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Bachelor thesis:

The influence of perceptual learning on conscious perception and its relation with attention

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Abstract

The question was investigated what the role of perceptual learning in a backward masking paradigm is and how perceptual learning evolves either due to feature sensitivity (Ahissar & Hochstein, 2004) or rather due to exogenous attention (Szpiro and Carrasco, 2015). EEG was used to measure spatial attention by focusing on lateralized activity in the alpha bands by computing lateralized power spectra (LPS). Different blocks were examined to study perceptual learning. However, no learning effect as well as no increase in attention was found. Reaction times of the participants actually were faster per block and SOAs. The missing learning effect was explained mostly by the short time coverage of the study. For future research a greater time coverage as well as multiple threshold values for the critical SOA are recommended.

Abstract (NL)

De vraag welke rol perceptueel leren speelt in een backward masking paradigma en hoe het ontstaat ofwel door eigenschap gevoeligheid (Ahissar & Hochstein, 2004) of door een verhoging in exogene aandacht (Szpiro and Carrasco, 2015) werd onderzocht in het huidige paper. EEG werd gebruikt om spatiele aandacht te meten door naar lateralisatie activiteit in de alpha banden te kijken en lateralized power spectra (LPS) te berekenen. Verschillende blokken werden gebruikt om perceptueel leren te onderzoeken. Echter zijn noch leereffecten noch een verhoging in aandacht gevonden. Reactietijden waren wel sneller per blok en SOAs. Het ontbrekende leereffect werd hoofdzakelijk verklaard door de korte tijdsduur van de studie. Voor toekomstige onderzoeken is aangeraden zowel een grotere tijdsduur met het onderzoek af te dekken als ook meerdere drempelwaardes voor het bepalen van de kritieke SOA te gebruiken.

Introduction

The goal of the current paper is to investigate the role of perceptual learning in a backward masking paradigm and the relationship between perceptual learning and attention. It is the question whether perceptual learning is rather due to feature sensitivity or due to attention. An example of the influence of perceptual learning in a backward masking task is the research of Szumska, Van der Lubbe, Grzeczkowski and Herzog (2016). By examining whether the sensitivity in binary choice tasks depends on the response modality, they asked participants to complete the same task on multiple sessions. The results indicated that the performance of participants had major increase in the second sessions compared to the first one. Their findings therefore imply that participants had learned.

It is argued that perceptual learning mainly is based on reinforcers and attentional feedback and works by suppressing irrelevant features and permitting relevant ones to come through in order to be learned (Roelfsema, Arjen van Ooyen & Watanabe, 2010). Stimulus specific features as shape and color are important for perceptual learning as well as general processes like how stimuli are presented and which response modality is used (Baeck & de Beeck, 2010). A theory, which explains the process of perceptual learning in terms of feature sensitivity is the reverse hierarchy theory developed by Ahissar and Hochstein (2004). The core assumption of the reverse hierarchy theory is that perceptual learning is guided by top-down processes and evolves with training in different stages. The reverse hierarchy theory proposes that the development of perceptual learning goes from high level representation to low level representation and in the very last step, when users had a great amount of training, back to high level representation (Ahissar & Hochstein, 2004). The definition of high level representations in this context are representations that are immediately retrievable for the consciousness of the participant. Low level representations are mostly unconscious and therefore not immediately accessible for the consciousness. The development of perceptual learning scales from “Naïve performers” to “Expert performers”. Naïve performers hereby use very rapid common sense perception (Fabre-Thorpe, Delorme, Marlot & Thorpe, 2001), which is further developed as participants get more training.

On the other hand, an approach of perceptual learning which is more based on focused attention is provided by Szpiro and Carrasco (2015). They argue that especially exogenous attention, which is attention automatically drawn, is responsible for perceptual learning. Through this kind of attention, perceptual changes are caused in participants. These changes stayed even with subsequent testing in neutral conditions, without exogenous cues. Perceptual learning with exogenous cues had therefore a long lasting effect. In addition to this, there are also findings that exogenous attention can support transfer in perceptual learning within and between the two visual fields to untrained locations (Donovan, Szpiro & Carrasco, 2015). Participants, who experienced a perceptual learning effect due to exogenous attention on a certain stimulus location can easily transfer what they have learned to other locations within or even between their left or right visual field.

Suitable research to investigate perceptual learning could be given form in a variation of the Posner cueing paradigm (Posner, 1980) with backward masking. Backward masking is a paradigm, where a target stimulus is ‘masked’ by a masking stimulus with differing time intervals, so called SOAs (stimulus onset asynchronies). The visibility of the target stimulus increases with the length of the SOA (Breitmeyer, 2014). Learning effects of participants can be compared using those SOAs to compute thresholds as an index of perceptual learning. The Posner cueing paradigm is developed in order to test participants for their ability to shift their attention. Attention and top down processes mediate perceptual learning and can guide learning related changes in behavior especially as the task demands are high (Byers & Serences, 2012). Due to the fact that the Posner paradigm works with different kinds of cues to examine attentional shifts, this paradigm is a useful tool to investigate perceptual learning. In the Posner paradigm endogenous cues, which cover voluntarily provided attention, as well as exogenous cues, which cover automatically provided attention, are used (Posner, 1980). With endogenous and exogenous cues, the shift between overt and covert attention is tested. Overt attention in this context describes attentional orienting with eye movements, covert attention is about attentional orienting without eye movements.

