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Abstract

Internal representations of looked-for objects facilitate scanning of our complex environment and therefore improve visual search. Accordingly, performance in visual search was found to benefit from positive templates containing information about upcoming targets, and besides that, to depend on the precise pre-stimulus phase of neural alpha- and theta oscillations. However, until now, it is unclear if negative templates, containing information about upcoming distractor features, can equally improve search by causing proactive suppression of distractors. Besides, it is discussed whether salient distractors automatically attract attention (as suggested by stimulus-driven models), or if specific behavioral goals can prevent this automatic capture (as suggested by goal-dependent models).

In light of these discussions, the present experiment (N=29) aimed to examine the effect of neural oscillations on attentional templates in visual search, by instructing participants to either search for or suppress a specific, trial-by-trial changing orientation in a subsequent search display that was presented at different stimulus onset asynchronies (SOAs).

We hypothesized to find alpha- or theta oscillations in hit rate and RTs associated with positive and negative templates in our visual search experiment. Since we could only find non-significant trends towards such oscillations, and mainly for the hit rate, our findings do not fully support these assumptions. However, together with previous studies, our results may provide important insights regarding the experimental- and stimulus design for future studies aiming to examine the effect of neural oscillations on attentional templates in visual search.

Keywords: *visual search, alpha oscillation, theta oscillation, positive template, negative template, proactive suppression, distractor, reaction time, hit rate*

Contents

Introduction

Attentional Templates in Visual Search

Imagine standing in a library in front of a huge bookshelf, searching for a specific book. Let us assume it is a dark blue book with golden letters. Do you see it in front of you? When searching for specific objects, scanning of our complex environment is facilitated by internal representations of what we look for (Wolfe, 2021). Thereby, such an *attentional template*, the active representation of target-relevant features (blue book and golden letters), is maintained in the visual working memory (VWM), and top-down biases search towards objects that show these features. This speeds up search times despite the many other books in the shelf that potentially distract attention towards them (de Vries et al., 2020). In other words, an attentional template that represents task-relevant features and biases attention towards visual stimuli resembling it, is referred to as *positive template* (de Vries et al., 2020; Salahub & Emrich, 2021). We are looking for a blue book with golden letters that resembles the one we have on our mind. In contrast, we can also think of many books with features that we are not looking for – for example red books with yellow letters – that potentially distract our attention. In short, while positive templates are thought to enhance features of the task-relevant targets, *negative templates*, specifying distractor features, are thought to reduce the activation of such task-irrelevant features (Conci et al., 2019). Current research has shown that negative templates could inhibit the processing of distractors that show features defined by the negative template (Arita et al., 2012; Reeder et al., 2017). For instance, Arita et al. (2012) found that color cues, indicating the color of upcoming distractors in a visual search array, improved search more compared to trials with neutral cues, indicating a color that would not appear in the following search display, as indicated by faster reaction times (RTs). However, negative templates might not always be effective in initially guiding attention away from stimuli matching the negative template. For example, Moher and Egeth (2012) suggested the *search-and-destroy hypothesis*, according to which individuals initially select stimuli matching the negative template instead of inhibiting their processing. This hypothesis was supported by behavioral evidence from several studies (Beck et al., 2018; Chang et al., 2019; Cunningham & Egeth, 2016). In a recent study, Berggren and Eimer (2021) picked up these previous contrary findings and discussed two possible explanations for the facilitation of visual search associated with negative templates. They conducted a *cueing procedure,* where negative, positive, or neutral color cues preceded the search display, either indicating the color of

an upcoming distractor, the target, or a color that would not be contained in the search display. While there was a benefit in RTs in trials where positive cues indicated the color of the upcoming target, findings suggest RT costs in trials where negative cues were used. This was even evident compared to trials with neutral cues, meaning that RTs were faster in neutral compared to negatively cued trials. Likewise, this effect of cue condition was also evident with regard to the error rates. Participants made less errors in positively cued trials, whereas error rates were higher in neutral and negatively cued trials. However, in contrast to RTs, the difference in error rates between neutral and negatively cued trials was not significant. Taken together, on a trial-by-trial basis, positive cues were found to enhance performance in visual search, while negative cues were found to impair attentional selection of search targets. However, if the negative cues remained the same in all trials, these initially observed costs associated with negative cues were only found for the first 24 trials within a block and even turned into benefits evident in RTs and error rates with extended practice. This is in line with Töllner et al. (2015) who found target detection to be more efficient if target-distractor similarity did not change trial-by-trial, but remained stable across trials. Taken together, it might be assumed that contrary findings regarding the effect of negative templates for distractor suppression might be due to different search tasks. This assumption is supported by findings by Conci et al. (2019) who found that negative templates only facilitated performance in difficult search tasks, when target-distractor similarity was high and responses were comparably slow. Similarly, Arita et al. (2012) reported increasing effectiveness of negative templates in facilitating visual search when search set size increased.

Combining Bottom-up and Top-down Models - The Signal Suppression Hypothesis
However, these diverging findings caused an intense debate whether and under which conditions *salient* (i.e., outstanding) but task-irrelevant stimuli capture attention automatically despite foreknowledge of distractor features that should suppress this attentional capture. The debate mainly involves two opposing theories, *stimulus-driven models* and *goal-dependent models*. Stimulus-driven models assume that salient stimuli capture attention automatically, even if they are task-irrelevant (Hickey et al., 2006; Jonides & Yantis, 1988; Theeuwes, 1993, 2010). In this regard, books in eye-catching colors are assumed to attract our attention, even if they are in the wrong color and do not show the characteristics we are searching for.   In contrast, goal-dependent models point out that attention is only attracted by stimuli that show task-relevant

features (Drisdelle & Eimer, 2021; Folk et al., 1992; Jannati et al., 2013; McDonald et al., 2013; Wykowska & Schubö, 2010, 2011). Thus, only books with characteristics corresponding to the ones we are searching for, are presumed to attract our attention. In short, goal-dependent models assume the attentional template stored in the VWM to cause *top-down* guidance on incoming visual signals, while stimulus-driven models assume attention to be guided in a *bottom-up* way directed by the salience of these processed visual stimuli (Kerzel & Huynh Cong, 2021).

In line with both theories, Sawaki and Luck (2010) proposed the *signal suppression hypothesis*, combining elements of both stimulus-driven and goal-dependent models. Consistent with stimulus-driven models, the theory assumes salient *singletons*, stimuli with unique characteristics (e.g., color, shape) to automatically generate *saliency signals* (i.e., attraction of attention caused by perceptual quality of a stimulus causing it to stand out) capturing attention. But, as suggested by goal-dependent models, these saliency signals can be suppressed if they do not match the task-relevant features (Drisdelle & Eimer, 2021). These predictions of the signal suppression hypothesis were supported by several studies, focusing on *event-related potentials* (ERPs; i.e., specific markers in electrical brain activity associated with different cognitive functions) and behavioral measures (Chang et al., 2019; Drisdelle & Eimer, 2021; Feldmann-Wüstefeld & Vogel, 2019; Gaspelin et al., 2015; Gaspelin & Luck, 2018, Stilwell et al., 2022; van Zoest et al., 2021; Vatterott & Vecera, 2012). In a recent paper, Luck et al. (2021) discussed new evidence supporting the intermediate position of the signal suppression hypothesis and pointed out that adaptions of the opposing theories have led to emerging consensus in two main areas. First, both theories agree that saliency signals can be automatically generated by stimuli, if there are no specific attentional control settings defined by task goals and selection history. Coming back to our example with a huge shelf full of differently looking books, missing or unclear information on the visual appearance of the book we are looking for - no specific attentional control settings - might cause salient books (e.g., books in eye-catching colors or very thick ones) to attract our attention very quickly. However, the second agreement of the two theories is that the appropriate configuration of attentional control settings (e.g., current behavioral goals such as clear knowledge about what to look for) can prevent capture of attention by salient singleton stimuli. Thus, if we do have information on the visual appearance of the book we are looking for - clearly defined attentional control settings - attentional capture and distraction by other outstanding books with irrelevant characteristics can be prevented. Anyway, the main disagreement between

the two theories still concerns the conditions under which singleton stimuli can be suppressed *proactively* (i.e., prior to display onset), and especially whether explicit behavioral goals can cause proactive suppression of specific features (Luck et al., 2021).

