p<0.0005$).

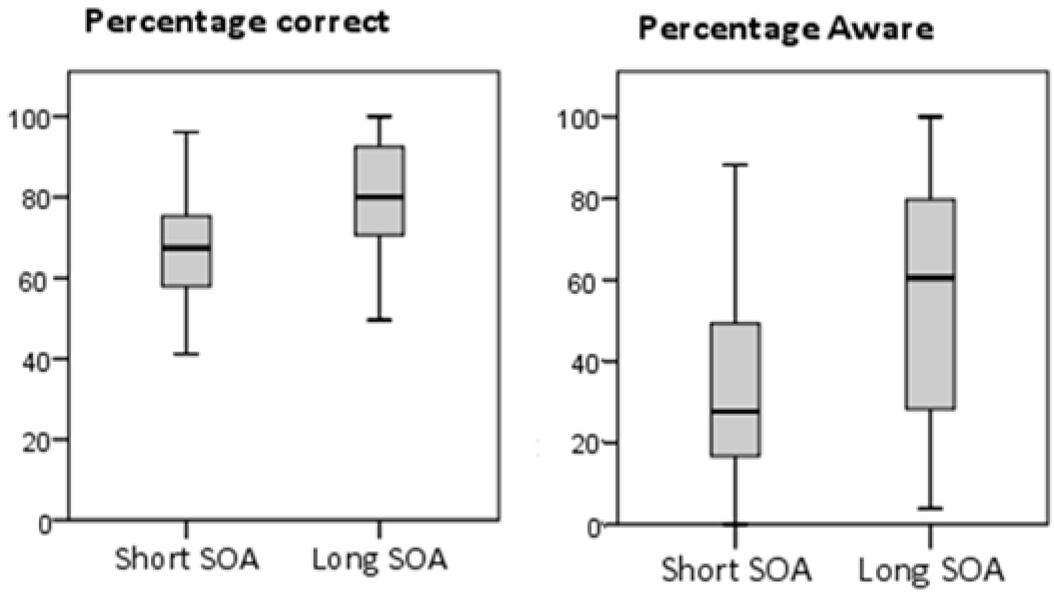

Figure 3. Box plots show the percentage of correct responses and reported awareness for short and long SOAs.

EEG-measurement

Figure 4 shows the course of the average lateralization of α-power from cue presentation to stimulus presentation in all trials. The degree α-lateralization just prior to the target presentation was reported to be related to the given responses (van der Lubbe & Utzerath, 2013). Figure 4 depicts a continuous lateralization in trials with reported awareness of the target stimulus in the interval between 680 ms and 960 ms, and a similar lateralization that ended at 920 ms in trials in which the participants reported to be unaware of the target stimulus. Therefore, the interval between 680 ms and 960 ms was examined in the further analysis.