To measure the relationship between perceptual learning and exogenous attention, lateralization has to be assessed. Lateralization refers to the brain activity from both cerebral hemispheres, which can be assessed with the Electroencephalogram (EEG) (Bolduc, Daoust, Limoges, Braun & Godbout, 2003). Van der Lubbe and Utzerah (2010) defined a new measure for attention Lateralized power spectra (LPS), which is derived from the raw EEG through wavelet analysis. In order to diminish hemispherical differences a double subtraction method is employed, which makes their measure more sensitive compared to event related lateralization (ERL) or event related potentials (ERP). There are two major advantages in LPS. The first advantage is the possibility to indicate internally and externally generated lateralization instead of only externally generated lateralization. Furthermore, there is no restriction regarding to the time span of the measurement. It can be measured from cue onset to reaction instead of only after target onset. Especially interesting regarding the relationship of attention and perceptual learning is LPS derived from the alpha bands as these bands give an indication of the visual target detection of participants (Thut, Nietzel, Brandt & Pascual-Leone, 2006; Rihs, Michel & Thut, 2009).

The discussed literature implicates two different ways in which perceptual learning could occur in a backward masking task. Either it is due to feature sensitivity or due to attention. If feature sensitivity is responsible for perceptual learning in a backward masking task the reverse hierarchy theory should be considered. According to this theory, the transition between “naïve performers” and “mildly trained performers” should manifest itself in Eureka like phenomena (Ahissar & Hochstein, 2004). The Eureka phenomenon was also predicted by Ahissar and Hochstein (2004) and describes the experience of a learning person, who has a moment of clarification within a difficult task. From that moment the person can perceive the stimulus much easier than before. Ahissar and Hochstein (1997) also suggest that depending on the task difficulty easier trials can guide the learning process for harder trials and therefore simultaneously improve learning on a slower and therefore not visible basis. Performances can only enhance as the task difficulty is high enough and will otherwise stay at the same level. On the other hand, as exogenous attention is responsible for perceptual learning (Szpiro and Carrasco, 2015; Donovan, Szpiro & Carrasco, 2015) in a backward masking task, perceptual learning should take place as a function of attention. Explicitly that means, as perceptual learning can be recognized also an increase in attention should appear.

The aim of the current study is to examine whether perceptual learning plays a role in a backward masking paradigm and if this is the case how perceptual learning evolves. Therefore, two hypotheses will be examined in the current paper.

The first hypothesis will cover the question whether perceptual learning occurs due to feature sensitivity, as predicted by the reverse hierarchy theory (Ahissar & Hochstein 2004).

Following this theory, it is expected that participants will experience a learning effect with time. The hypothesis will be tested with behavioral data and therefore critical SOA should decrease with time. This means specifically that the critical SOA should be lower in the second half of the experiment compared to the first half.

On the other hand, the second hypothesis covers the question whether perceptual learning evolves due to exogenous attention, as stated by Szpiro and Carrasco (2015), and will therefore be tested with EEG data and behavioral data. It is expected that participants will be better able to focus attention with time and that a correlation between perceptual learning and attention exists. The lateralization therefore is expected to increase within time as an index of attention. The LPS should then be higher in the second half of the experiment compared to the first half. To indicate a connection between perceptual learning and attention a correlation between LPS and critical SOA is expected.

To answer the research question whether perceptual learning plays a role in a backward masking paradigm and how it evolves, an experiment will be executed containing a backward masking task. Through EEG measurement, Lateralized Power Spectra (Van der Lubbe and Utzerah, 2013) will be derived from wavelet analysis.

Methods

Participants

25 participants, 9 male and 16 female, majority University of Twente students took part in the study (*M* = 22.35, *SD* = 4.22). Nearly all of them had normal or to normal corrected view as checked with the Freiburg Visual acuity test (Bach, 1996). Two participants had to be excluded. One due to bad sight and another on the basis of procedural errors in the EEG measurement. No one was color-blind and just one participant had a history of neurological disease in form of a treated depression. Color-blindness was examined by Ishihara's test for color-blindness (Ishihara, 1976). In exchange for participation, course credits were granted, therefore participants were assembled through convenience sampling. 14 participants were wearing glasses or lenses. There were 21 right handed participants and 3 left handed. One participant was ambidextrous. The handedness was assessed with Annett's Handedness Inventory (Annett, 1970). No one took medication at time of the study. The study was authorized by the local ethics committee of the faculty of Behavioral Management and Social Science. Participants signed a written informed consent before participating.