Optimal Windows of Stimulus Processing - The Role of Neural Oscillations

However, while these above discussed theories mainly focused on the effect of distractors depending on stimulus-characteristics, recent studies further suggest performance in visual search to depend on *neural oscillations* (Busch et al., 2009; Clayton et al., 2018; Fodor et al., 2020). Neural oscillations describe the rhythmic activity and synchronized interaction between populations of neurons that occur spontaneously and in response to stimuli (Bauer et al., 2022). This synchronous electric brain activity can, for example, be recorded via electroencephalography (EEG) and decomposed into its respective frequency bands – delta (1–3 Hz), theta (4–7 Hz), alpha (8–12 Hz), beta (13–30 Hz), and gamma (30–100 Hz) oscillations – using the *fast Fourier transform,* a computational tool for signal analysis (Bauer et al., 2022; Cochran et al., 1967; Hanslmayr et al., 2019; Saby & Marshall, 2012). In short, neural oscillations serve as mechanism that, through synchronizing neural activity within and across different groups of neurons in the brain, enables the coordination of neural activity that is fundamental to cognitive processes such as memory, and attention (Marko et al., 2019; Ward, 2003). In this regard, different kinds of cognitive processes were suggested to be associated with these different frequency domains (Klimesch, 2012). For instance, human beta oscillations were mainly observed during motor tasks or cognitive tasks that involve sensorimotor interaction (Barone & Rossiter, 2021; Engel & Fries, 2010; Kilavik et al., 2013). More precisely, an increase of sensorimotor beta was described at rest, while it was reduced during phases of movement (Kilavik et al., 2013). Further, beta oscillations were also found to be involved in the executive control of WM storage and inhibition (Miller et al., 2018), as well as in the maintenance of attentional resources and of the current sensorimotor state (Engel & Fries, 2010; Palacios-García et al., 2021; Richter et al., 2018). However, beta oscillations were mainly described to be involved in inhibition in the prefrontal and motor cortex (Miller et al., 2018), while inhibition in the visual cortex was primarily linked to alpha oscillations (Jensen & Mazaheri, 2010). Focusing on the visual domain, during the processing of visual information, neural excitability in the brain was shown to be mediated by the oscillatory phase in the alpha-, theta-, and delta-band (Busch & VanRullen, 2010; Daume et al., 2021; Schroeder & Lakatos, 2009). Accordingly, several studies

pointed out that visual detection performance depends on the exact pre-stimulus phase of alpha and theta-oscillations (Busch et al., 2009; Mathewson et al., 2009; Vigué-Guix et al., 2022). For example, Riddle et al. (2020) found causal evidence for the role of theta and alpha oscillations in the control of WM contents. They used transcranial magnetic stimulation (TMS) that either matched or mismatched task-driven oscillations, to investigate the effect of rhythmic TMS on performance in a WM task. Their findings point out the role of frontal theta oscillations in the prioritization of WM contents and the role of parietal alpha oscillations in the suppression of WM contents. Both alpha and theta oscillations were furthermore also shown to be associated with the inhibition of anticipated distractors (Fodor et al., 2020). Focusing on alpha oscillations, besides their involvement in top-down inhibition of to-be-ignored stimuli (Jensen & Mazaheri, 2010; Foxe & Snyder, 2011), increases in alpha power were observed during the maintenance of information in VWM (Jensen et al., 2002; Tuladhar et al., 2007). More precisely, an inverse correlation with cortical excitability was found, meaning that high alpha power is associated with low cortical excitability, thereby causing selective suppression of distractors and prevention of interference with VWM contents (Bonnefond & Jensen; 2012; Foxe & Snyder, 2011; Wang et al., 2016; Wianda & Ross, 2019). Accordingly, depending on the phase of the alpha oscillation at the moment of stimulus presentation, these optimal windows for stimulus processing become evident in varying RTs (Callaway & Yeager, 1960; Dugué et al., 2011; Dustman & Beck, 1965). In contrast, theta oscillatory activity was found to be involved in *cognitive control*, comprising the monitoring of behavioral strategies, feedback processing, and control of action, and therefore increased in response to unexpected distractors (Fodor et al., 2020; Folstein & Van Petten, 2008). Oscillations in the theta frequency range were also shown to be associated with the WM (Roux & Uhlhaas, 2014), as indicated by a rise in amplitude of theta activity during encoding and retention of information (Jensen & Tesche, 2002; Raghavachari et al., 2001; Sauseng et al., 2010). Thus, taken together, since different frequencies were described in association with specific cognitive functions as discussed above, neural oscillations are well suited to investigate human visual attention and distractor processing non-invasively.

Current State of Research & Hypotheses

In summary, until now, it remains controversial under which conditions distractors affect visual search, and whether and how negative templates might reduce such distractor-specific processing (Berggren & Eimer, 2021). While most evidence supports the assumption that negative templates

rather impair visual search for targets among distractors (Chang et al., 2019; Moher & Egeth, 2012), there is also contrary evidence pointing towards a beneficial effect of negative templates in suppressing attentional capture by predefined distractors in visual search tasks (Arita et al., 2012; Reeder et al., 2017). However, given these contrary findings, it becomes clear that the bottom-up vs top-down dichotomy associated with stimulus-driven and goal-dependent models is rather simplistic, and that the experimental and stimulus design need to be considered as decisive factors for the efficacy of attentional templates in ongoing discussions as well. A first step in this direction was taken by the signal suppression hypothesis suggested by Sawaki and Luck (2010) that, despite two major remaining divergences, involves converging viewpoints of stimulus-driven and goal-dependent models on stimulus perception and visual processing. However, as discussed above, it was further shown that effective processing of visual stimuli is subject to oscillating brain activity and that visual detection performance depends on the exact pre-stimulus phase of alpha and theta-oscillations (Busch et al., 2009; Dugué et al., 2015; Mathewson et al., 2009; Vigué-Guix et al., 2022). Thus, another aspect that remains to be discussed in this context concerns the effect of neural oscillations on the ability to suppress distractors. Even though beta oscillations were also discussed in the context of executive control of WM storage, and inhibitory function (Miller et al., 2018; Schmidt et al., 2019; Spitzer & Haegens, 2017), and could therefore possibly be of interest for the discussion as well, two main arguments speak against this. First, beta oscillations cover a broad frequency band, which is why they are commonly grouped into low (13-20 Hz) and high (21-30 Hz) frequency beta oscillations that are associated with various different cognitive functions (Barone & Rossiter, 2021; Cannon et al., 2014; Chandrasekaran et al., 2019; Pfurtscheller et al., 2000; Spitzer & Haegens, 2017), such as movement inhibition (Pogosyan et al., 2009), semantic encoding of episodic memories (Hanslmayr et al., 2009), and language processing (Weiss & Mueller, 2012). Second, even though these functions suggested to be associated with beta oscillations also involve the maintenance of the cognitive state, and the continuation of top-down settings to override potential effects of unexpected external stimuli (Engel & Fries, 2010), they were mainly associated with tasks involving sensorimotor interaction (Barone & Rossiter, 2021; Engel & Fries, 2010; Kilavik et al., 2013). Given these arguments, beta oscillations might therefore not be an ideal candidate for the current research question. Instead, alpha and theta oscillations were shown influence visual detection performance during visual search, depending on the exact pre-stimulus phase of these oscillations (Busch et al., 2009; Mathewson et al., 2009; Vigué-Guix et

al., 2022), and are therefore more relevant for the present research question. However, in summary it becomes clear that research in this field should not only focus on effects associated with the stimulus and experimental design, but also needs to consider possible effects of neural oscillations on visual detection performance.

Therefore, the present study aims to pick up these points and expand previous findings by investigating negative and positive templates in visual search, especially under consideration of the rhythmic fluctuation of the ability to suppress foreknown distractors.