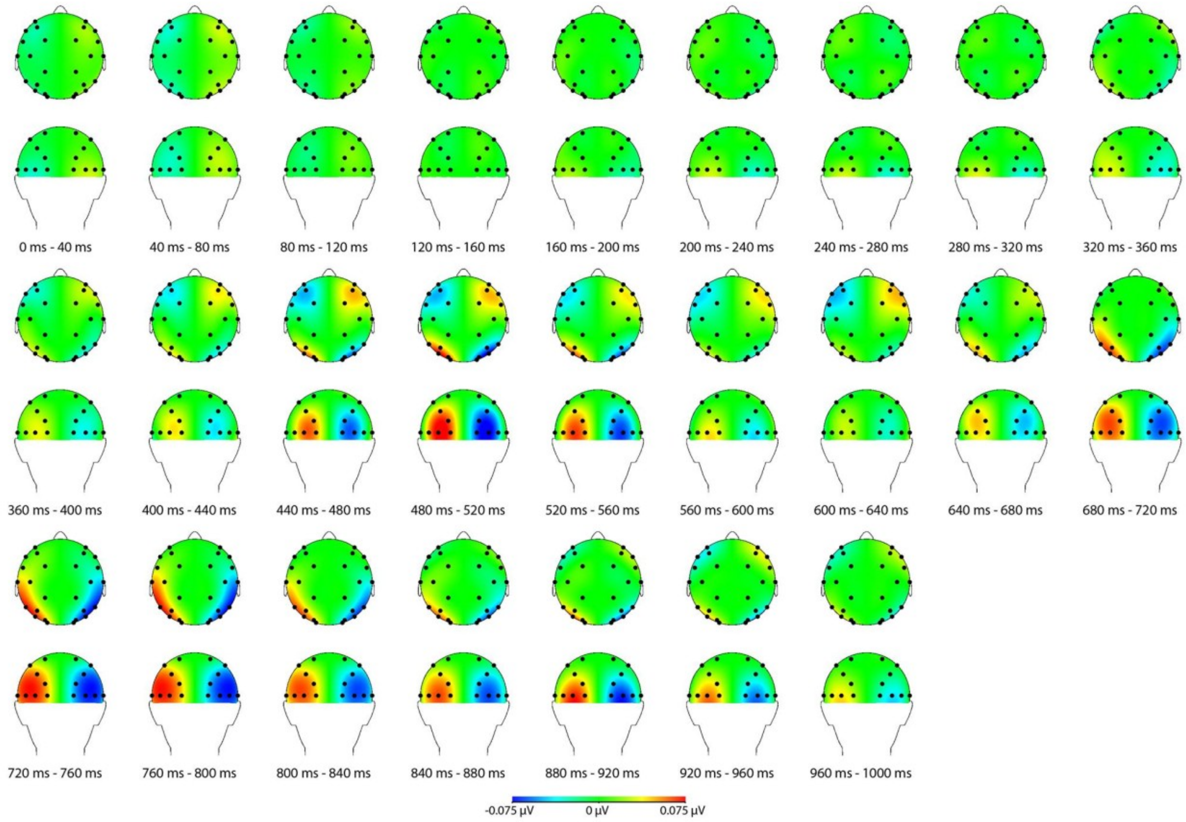

Figure 4. Topographical views of average lateralization of α-power in the orienting interval. Half of the values were mirrored, so that all values treat the left side as the one to be attended to. The left hemisphere shows ipsi- vs. contralateral power, while the right hemisphere depicts contra- vs. ipsilateral α-power. Positivity at the left hemisphere indicates higher α-power over the ipsilateral sites than above contralateral sites.

To further investigate these instances of lateralization, the data was divided by length of the target stimuli and reported awareness. As depicted in figure 5, it appears that the lateralization of α-power took place at different moments in time in the different conditions: For short SOAs with reported awareness, lateralized α-power that is centered at P7/8 and PO7/8 can be observed between 680 ms and 840 ms after cue onset. Additionally, there is a later instance of lateralization in O1/2 and PO7/8 between 880 ms and 960 ms after cue onset. In the condition with short SOAs without awareness, a similar lateralization around P7/8 and PO7/8 occurred between 720 ms and 880 ms after cue onset, however no lateralization around O1/2 and PO7/8 could be found. In trials with long SOAs and reported awareness, lateralization of α-power began at 840 ms and did not end until target presentation, while no such lateralization could be seen in trials with long SOAs without awareness of the target stimulus.