Task and Stimuli

A variation of the Posner task (1980) was used. The default display consisted a white fixation point in the middle of the screen (0.164° × 0.164°) on black background and two white empty circles on the left and right next to the point (12.06° with r = 0.614°). There were two response keys. The left response key used with the left index finger was 'control left' and the right response key used with the right index finger was 'control right'.

The participants were instructed to hold their eyes on the fixation point throughout the whole task, except at pause moments and to blink after every trial onset. In addition, it was indicated that responses have to be made as quick and accurately as possible. The practice set took 5000 ms. Within this set every SOA is given once. Therefore, there are 14 practice trials. Thereafter, 60000 ms “1 minuut rust voor de ogen” was displayed in order to give the participant a break. After the break the display said “Het tweede blok begint” for 5000 ms to make clear that the second set will start. When the participant made errors within the task the white dot turns red for 500 ms after the trial.

Before the target stimulus was shown, there was a rhombus shaped stimulus in the middle of the display shown for 600 ms. Half of the rhombus was blue, the other half yellow. There were two conditions differing only in the relevant color for the cue, which was a rhombus shaped stimulus. The participants were randomly assigned to a group beforehand to the experiment. The times between displaying the target stimuli and displaying the mask (SOA) varied from 7 to 277.8 ms. The exact times were: 7, 14, 21, 28, 35, 42, 49, 63, 83, 111, 139, 174, 208, 278. There were two different target stimuli: a circle filled with vertical lines and a circle filled with horizontal lines. Participants had to react with a left button response for horizontally stripped circles and with a right button response for vertically stripped circles. The circle opposite to the cued site was irrelevant. After the SOA a masking stimulus was displayed on both circles for 500 ms. The masking stimulus is a circle filled with crossing diagonal lines. Simultaneously with the target and masking stimuli a fixation point in the middle of the display was shown. The distance between the two shown stimuli on the screen was 15 cm. The distance between the fixation point and the stimulus was 7.5 cm. The white dot had a size of 0.3 cm, the bigger white dot had a size of 0.5 cm. The circles themselves had a diameter of 1.5 cm. The task was composed of 8 blocks with 112 stimuli per block, which made 896 trials per task. A representation of the whole event sequence for one trial is provided in figure 1.

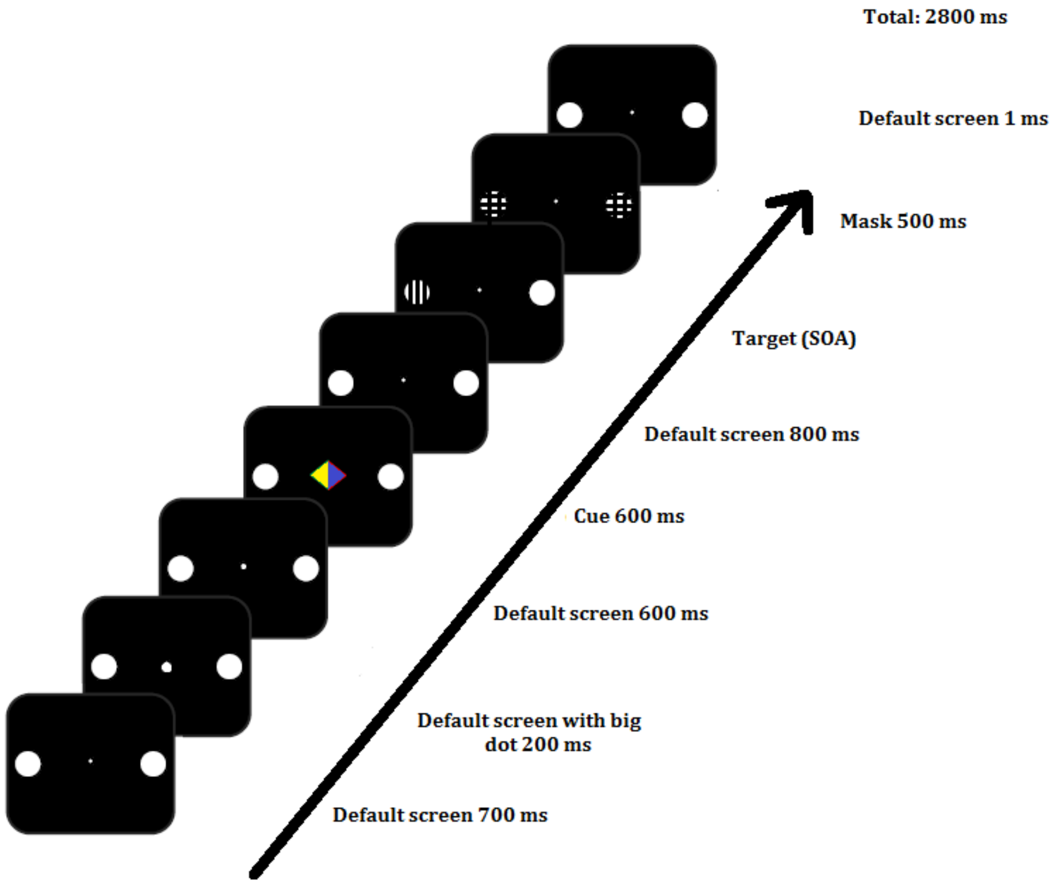

Figure 1 Representation of event sequence in one trial. Used SOAs in ms were 7, 14, 21, 28, 35, 42, 49, 63, 83, 111, 139, 174, 208, 278. The sequence contained a default screen, the cue, the target and the mask