In our experiment, participants saw a specific, trial-by-trial changing orientation that either had to be searched (positive condition) or suppressed (negative condition) in a subsequent search display that was presented at different intervals after a placeholder display. The task was to report the position of a gap in a circle surrounding the correct orientation. Given the above discussed evidence regarding the role of alpha and theta oscillations in top-down control of visual stimuli, and for target detection in visual search (Busch et al., 2009; Jensen & Mazaheri, 2010; Mathewson et al., 2009; Staudigl & Hanslmayr, 2013), we expect significant alpha or theta oscillations in search performance (hit rate and RT) associated with the target orientation in the positive instruction condition. Thus, regarding the effect of different durations of the placeholder display, a higher hit rate is expected if the search display is presented at the peak of the target template oscillation. Likewise, for the negative instruction condition, we also expect alpha and theta oscillations in performance associated with the to-be-ignored orientation evident in a higher hit rate and faster RTs at the peak of the suppression template oscillation.

Method

Participants

Comparable to similar studies (Arita et al., 2012; Chang et al., 2019; Cunningham & Egeth, 2016; Moher & Egeth, 2012; Pomper & Ansorge, 2021; Wen et al., 2018), our sample size consisted of twenty-nine participants, of which all were recruited via the university-intern lab system, receiving course credits for their participation[1]. All of the participants had normal or

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[1] As the data collection took place just before the summer holidays, the participation was lower than expected and the number of participants in the two conditions is therefore not balanced. However, similar sample sizes were used in the comparable studies.

corrected to normal visual acuity and gave written informed consent before the experiment. The data of all twenty-nine participants (24 females, mean age = 21 years, range = 19–49) was included in the data analysis.

Apparatus and Stimuli

The experiment took place in a dimly lit room. To maintain a stable viewing distance at 57 cm, participants were asked to place their head on a chin-forehead rest. Further, they were equipped with a hearing protection to prevent distraction by possible background noise. Stimulus generation and control was conducted using PsychoPy3 (Peirce et al., 2019). An LCD monitor with a resolution of 1,920 x 1,080 pixels (54.4 x 30.3 cm) and a refresh rate of 100 Hz was used to display the stimuli.

The background screen color was grey (RGB-values: -0.5,-0.5,-0,5) during the entire experiment. Stimuli were presented at an imaginary circle with a radius of 7° around a centrally placed white fixation point with a size of 0.1° *0.1°. Cues, targets, and distractors were Gaussian masks with a spatial frequency of 1.5. Cues had a transparency of 0.25, and cue masks and target masks consisted of deconstructed Gaussian masks with a noise element size of 0.0625. The size of stimuli (cues, targets, distractors, masks) was 6° * 6°, with each stimulus surrounded by a circle with a size of 6.5° * 6.5°. Of these surrounding circles each had a gap, consisting of a 1.2° * 2.5° sized rectangle in the background screen color, layered above the stimulus-surrounding circles. These gaps were always placed corresponding to the direction of the four arrow keys on a computer keyboard (up, down, left, right).
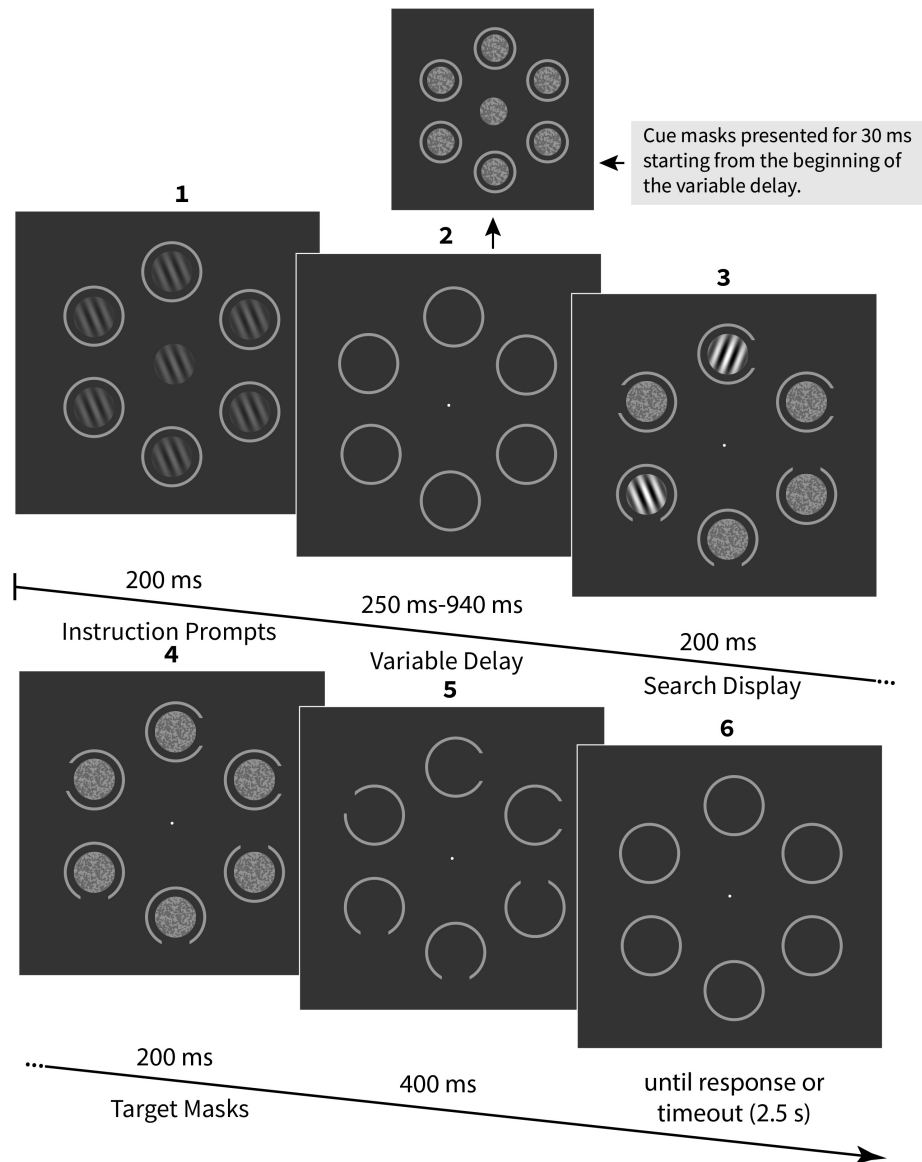
The stimulus choice was based on earlier studies which also used Gabor patches to investigate neural oscillations in the context of visual stimulation (Michail et al., 2022; Pomper & Ansorge, 2021; Sherman et al., 2016; Stenner et al., 2014). Also, *Landolt rings or squares,* interrupted circles or squares with a small gap, were used in such studies (Addleman & Störmer, 2022; Arita et al., 2012; Bergen & Eimer, 2021; Michel et al., 2022). In order to make sure that there were no congruency effects between the orientation of the grating and the position of the gap in the surrounding ring, we decided to solely use non-orthogonal grating orientations, and positioned the gaps in the surrounding rings corresponding to the four arrow keys on a computer keyboard that were used for responding during the experiment.

In total, there were 4 different orientations (Gaussian masks with a spatial frequency of 1.5 and a slope of either 22.5°, 67.5°, 112.5°, or 158.5°) that were combined pseudo-randomly, so that all possible combinations between target and distractor occurred equally often. Thus, it was ensured that there was no connection between the distractor and target orientation that could possibly have been recognized by participants and used to predict the target orientation from the distractor orientation. Further, target and distractor always had distinct Landolt-orientations. But since we used only four different Landolt-orientations (up, down, left, right), the same gap-position could occur twice in the search display, but only at non-relevant positions that neither contained the target nor the distractor orientation.