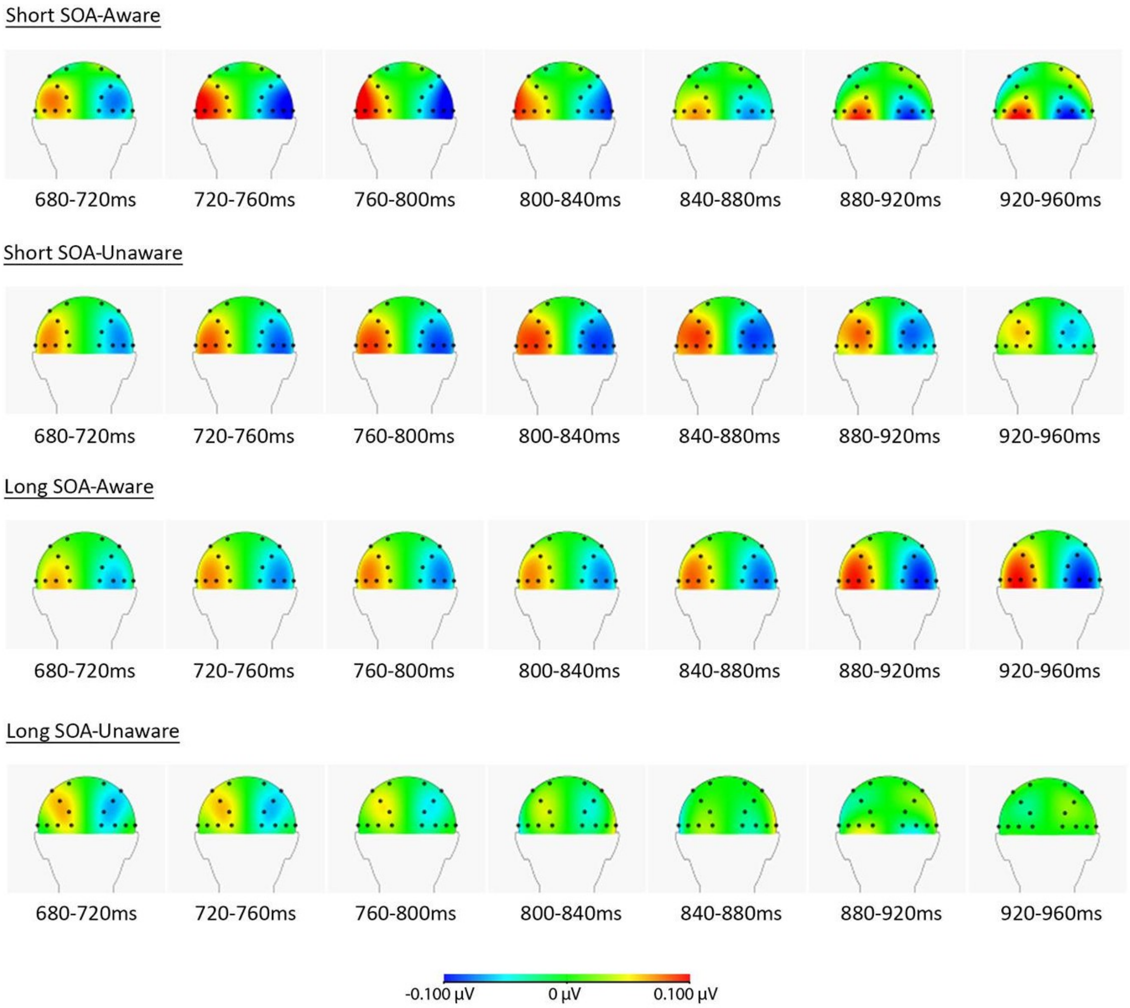

Figure 5. Topographical view of lateralized α-power per condition between 680 ms and 960 ms after cue presentation. For further information see Figure 4.

These observed differences in α-lateralization were further examined by conducting one-tailed t-tests. In both the short SOA and aware, and the long SOA and aware conditions, lateralized α-power could be observed at PO7/8 and O1/2. While several other instances with lateralization of α-power were measured at different electrodes in the different conditions, this lateralized α-power could be seen only above PO7/8 and O1/2 between 880 ms and 960 ms in the short SOA and aware condition. As lateralization of α-power appeared to be constant on only these locations in the conditions with reported awareness, only PO7/8 and O1/2 were taken into consideration in the further analysis.

The critical p-value was calculated as

$$p_{crit} = \sqrt[2]{0.05/(7-1) \times 2} = 0.06455.$$

As an effect of choosing only one pair of electrodes with seven time intervals, p_{crit} exceeded the significance level α=0.05. Thus, the latter was used to determine statistical significance.