Apparatus and EEG recordings

The participant sat in front of a 24-inch screen at a distance of 80 cm. The vertical distance between the table and the participants' eyes was set to 45 cm. The room was semi-darkened in order to enhance visibility. The stimuli were picked randomly for each trial. The response keys were situated on the bottom row of a normal 'QWERTY' keyboard. The task was presented to the participant through Presentation software (Neurobehavioral Systems, Inc., 2012) on a second computer.

In accordance with the 10-20 system active Ag/AgCl ring electrodes were placed at 32 locations in an elastic cap (Braincap, Brainproducts GmbH). Hereby, the EEG was recorded and displayed together with vertical and horizontal electro-oculogram (vEOG and hEOG). The electrodes were applied above and below the left eye and at the outer canthi of both eyes. Gel was applied at the electrodes in order to bring the electrode resistence below 10 kΩ. The amplifier actiCHamp (BrainProducts GmbH) was used with 34 channels. 32 EEG channels and 2 EOG channels. The task itself as well as EOG and EEG were recorded on a separate research computer with Brain Vision Recorder (BrainProducts GmbH). The sampling rate of the signals were 500 Hz and the following filters were used: High cut off filter with 200 Hz and 24 dB and Notch filter with 50 Hz.

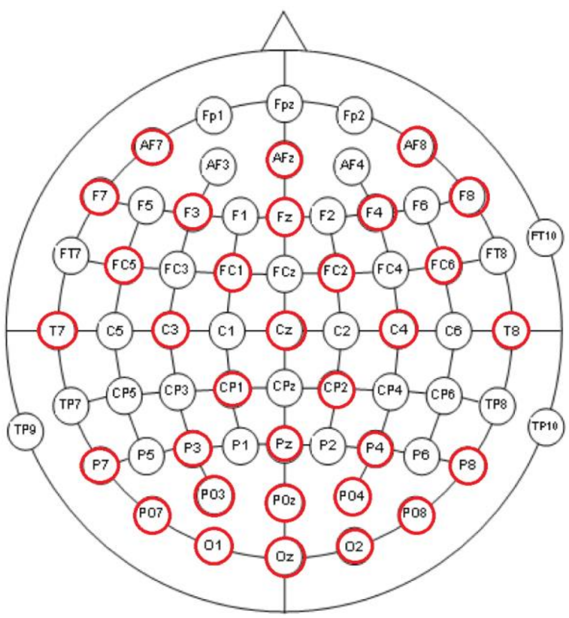

Figure 2 Electrodes used in the experiment are marked red

Data processing

Behavioral measures. For the proportion correct of the participants' responses a repeated measures ANOVA was conducted with the within-subject factor SOA. For the critical SOAs a repeated measures ANOVA was conducted with the factor Block. In addition to this for the reaction times a repeated measures ANOVA was conducted with the factors Block and SOA. For the behavioral measures a significance value of $p = 0.05$ is held.

EEG measures. The analysis of the data was executed with Brain Vision Analyzer 2.0 (Brain Products GmbH, 2012). There were several steps in analyzing the raw EEG. First, the raw EEG was filtered with a Butterworth filter and a Notch filter (50 hz). A low cut-off was used at 0.016 hz. The data was partitioned in segments from -1000 to 3400 ms relative to cue onset. The baseline was set from -100 to 0 ms before cue onset. Trials, which contained eye movements 0 – 1400 ms relative to cue onset were removed. Now, the markers set during the task for behavioral data were exported. The EEG window was shrunken to -1000 to 2000 ms relative to cue onset. EEG segments, which contained artefacts were removed with a gradient criterion of 100 µv, a min-max criterion of +/-250 µv and a low-activity criterion of 0.1 µv. Thereafter, an ocular correction was executed with the help of an independent component analysis (ICA). Also a new baseline was set and an artifact check is made with a min-max criterion of +/-150 µv. Wavelet analysis were carried out and the lower and higher α bands (see Van der Lubbe & Utzerath, 2013) were extracted for respectively the left and right stimulus as well as for the first four blocks and the second four blocks. The values were averaged. Now the double subtraction method was employed. After the wavelet analysis, a repeated measures ANOVA was conducted on the EEG data with the factors Block, Electrode and Band. The significance standard for the *p*-value for two consecutive time windows is computed as in the research of Van der Lubbe, Bundt, and

Abrahamse (2014) in the following way, $p < \sqrt{\frac{0.05}{9}} = 0.07$. Therefore, it was decided to take the general significance standard of $p = 0.05$.