Procedure

At the beginning of the experiment, each participant completed 20 practice trials, 10 for the positive condition and 10 for the negative condition. For the entire experiment, participants were instructed to answer as quickly and as accurately as possible. The course of a trial was as follows: each trial started with instruction prompts (presented for 200 ms), containing six Gabor patches that surround a centrally placed Gabor patch, all showing the to-be searched or to-be-suppressed orientation for the current trial (depending on the experimental condition). In contrast to subsequent displays, the rings surrounding the Gabor patches shown during the instruction prompts did not contain a gap (see figure 1). The instruction prompts display was followed by a cue masking display that was presented for 30 ms, starting from the beginning of the variable delay, which consisted of 70 possible variable delays ranging from 250 - 940 ms, that were grouped into steps of 10 ms. During these 30 ms, masks surrounded by rings (still not containing gaps) were shown instead of the before presented Gabor patches. After the 30 ms, for the remaining time of the variable delay, only empty rings without gaps were shown. As the instruction prompts display, showing the relevant orientation for the current trial, induced neural oscillations, the varying delay allowed for presentation of the search display at different oscillatory phases of the attentional template. This display was followed by the search display (presented for 200 ms), again consisting of six Gabor patches, of which two showed an orientation pattern while the others were looking like the masks in the placeholder display. In this display, the circles surrounding the Gabor patches showed gaps at different positions (up, down, left, right). After that, a similar display followed, with the only difference that now all six circles contained target masks (presented for 200 ms). In the next display (presented for 400 ms),

Figure 1

Procedure of the experiment

Note. In display 1, the relevant orientation for the present trial is shown (depending on the condition, the orientation either has to be searched for or suppressed in the search display (display 3), that is shown at a variable delay between 250 ms - 940 ms). For the first 30 ms of the variable delay (display 2), cue masks are shown, while there are only empty rings for the remaining time. In display 4, target masks are presented, that were manipulated in terms of transparency, using an adaptive staircase procedure to keep task performance stable at approximately 70 %. In display 5, these masks disappeared and only rings with gaps were visible for 400 ms. The last display, displays 6, contained rings without gaps, and was shown until response or timeout (after 2.5 s).

For the positive condition, the correct response would be to press the down arrow key, because the gap in the ring surrounding the orientation introduced in display 1 points down. For the negative condition, the correct response would be to press the right arrow key, because the orientation introduced in display 1 needs to be suppressed. Instead the position of the gap in the ring surrounding the not-to-be suppressed orientation needs to be reported.

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only the stimulus-surrounding circles with gaps were shown, but they neither contained targets nor target masks. Each trial ended with a display showing only the six circles without gaps. This last display was shown until response (At which position was the gap in the circle surrounding the relevant orientation? - up, down, left, right) or timeout (2.5 s, starting with the presentation of the search display), until the next trial started. The relevant orientation, that either had to be searched or suppressed, changed on a trial-by-trial basis.

In total, the experiment consisted of 1400 trials, 700 trials per instruction condition. For each condition, there were 70 catch trials, in which both of the two orientations in the search display corresponded to the to-be-suppressed orientation. Participants were instructed not to give an answer via the keyboard, if none of the orientations was the one they looked for. After each trial, participants received feedback („Correct" [„Richtig"], „Incorrect" [„Falsch"], „Too slow. Please respond faster." [„Zu langsam. Bitte schneller reagieren."]). Overall, the trials were grouped into 4 blocks of 350 trials each, with alternating positive and negative blocks. 20 of the participants started the experiment with a positive block, the remaining 9 participants started with a negative block. Participants of both groups could take a self-terminated short break after every 175 trials.

Further, comparable to similar studies (Busch et al., 2009; Michel et al., 2022; Pomper & Ansorge, 2021) we implemented an adaptive staircase procedure for the manipulation of the transparency of the target mask, to maintain a mean accuracy rate of 70%. The mask transparency was calculated for each participant individually, for 10 succeeding trials. If the mean accuracy after these 10 trials fell below 70%, mask transparency was increased by 0.1 in order to make the task easier (the maximum value for make transparency was set to 1). In contrast, if the mean accuracy increased to over 70%, the mask transparency was decreased by 0.1 which made the task more difficult (the minimum value for mask transparency was set to 0.1).

Data Analysis

All data analyses were performed with R (Version 4.1.3; R Core Team, 2022), using the R-packages *broom* (Version 1.0.1; Robinson et al., 2022), *data.table* (Version 1.14.2; Dowle & Srinivasan, 2021), *emmeans* (Version 1.7.2; Lenth, 2022), *ggplot2* (Version 3.3.6; Wickham, 2016), *ggrepel* (Version 0.9.1; Slowikowski, 2021), *ggtext* (Version 0.1.1; Wilke, 2020), *gsignal* (Version 0.3.4; Van Boxtel, G.J.M., et al., 2021), *kableExtra* (Version 1.3.4; Zhu, 2021), *knitr*

(Version 1.40; Xie, 2015), *lme4* (Version 1.1.29; Bates et al., 2015), *lmerTest* (Version 3.1.3; Kuznetsova et al., 2017), *MBESS* (Version 4.9.0; Kelley, 2022), *nlme* (Version 3.1.155; Pinheiro et al., 2022)*, papaja* (Version 0.1.1; Aust & Barth, 2022), *questionr* (Version 0.7.7; Barnier et al., 2022), and *rmTools* (Version 0.1.8; Michel, 2022). Further, we used Matlab (2018, Mathworks inc., Natick MA) including the CircStat toolbox (Berens, 2009). For the analysis, outlier trials with RTs deviating more than 2.5 standard deviations from the mean were removed separately for each participant and for each condition. Mean hit rates, describing the percentage of correctly answered trials, and mean RTs for trials that were answered correctly, were computed separately for the two different conditions (positive, negative), as well as for both conditions together.

To examine our hypothesis, whether the hit rate or RTs fluctuate over different stimulus onset asynchronies (SOAs), we further looked at the time course of hit rates and RTs separately for the two conditions. This was done by using a moving-window approach with step sizes of 10ms, in which the average hit rates or RTs within these bins were calculated. Further, to compute the spectral composition, the resulting time courses of hit rate and RTs were detrended by applying a subtraction of the second-order polynomial fit, and further a fast Fourier transform was performed. This resulted in power values for 19 frequency bins covering 0 to 25 Hz. A non-parametric resampling procedure was then applied to the resulting temporal pattern in the time course of the hit rate and RTs to assess the statistical significance of peaks in the power spectrum. For this purpose, hit rates and RTs were randomly reshuffled across the different delay-periods separately for the two conditions and within each participant. The reshuffled data was then analyzed as the observed data. Since this procedure was repeated 10, 000 times, a distribution of 10, 000 power values for the different frequency bins resulted, which was used to determine the statistical thresholds. FDR correction was applied for all 19 frequency bins (Benjamini & Hochberg, 1995). Thus, only those observed spectral peaks which exceeded 99.5% of the surrogate data peaks were considered as significant.

Further, we calculated dependent one-sample t-test to compare the mean RT and the mean hit rate in the two different conditions, respectively.
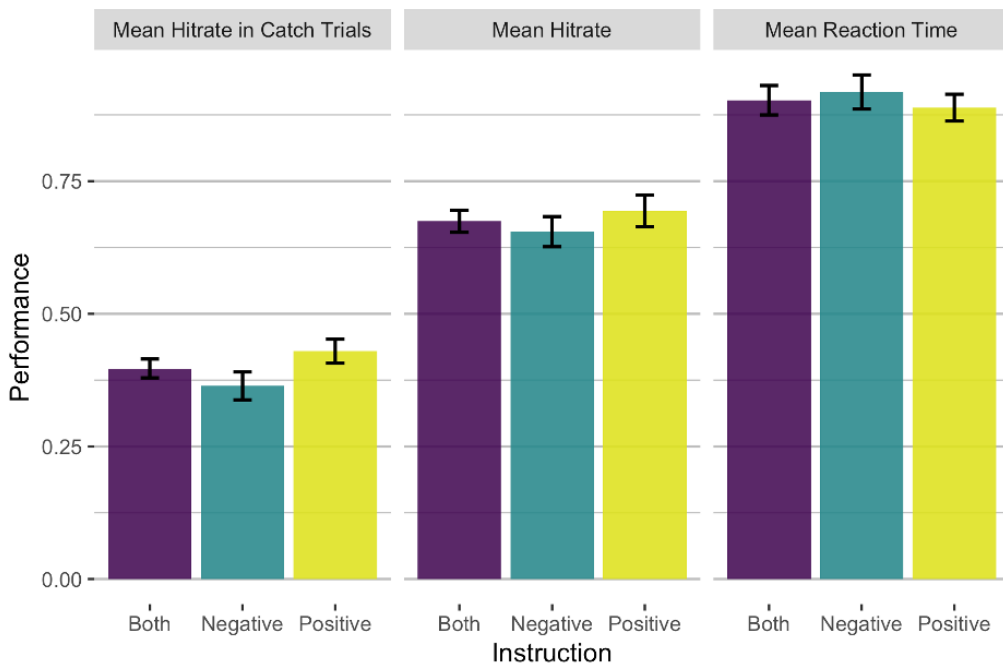
Results