Table 2

Significance of observed lateralization of α-power at PO7/8 and O1/2

	PO7/8						
	680ms-720ms	720ms-760ms	760ms-800ms	800ms-840ms	840ms-880ms	880ms-920ms	920ms-960ms
Short SOA – Aware	0.11	0.04*	0.05*	0.25	0.26	0.13	0.01*
Short SOA – Unaware	0.00**	0.01**	0.03*	0.04*	0.02*	0.05*	0.25
Long SOA - Aware	0.02*	0.06	0.04*	0.03*	0.04*	0.02*	0.01**
Long SOA - Unaware	0.27	0.33	0.56	0.59	0.38	0.18	0.97

	O1/2						
	680ms-720ms	720ms-760ms	760ms-800ms	800ms-840ms	840ms-880ms	880ms-920ms	920ms-960ms
Short SOA – Aware	0.05	0.04*	0.02*	0.05*	0.02*	0.01**	0.01*
Short SOA – Unaware	0.34	0.14	0.04*	0.01**	0.00**	0.03*	0.11
Long SOA - Aware	0.02*	0.08	0.09	0.10	0.08	0.03*	0.01*
Long SOA - Unaware	0.14	0.18	0.22	0.28	0.44	0.32	0.95

P-Values were calculated with df=7 degrees of freedom. Lateralization in the α-band is significant for p≤0.05. *p<.05. **p<.01.

The outcomes of the t-tests can be seen in table 2. The results support systematic differences from zero in different intervals for the conditions. For short SOA and reportedly aware trials, lateralization of α-power was significant between 720 ms and 800 ms at PO7/8 and between 720 ms and 960 ms at O1/2. The degree of lateralization of α-power over PO7/8 may have also been different from zero between 920 ms and 960 ms. It is not viewed as significant because of the condition that lateralization would only be interpreted as significant if the p-value was smaller than the significance level for at least two consecutive intervals. For short SOA and unaware trials, lateralized α-power was observed over PO7/8 from 680ms to 920ms and above O1/2 between 760 ms and 920 ms. In trials with long SOA and reported awareness, lateralization of α-power was significant at PO7/8 between 760 ms and 920 ms and from 880 ms to 960 ms at O1/2. No significant lateralization of α-power could be observed in the long SOA and unaware condition.

The predicting effects of reported awareness, length of SOA and an interaction of both on the degree of lateralization have been tested via ANOVA analysis. An effect of awareness of the target stimulus on observed lateralization could be found at O1/2 between 920 ms and 960 ms after cue presentation ($F(1,28)=4.72$, $p=0.04$). Furthermore, a near significant effect of awareness of the target stimulus at PO7/8 between 920 ms and 960 ms after cue presentation ($F(1,28)=3.13$, $p=0.09$) was observed. These outcomes support the theory that a contralateral prestimulus decrease in α-activity predicts higher target detection or correct discrimination rates.

Discussion

The purpose of this study was to examine whether visual awareness of a stimulus in a target discrimination task can be predicted by a decrease in contralateral α-power in the posterior regions of the brain during the orienting phase. A variation of the Posner task (1980) with two near threshold stimuli was chosen to assess the relation between prestimulus lateralization of α-power, which was expected to correlate with the direction of visuospatial attention, and the reported visual awareness of the target stimulus. To try and create roughly even numbers of trials with and without reported awareness of the target stimulus, the test was programmed to adapt the duration between target presentation and presentation of the masking stimulus to the participants performance. Furthermore, in order to avoid bias by systematically disregarding slower responses, a forced response setting was employed. When responding, both hands had to be used to give one of four possible responses indicating which target stimulus had been presented and whether it had been perceived consciously or not.

Instances of lateralized α-activity that was centered at the electrode pairs PO7/8 and O1/2 were measured in the 280 ms prior to target presentation for trials with reported awareness of the target stimulus. In trials without awareness of the target stimulus, α-activity was measured in trials with short SOAs, while no lateralized activity could be observed in trials with long SOAs. A predictive effect of lateralization of α-activity above O1/2 on reported awareness could be found for the 40 ms interval prior to target presentation. Although expected, no significant effect was found for lateralized α-activity above PO7/8. Based on the graphical representation of the distribution of α-activity in figure 5 it can be argued that there is lateralized α-activity in the last 80 ms before target presentation in the conditions with reported awareness. This lateralized activity seems to predict reported awareness as it declines in the condition with short SOAs without awareness of the target stimulus between 80 ms and 40 ms before target presentation and is absent in the last interval before target presentation in both conditions without reported awareness of the target stimulus. This was interpreted as a sign of the statistical analysis lacking power due to the small sample size. Note that the correlations that were found by conducting statistical analysis were interpreted as predictive value of lateralized α-activity, as the measured activity that was taken into account was present before the target presentation.