Results

Behavioral measures

The behavioral measures mostly covered the first hypothesis about perceptual learning due to feature sensitivity. The repeated measures ANOVA for the mean proportion of correct responses of participants was used in order to check whether participants reacted significantly faster with longer SOAs. A significant effect for the factor SOA $F(13, 8) = 48.11$ $p < 0.001$ was found. As can be seen in figure 3, the mean proportion correct increases with higher SOA’s. That implies that participants reacted with a higher proportion correct responses on trials with longer SOA’s.

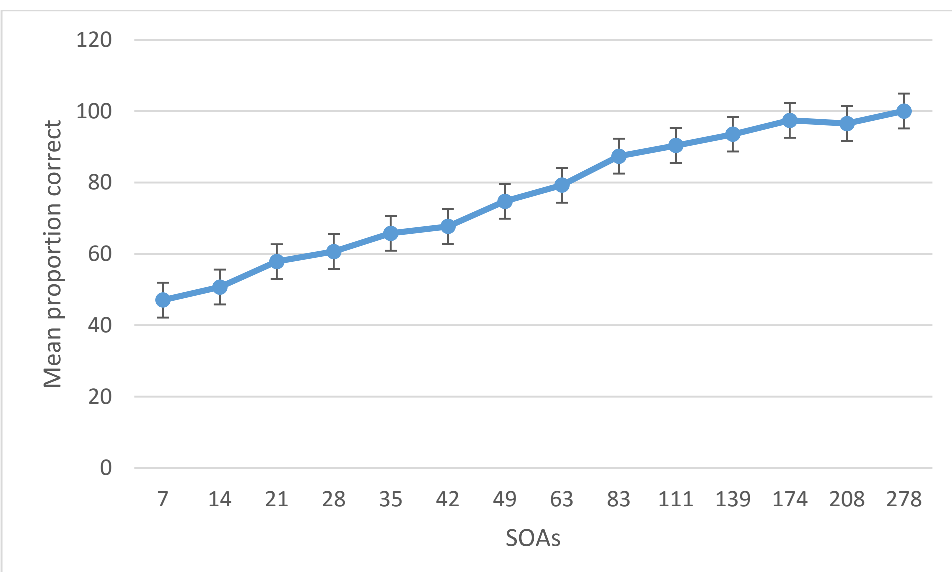

Figure 3 Mean proportion correct plotted against the SOAs

The repeated measures ANOVA for the critical SOAs checks whether participants experienced a learning effect during the task, which is the case as participants respond with a higher percentage correct at shorter SOAs in the last half of the experiment compared to the first half. However, no significant effect for the factor Block $F(6, 17) = 1.08$, $p = 0.37$ was found. Participants therefore, reached no significant shorter SOA in the last four blocks compared to the first four blocks. That means that against the first hypothesis no learning effect is found. Figure 4 shows the mean critical SOA per block.

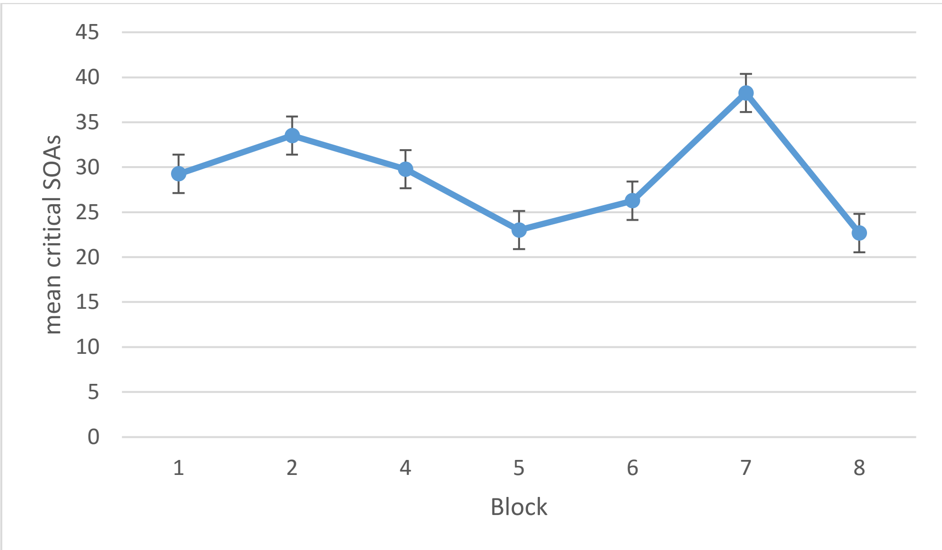

Figure 4 Mean critical SOA plotted per block

The repeated measures ANOVA for the reaction times tests whether participants reacted faster with time. This ANOVA revealed significant effects for the factor block $F(6, 6) = 13.04$, p <0.001 as well as SOA $F(13, 11) = 7.03$, $p < 0.001$. Thus, the reaction times of the participants were significant faster in the last blocks compared to the first blocks. These were also significant faster per SOA. That indicates that although participants did not perform qualitatively better, their reaction times were shorter in the second half compared to the first half. Figure 5 shows the decrease of the reaction time per block.