Comparison of the Performance in the Experimental Conditions

We found a slightly higher mean hit rate in the positive condition (M=69.39 %, SD=16.17 %), compared to the negative condition (M=65.49 %, SD=15.13%). We calculated a paired two-sided t-test and found that this difference was significant (M = 3.90 ms, 95% CI [1.47, 6.33], SD = 6.39 ms, t(28) = 3.29, p = .003, d_{unb} = 0.59 [0.21, 1]).

Looking at the mean RTs, we found an overall mean RT of 903 ms (SD=149 ms), with slightly lower mean RTs in the positive condition (M=889 ms, SD= 135 ms) compared to the negative condition (mean=918 ms, SD=172 ms). Again, this difference was significant (M = -29 ms, 95% CI [-56, -2], SD = 71 ms, t(28) = -2.23, p = .034, d_{unb} = -0.40 [-0.79, -0.03]), showing that participants performed significantly better in the positive than in the negative instruction condition.

Figure 2
Performance measures

Note. Mean hit rate in catch trials, mean hit rate and mean RT in non-catch-trials. Displayed as overall measure and separately for the two instructions.

Table 1
Descriptives

Instruction Condition	Measured Variable	Value	*SD*	*SE*
Both Instructions	Mean Hit Rate (in %)	67.44	15.73	2.07
Negative	Mean Hit Rate (in %)	65.49	15.31	2.84
Positive	Mean Hit Rate (in %)	69.39	16.17	3
Both Instructions	Mean Reaction Time (in ms)	903	149	28
Negative	Mean Reaction Time (in ms)	918	172	32
Positive	Mean Reaction Time (in ms)	889	135	25
Both Instructions	Mean Hit Rate in Catch Trials (in %)	39.68	13.53	1.78
Negative	Mean Hit Rate in Catch Trials (in %)	36.40	14.26	2.65
Positive	Mean Hit Rate in Catch Trials (in %)	42.96	12.14	2.25

Note. Mean reaction times in ms. Mean hit rates in %. Standard errors (*SE*) and standard deviations (*SD*) are in ms or %, depending on the measured variable (e.g., *SE* in ms for mean reaction times).

Note. Overview of descriptive performance measures. Mean hit rate in catch trials, mean hit rate and mean RT in non-catch-trials. Values described as overall measures and separately for the two instructions.

However, overall performance in catch trials, where no reaction was required as both of the Gabor patches in the search display showed the to-be-suppressed orientation, was lower (M = 39.68 %, SD = 13.53 %) compared to trials in which an active reaction was required. In the negative condition, the mean hit rate in catch trials was even lower, reaching only 36.40 % (SD=14.26 %), and slightly higher in the positive condition (M=42.96 %, SD=12.14 %).

Neural Oscillations

To test our hypothesis whether there are significant alpha or theta oscillations in search performance (hit rate and RT) associated with the attentional templates in the positive or negative condition, we looked at RTs and hit rates depending on the SOA. However, spectrally these fluctuations were not associated with significant oscillatory peaks.

Additional Analysis

For exploratory interest, we further looked at the wrong answers that were given by the participants.
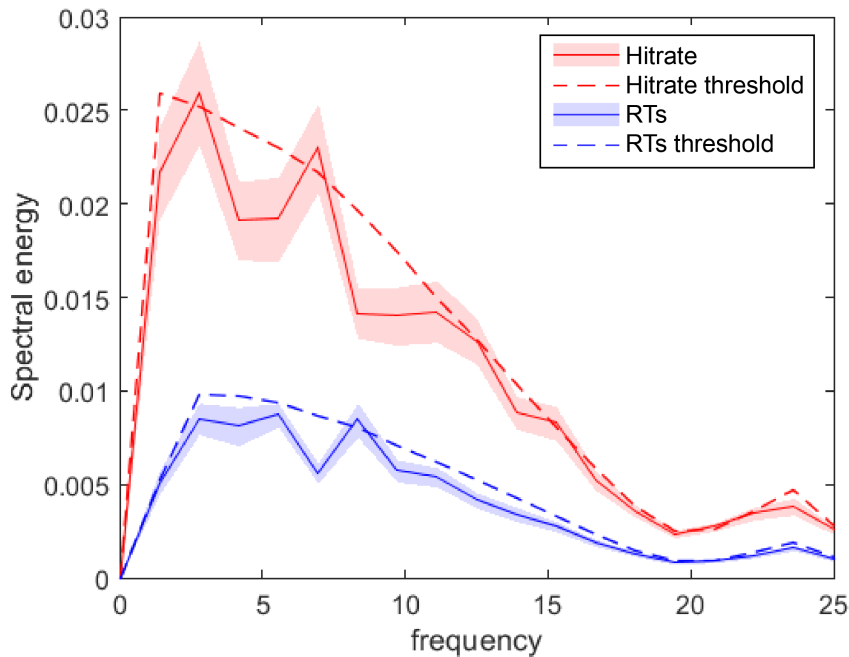
Indeed, when participants answered wrong, it turned out that they were highly likely to react to the irrelevant, to-be-suppressed orientation shown in the search display. Taken both conditions together, 89.81% (SD =15.00 %) of the incorrect answers referred to the irrelevant orientation presented in the search display. This value was slightly higher in the negative (M=91.54 %, SD = 14.69 %) than in the positive (M=87.86%, SD=15.94 %) condition.

Discussion

Previous studies found performance in visual search to benefit from positive cues indicating characteristics of upcoming targets (Arita et al., 2012; Berggen & Eimer, 2021; Conci et al., 2019; Vickery et al., 2005), and further to depend on the precise pre-stimulus phase of certain neural oscillations (Busch et al., 2009; Mathewson et al., 2009; Vigué-Guix et al., 2022). However, since these findings focused on positive templates, our study aimed to expand this knowledge by examining the effects of negative templates containing information about upcoming distractors in visual search, especially under consideration of the rhythmic fluctuation of the ability to suppress distractors corresponding to these templates. Based on these earlier findings, we hypothesized to find alpha- or theta oscillations in hit rate and RTs associated with the positive or negative templates in our visual search experiment. For this purpose, trials with positive, to-be-searched-for templates and negative, to-be-ignored templates were blocked and presented separately. The varying delay of a placeholder display allowed for examination of hit rates and RTs depending on the precise oscillatory phase of the attentional template before the search display was presented. However, contrary to our hypotheses, we neither found significant alpha or theta oscillations in the hit rates or RTs associated with the templates in the positive nor in the negative condition (see figure 3).