To begin with, the high correlation between correct responses and reported awareness of the target stimulus further corroborated the claim that participants would be able to correctly report conscious perception. Next, the instances of lateralization of α-activity around the visual cortex and the lack of them in the condition with long SOAs and no awareness of the target stimulus confirm that lateralized α-power correlates with the covert direction of visuospatial attention. The fact that the α-activity increases contralaterally to the not-to-be-attended side further supports the inhibition account of α-activity that was proposed in several studies (Kelly, Lalor, Reilly & Foxe, 2006; Thut, Nietzel, Brandt & Pascual-Leone, 2006; Wyart & Tallon-Bauldry, 2009).

Rees and Lavie (2001), and Dehaene, Changeux, Naccache, Sackur and Sergent (2006) suggested that in order for conscious perception to arise, attention would be a necessity. Dehaene, Changeux, Naccache, Sackur and Sergent (2006) propose a model that differentiates not only between subliminal (unconscious) and conscious perception, but add a preconscious processing. While subliminal processing occurs when the stimulus is too weak to elicit a large-scale neural activation, preconscious processing is expected to occur with stimuli that are just sufficiently salient to be perceived, but that are not because they are not attended to. Conscious perception in this account occurs when a just salient enough stimulus is attended to, or if a stimulus is salient enough to draw the attention. This concurs with the findings of the current study: Stimuli in the long SOA condition were reported to not have been consciously perceived when there was no lateralization of α-activity in the prestimulus interval. The presentation time has to have been long enough for the target stimulus to be detected, because participants were able to detect stimuli with shorter presentation times. The fact that there was no lateralization of α- activity indicates that there was no direction of visuospatial attention, which lead to the target stimulus not being consciously perceived. Rees and Lavie (2001) reported that lesions in parietal areas prevented conscious perception to arise. They concluded, therefore, that these parietal areas are involved in directing attention and giving rise to conscious perception. When applying Dehaene, Changeux, Naccache, Sackur and Sergent's (2006) approach to this theory, it seems reasonable to suspect that the missing ability to direct attention prevents processing to exceed the preconscious state.

Several task unrelated instances of α-lateralization in the orienting phase can be seen in figure 4. Lateralized α-activity can be recognized as early as 360 ms after cue presentation. At this point in time in each trial, the cue was still visible. Activity in the posterior cortex suggested that the participants interpreted the cue and directed their visuospatial attention to the side to be attended to in each trial. An additional increase in contralateral α-power was observed above anterior regions between 440 ms and 560 ms after cue presentation. Rees and Lavie (2001) and Weisz et al. (2014) deemed this activity crucial to enable conscious perception. As stated in earlier, this activity could be entirely unrelated (van Rullen; 2011) and was, therefore, not taken into account.

Figure 5 shows differences in location of the α-lateralization in trials with long and short SOAs. For trials with reported awareness of the target stimulus and short SOAs, the area with lateralized α- activity is centered around PO7/8 and O1/2 and more confined than for trials with long SOAs. These differences were likely also an effect of bias because of the design of the experiment: Each participant started with long SOAs and was presented shorter SOAs after adjusting to the requirements of the task and learning when to expect the target presentation. Dehaene, Changeux, Naccache, Sackur and Sergent (2006) wrote that conscious perception might be influenced by learning and strategies. It is possible that these strategies lead to a lower degree of lateralization of α-power, while performance improves over time. This would explain the more confined area with lateralized α-activity in the condition with short SOAs and reported awareness with respect to the long SOA aware condition.