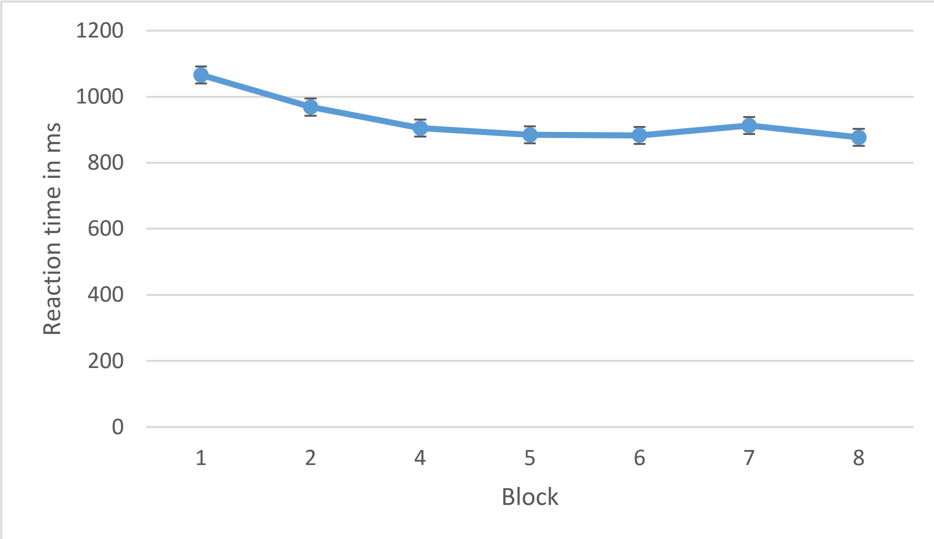

Figure 5 Reaction time in ms for block 1-8

EEG analyses

The EEG analyses revealed information about the second hypothesis, which stated that perceptual learning evolves due to exogenous attention. The repeated measures ANOVA for the different time-windows from 400-500 to 1300-1400 ms tests whether there was an increase in focused attention in the last half of the experiment compared to the first half. For the time-windows from 400-500 to 1300-1400 ms the between-subject effects were significant with $p < 0.03$. That means that there was a significant difference from zero in the lateralization, which only indicates that lateralization was measured at all. However, there were no significant results for the factor block. That implicates that against the expectation of the second hypothesis attention did not increase in the second half of the experiment compared to the first half. Figure 6 shows the relationship of the lateralization of the first and last blocks for the time-window 400-500 ms.

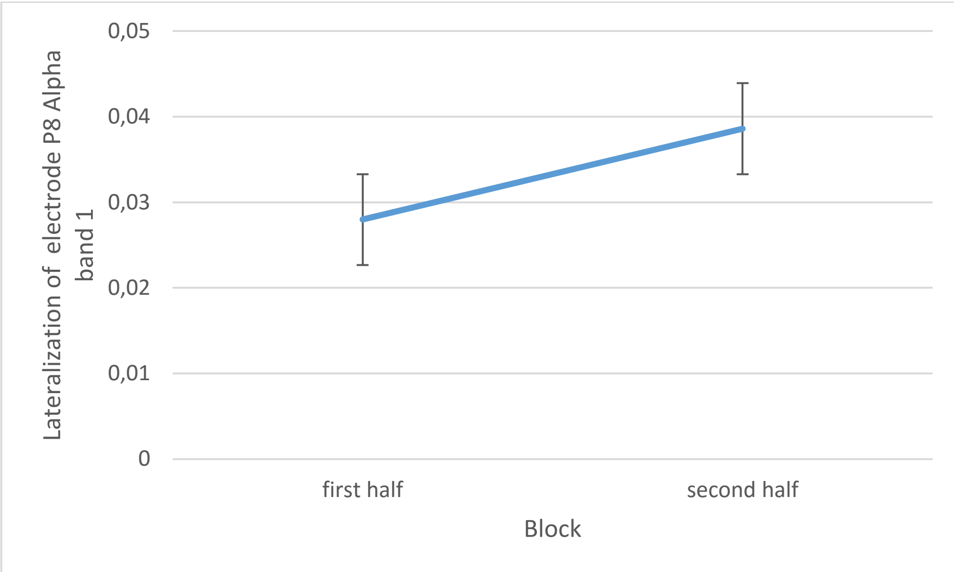

Figure 6 shows the relationship of lateralization between block 1-4 and 5-8 in time-window 400-500 ms for the electrode P8 in alpha band 1

Although the lateralization seems to increase over time, the difference between the first and second half of the experiment is not significant. Figure 7 shows the lateralization of the electrode PO8 for the first and second half of the blocks for the alpha band 1. As visible in figure 7, no difference was found due to the fact that not at least two consecutive time-windows had a p-value of $p = 0.05$ or below.