Even if the present findings are therefore not fully in line with earlier studies that found such oscillating performance depending on the pre-stimulus oscillatory phase in positive search (Busch et al., 2009; Mathewson et al., 2009; Vigué-Guix et al., 2022), if separated by condition,

Figure 3

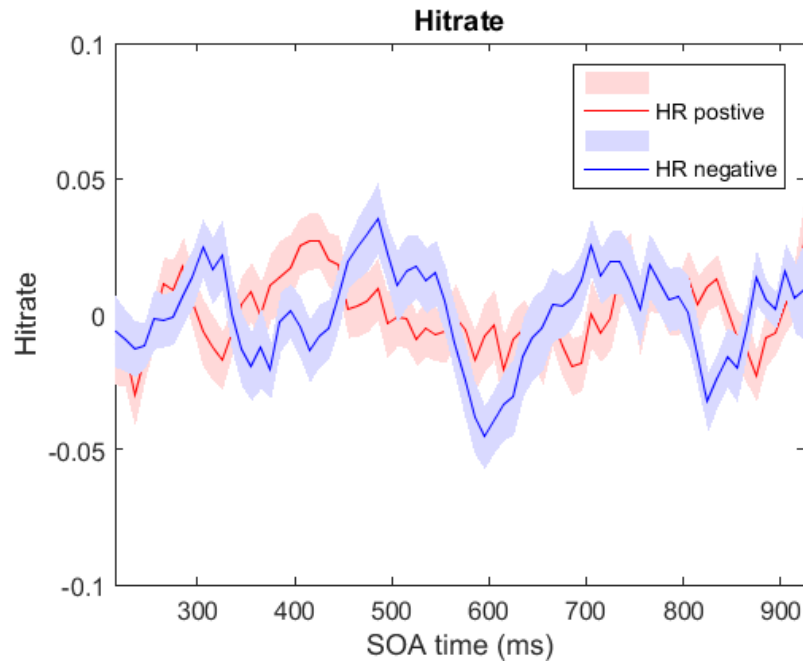*Spectral analysis of mean hit rate and mean RTs for both conditions together*

Note. Spectral analysis of the mean hit rate and mean RTs taken the two conditions together. Data from hit rates is shown in red, data from RTs is shown in blue. The interrupted lines show the surrogate data. The lighter colored areas surrounding the lines indicate the standard errors of the mean. Only peaks exceeding 99.5 % of the surrogate data were considered as significant.

our findings suggests a tendency towards alpha oscillations in the hit rate in the negative condition. The spectral analysis revealed two significant peaks at 6.9 Hz, and at 15.3 Hz. This tendency is also reflected in the time course of the hit rate as can be seen in figure 4. Upon visual inspection, there seem to be rhythmic increases and decreases in hit rates in the negative condition, depending on the different SOAs, suggesting a tendency towards fluctuations at an alpha frequency. Further, when analyzing both conditions together, we found other significant peaks in the spectral analysis - at 2.8 Hz, 6.9 Hz, 15.3 Hz, and at 20.8 Hz. In contrast, for the RTs we found only one significant peak in the spectral analysis at 8.3 Hz when analyzing both conditions together. However, these initially significant oscillatory peaks did not remain significant after correction for multiple comparison. Even though these findings were not significant, they still contribute to the question how positive and negative templates affect visual search, and how oscillations of attentional templates could be reflected in fluctuations in

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performance measures. More specifically, our study provides relevant insights into the importance of characteristics of the experimental design and stimulus choice for future studies addressing this question.

Figure 4
Time course of the hit rate

Note. Time course of the hit rate with mean hit rates for the two conditions, depending on SOA time (ms). Data from positive condition is shown in red, data from negative condition is shown in blue. The lighter colored areas surrounding the lines indicate standard errors of the mean.

Stimulus Features and Complexity

In fact, divergences between earlier findings supporting the idea of oscillating performance in visual search and the present findings might be explained by the experimental design used in our study, as Merholz et al. (2022) recently discussed a link between attentional demands of visual search and associated neural oscillations. For instance, previous studies that found benefits of attentional templates on search performance used comparably simple cues, mostly including colors. Conci et al. (2019) found that positive cues indicating the color of an upcoming target caused significant increases in search efficiency relative to neutral cues indicating a color that would not appear in the search display. Likewise, Arita et al. (2012) found positive color cues,

but also negative cues, containing information about the color of an upcoming distractor, to significantly improve search performance. After extensive practice with the same distractor, such an effect was also evident when written instructions (e.g., „Ignore Red") were used as cues (Cunningham & Egeth, 2016). These findings are in line with Zhuang and Papathomas (2011) and Anderson et al. (2010) who both found that visual search could benefit from color cues (in visual and verbal form), but that more complex cues, showing the orientation of an upcoming target, could not improve search performance. Further, this assumption is supported by the findings discussed by Töllner et al. (2015) who showed that high target-distractor dissimilarity is required for efficient target detection - colored stimuli allow for higher and more easily perceptible differences between targets and distractors compared to Gabor patches with differently tilted orientations as used in our study. Thus, in line with Zhuang & Papathomas (2011) who found color cues to be more efficient for the guidance of attention during visual search than orientation cues, it is likely that the orientation stimuli used in the present study were less suited for the configuration of attentional templates compared to the color cues used in earlier studies.

Beyond that, the specific features of stimuli were further shown to have an influence on the time-course of top-down guided visual search (Zhuang & Papathomas, 2011). More precisely, in an experiment involving motion stimuli, feature-based attention based on color was found to modulate task performance faster than spatial attention (Liu et al., 2007; Zhuang & Papathomas, 2011). In line with that, Moher and Egeth (2012) found the duration between the negative cue and the search display to be a decisive factor for the efficacy of negative cues for the guidance of attention during visual search. More precisely, in their experiment search was only speeded if the duration between the cue of distractor features (location) and the search display was at least 800 ms. In contrast, if the placeholder duration was below 800 ms, negative cues slowed search compared to neutral or positive cues. According to their interpretation, placeholder durations below 800 ms were too short for participants to select and subsequently inhibit the cued distractor features. In contradiction to this finding, using color stimuli,

Arita et al. (2012) showed that 100 ms were enough time for participants to configure a template for rejection that speeded visual search. Critically, even though they argue that the efficacy of negative templates increased with the processing load of the visual scene, it needs to be considered that their search display consisted of either 4, 8 or 12 stimuli presented in only two

different colors with items within the same hemifield in the same color. Thus, as this search display was comparably simple, 100 ms were possibly enough for participants to configure and efficiently use attentional templates to initially reduce search set size by 50%. However, Moher and Egeth (2012) who used more than two colors and more inhomogeneously arranged stimuli in the search display found that participants needed at least 800 ms to set up such attentional templates to effectively improve search performance. These divergences might point towards an explanation, why participants in our study could not configure attentional templates for improvement of search performance. Even though the mean RTs and mean hit rates both were significantly better in the positive compared to the negative condition, these differences still were comparably small (e.g., see much more significant RT-differences in Arita et al., 2012; Becker et al., 2015; Conci et al., 2019). Following these earlier findings, if the attentional template could have been configured accurately in our study, performance measures should have been significantly better in the positive condition.

However, with regard to the cue-search interval in our study design, the placeholder duration ranged from 250 ms - 940 ms, and was therefore below the 800 ms suggested by Moher and Egeth (2012) in most of the trials. It is likely that the short cue-search interval impeded the configuration of such a complex attentional template in our study. This assumption is supported by the findings of our additional analysis on the error rates. Approximately 87 % of the wrong answers, and even more (approx. 91 % of the wrong answers) in the negative condition referred to the irrelevant orientation presented in the search display. As the time was too short for the accurate configuration of an attentional template, participants erroneously attended the wrong orientation so often. Further, it cannot be ruled out that participants initially attended the to-be-ignored orientation in the negative condition, before they could focus their attention on the correct orientation, therefore causing higher mean RTs in the negative condition. In this regard, it would have been interesting to examine if the attentional templates could have been configured more accurately by participants in our study in trials with longer placeholder durations. However, with our data, a separate analysis would not have been reasonable, since this would have excluded approximately 85% of trials with placeholder durations below 800 ms, leaving too little data for a statistical analysis. Further, as Moher and Egeth (2012) grouped the placeholder durations (100 ms, 800 ms, and 1500 ms), it is likely that 100 ms were too short for participants to establish a template for rejection in their experimental design, but that this would have been

possible with slightly longer durations between 100 ms and 800 ms, as suggested by Arita et al. (2012).

Taken together, the complexity of the cue, and the cue-search display interval might be decisive factors for the ability to configure attentional templates. Thus, regarding future studies, these findings point towards an important aspect of the experimental design, as our results suggest that especially for more complex cues, longer cue-search intervals seem to be required for the configuration of attentional templates.