General recommendations for future research

After discussing the findings, three design choices that were made in constructing this experiment are discussed critically to give recommendations for future research:

The first choice was to adapt the SOAs to each participant's performance. The purpose of using adaptive difficulty in the experiment was to lower frustration in the participants and to produce more valid trials for the analysis. Mathewson, Gratton, Fabiani, Beck and Ro (2009) reported exclusion of a large number of participants while using a fixed SOA of around 11 ms. Seeing that in this study 12 out of 26 participants could ultimately be considered in the pilot and the actual experiment, the procedure has to be improved. Possible downsides to keeping the SOAs adaptive to the participants' performances were decreased comparability between the participants and also the uncertainty of how much variance there would be in the encountered SOAs per participant. At an earlier stage of development of the experiment, it was also planned to examine the effects of the wave phase of the α-oscillation at the moment of stimulus presentation. The pilot testing showed a low chance of participants encountering SOAs of around 45ms or less. In cases of longer SOAs, the duration of target presentation exceeded the length of a wave phase and therefore made it impossible to make statements about which phase at the moment of target presentation improved visual awareness of it. Based on this experiment, it would be recommendable to decrease the number of trials that are evaluated before the SOAs are adapted, so that changes in the participants' performance can be corrected for more quickly. If the examination of wave phase is also an objective, it is possible to employ a mix of blocks that contain predefined and adaptive SOAs.

The second choice was to not include a distracter stimulus. The focus of this thesis was the lateralization of α- power before target presentation. Therefore, no distracter stimulus was presented on the unattended side. Posner, Snyder and Davidson (1980) and Babiloni, Vecchio, Bultrini, Romani and Rossini (2005) described visuospatial attention as having exogenous and endogenous qualities. This means that attention can be drawn at the moment of target presentation as the one side that features the target stimulus undergoes a salient change while the other does not. Analyzing the data that was collected in this experiment at the time of target presentation would introduce a bias to the outcomes that cannot be corrected for at this point. In retrospect, not using a distracter is a downside that does not come with any advantages. Thus, it should be implemented in future experiments.

The third choice was to ask the participants to report target orientation and visual awareness of it within a single response. The findings indicate a high correlation of reported awareness of the target stimulus and correct responses, so it can be said that the participants were able to successfully employ this method of reporting their answers. Furthermore, possible bias that might be introduced when giving two separate responses after another was eliminated. It was however necessary to monitor the participants' responses and to prompt them quite often to see if they really were consistently aware or unaware of the target stimulus. The introduction of control trials will likely improve this process: These control trials can be manipulated in terms of SOA, stimulus salience, or even in whether a target is presented or not to produce trials in which participants cannot possibly be truthfully report being aware or unaware of the target stimulus. They can then be prompted by the experimenter or presented a prewritten appeal to try and report awareness as reliably as possible.

Conclusion

In conclusion it can be said that a decrease in lateralized α-activity in the 40 ms before target presentation above the electrode pair O1/2 holds predictive value with respect to visual awareness of near threshold stimuli in target discrimination tasks. This predictive effect and especially the observation of missing lateralization of α-activity for reported unawareness of the target stimuli with the longest presentation times and , therefore, highest salience, supports Dehaene, Changeux, Naccache, Sackur and Sergent's (2006) theory of a preconscious state of processing. The employed method that included adaptive SOA and a rather complex manner of reporting the observed target stimulus and visual awareness of it may have to be further refined but have proven to be promising in researching the relationship between visuospatial awareness as measured in form of lateralized α-activity and visual awareness.

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Appendix A

Table A provides information about the length of the SOAs in the different sets that were used to make the difficulty of target detection adaptable to the participants' performance. Each set contained seven different SOAs with four trials for each of them.

Table A

Longest and shortest SOA per set

Set	Length of featured SOAs in ms						
1	270	285	299	313	326	340	354
2	257	270	285	299	313	326	340
3	243	257	270	285	299	313	326
4	229	243	257	270	285	299	313
5	215	229	243	257	270	285	299
6	201	215	229	243	257	270	285
7	188	201	215	229	243	257	270
8	174	188	201	215	229	243	257
9	160	174	188	201	215	229	243
10	146	160	174	188	201	215	229
11	132	146	160	174	188	201	215
12	118	132	146	160	174	188	201
13	104	118	132	146	160	174	188
14	90	104	118	132	146	160	174
15	76	90	104	118	132	146	160
16	63	76	90	104	118	132	146
17	49	63	76	90	104	118	132
18	35	49	63	76	90	104	118
19	21	35	49	63	76	90	104
20	7	21	35	49	63	76	90

Each set contained seven different SOAs.