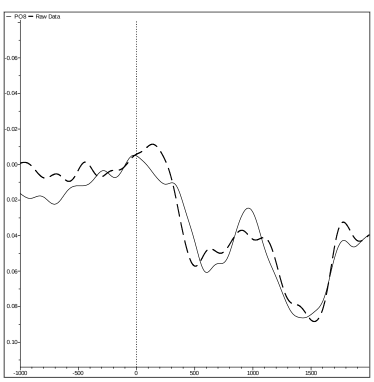

Figure 9 LPS alpha 1 (left) and alpha 2 frequency band (right) first half versus second half for electrode PO8

Due to the fact that focused attention increases not significant over time also no correlation between attention and perceptual learning could be computed. Therefore, it is decided to not compute a Pearson correlation between critical SOA and LPS.

Discussion

The goal of the current study was to examine the role of perceptual learning in a backward masking task and its influence on attention. Therefore, it was asked how perceptual learning evolves within a backward masking task. The hypothesis tested were based on the assumption that perceptual learning evolves either due to feature sensitivity or due to exogenous attention. However, the results of the current study do not provide any evidence for either of the hypothesis tested.

The first hypothesis covered the question whether perceptual learning occurs due to feature sensitivity, as predicted by the reverse hierarchy theory (Ahissar & Hochstein, 2004). Following this theory, it is expected that participants will experience a learning effect with time. The hypothesis was tested with behavioral data and therefore critical SOA were expected to decrease with time. That meant specifically that the critical SOA were expected to be lower in the second half of the experiment compared to the first half. However, the results did not confirm that participants reacted qualitatively better in the second half of the experiment compared to the first half and therefore participants did not learn. Although no learning effect was found, participants reacted faster on the stimuli with time.

Explaining the results in the context of the reverse hierarchy theory (Ahissar & Hochstein, 2004) it could be argued that the increase of performance from block 4 to 5 with a difference of

6.7 ms could be seen as an indication of the predicted first transition between “Naïve performer” and “mildly trained performer” due to the fact that the increase still began in the first half of the experiment and that it was rather sudden. Following Ahissar and Hochstein (2004) this transition utters in Eureka like phenomena, which means that performances improve suddenly after a rather short amount of time. Though it has to be kept in mind that the difference between block 4 and 5 was not significant. However, after this increase in performance, the critical SOA did not stay constant and the performance even decreased again in block 7. According to the reverse hierarchy theory (Ahissar & Hochstein, 2004) the performance of the participants should stay at least constant after the first transition.

Another explanation for the current results could be sought in underlying learning mechanisms, which precede the actual learning effect. Even though no learning effect was found, the reaction times decreased with time. This effect could be in line with the theories of Ahissar and Hochstein (1997) regarding the underlying learning mechanisms of the reverse hierarchy theory (Ahissar & Hochstein, 2004). They suggest that depending on the task difficulty, easier trials can guide the learning process for harder trials and guide learning on a slower and therefore not visible basis. This explanation would suggest that the current findings speak not clearly against the reverse hierarchy theory (Ahissar & Hochstein, 2004), but rather that the time coverage of the measurement was too short to let learning effects become visible.

However, if the current results are considered beyond the implications of the reverse hierarchy theory also another type of learning could be indicated by the results. It could be argued that participants learned rather motoric than perceptual. Clegg, DiGirolamo, and Keele (1998) offer a paradigm, which explains motoric learning in terms of a layer structure. Salient stimulus features as well as constantly the same motor response can support motoric learning (Kemény &

Lukács, 2011; Koch & Hoffmann, 2000; Willingham, 1999). Although this theory would support the findings of decreasing reaction times, the current task provides no motoric sequences. Therefore, motoric learning as only explanation for the current results is not sufficient, but at least it can take part in the explanation.

The second hypothesis covered the question whether perceptual learning evolves due to exogenous attention, as stated by Szpiro and Carrasco (2015), and was tested with EEG data and behavioral data. It was expected that participants will be better able to focus attention with time and that a correlation between perceptual learning and attention would exist. The lateralization therefore was expected to increase within time as an index of attention. The LPS should have been higher in the second half of the experiment compared to the first half. To indicate the connection between perceptual learning and attention a correlation between LPS and critical SOA was expected. However, there was no increase of focused attention in the second half of the experiment compared to the first half. As stated earlier also no learning effect was found on the basis of the current results. Therefore, it was not possible to assess a correlation between learning effect and attention.