Saliency-Increase caused by Cues

Besides these insights on stimulus choice and cue-search intervals, our results contribute to the initially introduced discussion between stimulus-driven models and goal-dependent models, supporting the intermediate position of the signal suppression hypothesis (Sawaki & Luck, 2010) that integrates these two theories. Following stimulus-dependent models that assume salient stimuli to capture attention automatically, the orientation cues possibly caused the cued orientation to be perceived with higher saliency, therefore automatically attracting the participants attention. This assumption that the perceived salience of the cued orientation was increased is in line with Nothdurft (2002) who showed that visual cues evoke salience similar to outstanding stimulus features. In the positive condition of our study, participants were asked to report the position of the gap in the ring surrounding the cued orientation. But in the negative condition, participants were instructed to ignore this cued orientation and instead report the position of the gap surrounding the orientation that was not cued. However, in line with the assumption that the cued orientation was perceived with higher salience, we found a higher mean hit rate in the positive condition, associated with lower mean RTs. Nonetheless, it is likely that the participant's attention was not only attracted by the orientation perceived with higher salience evoked by the cue in the positive condition where they were instructed to do so, but also in the negative condition, where they should have suppressed this cued orientation. As suggested by the stimulus-dependent models, participants might have initially attended the to-be-suppressed orientation, before they directed their attention to the uncued orientation in the search display, which could explain the higher mean RTs in the negative condition. As discussed above, this might be especially likely when distractors change on a trial-by- trial basis, because this possibly impedes the accurate configuration of an attentional template. However, in line with goal-dependent models that point out that attention is only attracted by stimuli that show task-relevant

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features, the signal suppression theory suggests that this automatic attraction of attention can be prevented if there are appropriate attentional settings - configured through the repeated use of the same distractor. In other words, extensive practice with the same distractor might be required for efficient attentional control, enabling participants to suppress the corresponding distractor-orientation instead of being attracted by it. If there are no such attentional control settings, irrelevant stimuli (e.g., the to-be-suppressed distractor orientation in our experiment) can automatically attract attention. Using color stimuli, Berggren and Eimer (2021), found that search performance did not benefit from negatively cued non-targets if they changed on a trial-by-trial basis. However, only if there was extensive training with the same distractor for at least 24 trials, these initial costs associated with negative templates turned into benefits for visual search. Similarly, Cunningham and Egeth (2016) also found improved search performance through ignoring benefit after 72 trials when the distractor remained the same. Consequently, the trial-by-trial change of stimuli, as used in our study, might impede the configuration of appropriate attentional control settings, therefore not enabling participants to use the cued information effectively. Precise attentional templates were, however, described to enable more efficient disregard of distractors, especially under conditions with high target-distractor similarity (Leber & Egeth, 2006) as in our study. In this regard, as our findings suggest only non-significant trends towards oscillating search performance, it might be interesting to adapt our study design by keeping distractors or targets constant over multiple trials.

Limitations and Future Research Implications

The above discussed aspects point towards limitations of the current study, and at the same time, propose starting points for future research resulting from the present findings.

We inferred neural oscillations from time courses of behavioral measures, hypothesizing oscillations of the attentional templates to be reflected in alpha- or theta oscillations of the hit rate and RTs. However, since this hypothesis could not be supported with the present data, the purely behavioral approach might have constrained the probability to detect the underlying neural oscillations of the attentional templates. Thus, in addition to the behavioral data, EEG could be used to assess the neural oscillations of interest. However, what needs to be considered is that the effect of alpha oscillation phase on stimulus perception is moderated by attention

(Busch and VanRullen, 2010). As it is likely that attention is not constant over the entire course of an experimental block, future studies might further examine hit rates and RTs not only with regard to a single average measure for the entire block, but divide the analysis of the performance measures into multiple subgroups to control for possible fluctuations of attention within the blocks. Further, the exploration of ERPs would provide information on whether the negative templates were actually suppressed, or, as assumed by the search-and-destroy hypothesis (Moher & Egeth, 2012), initially attracted attention before they could be ignored. An indication for this assumption might be the longer RTs we found in the negative condition, but based on the behavioral data collected, we cannot make any reliable statements about the functioning of the attentional templates. Thus, two ERPs that might be of interest are the N2pc, a negative deflection in the EEG wave contralateral to the stimulus occurring approximately 200 ms after stimulus presentation, and the Pd (distractor positivity) describing a positive deflection occurring with a post-stimulus latency of approximately 200 ms (Hickey et al., 2009; Luck & Hillyard, 1994; Mertes et al., 2016). The N2pc was discussed as marker of selective attentional processing associated with the initial focusing on target stimuli in multiple-stimuli search arrays and attentional suppression of non-targets surrounding relevant stimuli (Eimer, 1996; Kiss et al., 2008; Luck & Hillyard, 1994). In contrast, the Pd was assumed to indicate attentional suppression and the reduction of attentional priority associated with salient distractor stimuli to facilitate target processing (Hickey et al., 2009; Hilimire et al., 2012; Sawaki & Luck, 2011). However, with regard to the fact that we could not find significant oscillations associated with positive templates - which is in contrast to earlier findings - it is likely that our sample size was too small to detect significant effects. Even though comparable studies had similar sample sizes, it needs to be considered that these studies used comparably simple color stimuli, possibly causing larger effects than our more complex orientation stimuli. Further, due to the data collections starting just before the summer holidays, less participants than expected participated in the experiment, causing an unequal distribution of the participants in the two conditions. Thus, to obtain more robust findings, future studies using such comparably complex stimuli or examine related research questions exclusively with behavioral measures, might choose larger sample sizes.

Even though we aimed to focus on positive and negative templates in visual search, the integration of a neutral condition, as was frequently done in comparable studies, would have

enabled a more detailed exploration of the effects of informative attentional templates compared to uninformative templates. Performance measures in the positive and negative condition relative to a neutral, baseline condition, would allow for more extensive conclusions, as previous findings (Arita et al., 2012; Conci et al., 2019) suggest that, compared to neutral cues, negative cues could indeed improve search performance.

Conclusion

To sum up, together with earlier findings indicating that negative templates could indeed be beneficial for visual search, our results indicate that the characteristics of the experimental design are decisive for the efficient configuration of attentional templates. Even though we neither found significant alpha- or theta oscillations in hit rates or RTs associated with negative nor with positive templates, the present thesis intended to take the obtained findings as a starting point to identify crucial aspects of the experimental design to provide guidance for future studies. As discussed above, it is suggested that the stimulus complexity and the cue-search interval could be decisive factors for negative, but also positive attentional templates to effectively improve search performance. Thus, future studies might examine the effect of negative and positive attentional templates by varying the stimulus complexity and the cue-search interval. For instance, it might be interesting if such complex cues as used in the present design could be used for the configuration of appropriate attentional templates with different longer cue-search intervals, and if the initially hypothesized oscillations in performance measures become visible then. Apart from that, the assessment of the underlying neural oscillations and ERPs using EEG might be more reliable and could also provide more detailed insights about the function of attentional templates.