In the context of the findings of Szpiro and Carrasco (2015) the current results probably are due to a too short time coverage of the experiment. In their research Szpiro and Carrasco (2015) indicate that in order to learn many iterations are necessary.

In hindsight positive as well as negative points of the research became apparent. First of all, a strong point of the current research were the exclusion criteria, which were assessed for each participant ahead of the experiment. Through taking enough time for testing every participant for visual acuity and colorblindness it could be prevented that those factors have influence on the study. A weaker point of the current research was in hindsight the length of the experiment session. The great decrease in performance in block 7 could be due to exhaustion and tiredness of the participants during the experiment as the experiment took about 90 minutes to be completed in a darkened room with a constantly iterating task. There is a chance that tiredness had influence on the current results and that also therefore no effects could be found. Above this there was less data than expected available for analysis due to programming errors in block 3, data from this block had to be excluded. Furthermore, many eye movements from the participants than expected were detected, which also lead to data exclusion. As a consequence, the data was rather noisy. Another weak point concerns the threshold value. In hindsight it could be argued that another decision regarding the threshold value could have changed the results due to chance correction of the participants. In the current study there is no validation for participants, who were just gambling and therefore had a good performance. Maybe a learning effect could be seen if the data was analyzed with a tighter threshold value of 80 % or higher. This tighter threshold value would provide more certainty regarding the question whether participants actually saw the target or were just gambling. The chance of not recognizing a learning effect due to gambling would be diminished. Due to time issues the critical SOA could not be defined for differing threshold values in the current study. Another problem of the current study, which was more of an execution error, was the fact that after 45 minutes during the session the experimenters changed positions. Participants gave afterwards the feedback that they were distracted by the change of positions. Also this could be of influence for the current results.

At last there are also references in the current literature that the current experiment covered a too short period of time. The study of Kami and Sagi (1993) stated that perceptual learning mostly works over a time period of more than eight hours. Therefore, the greatest learning achievements were recorded in the second of multiple sessions with the participant. The same phenomenon was observed in the study of Szumska, Van der Lubbe, Grzeczkowski and Herzog (2016). While they looked for the importance of the response modality in binary choices, it was also observed that participants had major learning effects on the second day session compared to the first and third day. Applying those findings to the current experiment leaves the impression that even if perceptual learning could play a role in a backward masking paradigm there is more time needed to discover effects of the learning process.

Although both hypothesis had to be rejected due to multiple causes, the results of the current research should not be seen as prove against the influence of perceptual learning on conscious perception. In order to bring more clarity in the relationship between perceptual learning and attention and their influence on conscious perception further research is needed. In the current research impracticalities were detected, which should be avoided in future research. It is proposed that future research on the topic of perceptual learning in a backward masking paradigm should contain at least two or more sessions with the participants with a time-interval of at least eight hours between those sessions as suggested by Kami and Sagi (1993) in order to be able to detect learning effects. Moreover, the length per session should be reduced in a way appropriate to the attention span of humans. To avoid excessive data loss due to eye movements there could be an auditory warning given whenever participants drift away with their eyes from the fixation point. In the current study, verbal warnings were given from the researcher, but that seemed not enough to prevent immoderate data exclusion due to eye movements. Furthermore, determining the critical SOA based on different threshold values could offer new insight in the learning process of participants already on an early stage. The chances that effects get lost due to gambling will be diminished in this way. In addition to this, future research should also check more explicitly for motoric learning as this could possibly explain at least a part of the current findings. Above all, the environment of the experiment should be as quiet and stable as possible.

Implications

The main implication of the current study is that it is still unclear how perceptual learning evolves in a backward masking paradigm and that it is therefore still important to research on this particular topic. Although there is no learning effect found in the current study, there are many references in the current literature that perceptual learning should evolve after an appropriate amount of time (Ahissar & Hochstein, 2004; Baeck & de Beeck, 2010; Byers & Serences, 2012; Kami & Sagi, 1993; Szpiro & Carrasco, 2015). Another major implication is therefore that research regarding perceptual learning should not be carried out in less than at least two sessions. The question which still stays unanswered is how perceptual learning evolves whether it is due to feature sensitivity, due to exogenous attention or even due to a mixture of both. Knowing that fact can let earlier research stand in another light and could have explanatory power regarding phenomena, which are linked to visuospatial attention. In a more distance future the question of how perceptual learning evolves could also have implications in educational settings. Depending on the answer of this question learning material or even the style of providing students with information could be adapted to maximize the learning effect.

Conclusion

On the basis of the current result no conclusion can be made about the influence of perceptual learning in a backward masking task and its relation with attention, because no perceptual learning effect is found. Therefore, it cannot be said whether perceptual learning evolves rather due to feature sensitivity or exogenous attention. However, the reaction times of the participants increased with time, which either indicates underlying, but not yet visible learning mechanisms or the involvement of motoric learning. Further research is necessary to investigate this topic.

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