References

Addleman, D. A., & Störmer, V. S. (2022). Distractor ignoring is as effective as target enhancement when incidentally learned but not when explicitly cued. *Attention, Perception & Psychophysics*, 10.3758/s13414-022-02588-y. Advance online publication. https://doi.org/10.3758/s13414-022-02588-y

Anderson, G. M., Heinke, D., & Humphreys, G. W. (2010). Featural guidance in conjunction search: The contrast between orientation and color. *Journal of Experimental Psychology. Human Perception and Performance*, *36*(5), 1108–1127. https://doi.org/10.1037/a0017179

Arita, J. T., Carlisle, N. B., & Woodman, G. F. (2012). Templates for rejection: Configuring attention to ignore task-irrelevant features. *Journal of Experimental Psychology: Human Perception and Performance*, *38*(3), 580–584. https://doi.org/10.1037/a0027885

Aust, F., & Barth, M. (2022). *papaja: Prepare reproducible APA journal articles with R Markdown*. https://github.com/crsh/papaja

Barnier, J., Briatte, F., & Larmarange, J. (2022). *Questionr: Functions to make surveys processing easier*. https://CRAN.R-project.org/package=questionr

Barone, J., & Rossiter, H. E. (2021). Understanding the role of sensorimotor beta oscillations. *Frontiers in Systems Neuroscience*, *15*, Article 655886. https://doi.org/10.3389/fnsys.2021.655886

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, *67*(1), 1–48. https://doi.org/10.18637/jss.v067.i01

Bauer, E. A., Wilson, K. A., & MacNamara, A. (2022). Cognitive and affective psychophysiology. In G. J. D. Asmundson (Ed.), *Comprehensive Clinical Psychology* (2nd ed., Vol. 11, pp. 49–61). Elsevier. https://doi.org/10.1016/B978-0-12-818697-8.00013-3

Beck, V. M., Luck, S. J., & Hollingworth, A. (2018). Whatever you do, don't look at the . . .: Evaluating guidance by an exclusionary attentional template. *Journal of Experimental Psychology: Human Perception and Performance, 44*(4), 645–662. https://doi.org/10.1037/xhp0000485

Becker, Hemsteger, S., & Peltier, C. (2015). No templates for rejection: A failure to configure attention to ignore task-irrelevant features. *Visual Cognition*, *23*(9-10), 1150–1167. https://doi.org/10.1080/13506285.2016.1149532

Benjamini, Y., & Hochberg, Y. (1995). Controlling the false discovery rate: A practical and powerful approach to multiple testing. *Journal of the Royal Statistical Society*, *57*(1), 289– 300. https://doi.org/10.1111/j.2517-6161.1995.tb02031.x

Berens, P. (2009). CircStat: A MATLAB toolbox for circular statistics. *Journal of Statistical Software*, *31*(10), 1–21. https://doi. org/10.1002/wics.10

Berggren, N., & Eimer, M. (2021). The guidance of attention by templates for rejection during visual search. *Attention, Perception & Psychophysics*, *83*(1), 38–57. https://doi.org/ 10.3758/s13414-020-02191-z

Bonnefond, M., & Jensen, O. (2012). Alpha oscillations serve to protect working memory maintenance against anticipated distracters. *Current Biology*, *22*(20), 1969–1974. https://doi.org/10.1016/j.cub.2012.08.029

Busch, N. A., Dubois, J., & VanRullen, R. (2009). The phase of ongoing EEG oscillations predicts visual perception. *The Journal of Neuroscience*, *29*(24), 7869–7876. https:// doi.org/ 10.1523/JNEUROSCI.0113-09.2009

Busch, N. A., & VanRullen, R. (2010). Spontaneous EEG oscillations reveal periodic sampling of visual attention. *Proceedings of the National Academy of Sciences of the United States of America*, *107*(37), 16048–16053. https://doi.org/10.1073/pnas.1004801107

Callaway, E., & Yeager, C. L. (1960). Relationship between reaction time and electroencephalographic alpha phase. *Science, 132*, 1765 - 1766. https://doi.org/ 10.1126/science.132.3441.1765

Cannon, J., McCarthy, M. M., Lee, S., Lee, J., Börgers, C., Whittington, M. A., & Kopell, N. (2014). Neurosystems: Brain rhythms and cognitive processing. *The European Journal of Neuroscience*, *39*(5), 705–719. https://doi.org/10.1111/ejn.12453

Chandrasekaran, C., Bray, I. E., & Shenoy, K. V. (2019). Frequency shifts and depth dependence of premotor beta band activity during perceptual decision-making. *The Journal of Neuroscience*, *39*(8), 1420–1435. https://doi.org/10.1523/JNEUROSCI.1066-18.2018

Chang, S., Cunningham, C. A., & Egeth, H. E. (2019). The power of negative thinking: Paradoxical but effective ignoring of salient-but-irrelevant stimuli with a spatial cue. *Visual Cognition*, *27*(3-4), 199-213. https://doi.org/10.1080/13506285.2018.1541950

Clayton, M. S., Yeung, N., & Cohen Kadosh, R. (2018). The many characters of visual alpha oscillations. *The European Journal of Neuroscience*, *48*(7), 2498–2508. https://doi.org/10.1111/ejn.13747

Cochran, W. T., Cooley, J. W., Favin, D. L., Helms, H. D., Kaenel, R. A., Lang, W. W., Maling, G. C., Nelson, D. E., Rader, C. M., & Welch, P. D. (1967). What is the fast Fourier transform. *IEEE Transactions on Audio and Electroacoustics, 15*, 45-55. https://doi.org/10.1109/PROC.1967.5957

Conci, M., Deichsel, C., Müller, H. J., & Töllner, T. (2019). Feature guidance by negative attentional templates depends on search difficulty. *Visual Cognition, 27*(3-4), 317–326. https://doi.org/10.1080/13506285.2019.1581316

Cunningham, C. A., & Egeth, H. E. (2016). Taming the white bear: Initial costs and eventual benefits of distractor inhibition. *Psychological Science*, *27*(4), 476–485. https://doi.org/10.1177/0956797615626564

Daume, J., Wang, P., Maye, A., Zhang, D., & Engel, A. K. (2021). Non-rhythmic temporal prediction involves phase resets of low-frequency delta oscillations. *NeuroImage*, *224*, Article 117376. https://doi.org/10.1016/j.neuroimage.2020.117376

de Vries, I. E., Slagter, H. A., & Olivers, C. N. (2020). Oscillatory control over representational states in working memory. *Trends in Cognitive Sciences*, *24*(2), 150-162. https://doi.org/10.1016/j.tics.2019.11.006

Dowle, M., & Srinivasan, A. (2021). *Data.table: Extension of 'data.frame'*. https://CRAN.R-project.org/package=data.table

Drisdelle, B. L., & Eimer, M. (2021). PD components and distractor inhibition in visual search: New evidence for the signal suppression hypothesis. *Psychophysiology*, *58*(9), Article e13878. https://doi.org/10.1111/psyp.13878

Dugué, L., Marque, P., & VanRullen, R. (2011). The phase of ongoing oscillations mediates the causal relation between brain excitation and visual perception. *The Journal of Neuroscience*, *31*(33), 11889–11893. https://doi.org/10.1523/JNEUROSCI.1161-11.2011

Dugué, L., Marque, P., & VanRullen, R. (2015). Theta oscillations modulate attentional search performance periodically. *Journal of Cognitive Neuroscience, 27*(5), 945–958. https://doi.org/ 10.1162/jocn_a_00755

Dustman, R. E., & Beck, E. C. (1965). Phase of alpha brain waves, reaction time and visually evoked potentials. *Electroencephalography & Clinical Neurophysiology, 18*(5), 433–440. https://doi.org/10.1016/0013-4694(65)90123-9

Eimer, M. (1996). The N2pc component as an indicator of attentional selectivity. *Electroencephalography & Clinical Neurophysiology, 99*(3), 225–234. https://doi.org/ 10.1016/0013-4694(96)95711-9

Engel, A. K. & Fries, P. (2010). Beta-band oscillations — signalling the status quo? *Current Opinion in Neurobiology, 20*(2), 156–165. https://doi.org/10.1016/j.conb.2010.02.015

Feldmann-Wüstefeld, T., & Vogel, E. K. (2019). Neural evidence for the contribution of active suppression during working memory filtering. *Cerebral Cortex, 29*(2), 529–543. https://doi.org/10.1093/cercor/bhx336

Fodor, Z., Marosi, C., Tombor, L., & Csukly, G. (2020). Salient distractors open the door of perception: Alpha desynchronization marks sensory gating in a working memory task. *Scientific Reports, 10*(1), Article 19179. https://doi.org/10.1038/s41598-020-76190-3

Folk, C. L., Remington, R. W., & Johnston, J. C. (1992). Involuntary covert orienting is contingent on attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance, 18*(4), 1030–1044. https://doi.org/ 10.1037//0096-1523.18.4.1030

Folstein, J. R., & Van Petten, C. (2008). Influence of cognitive control and mismatch on the N2 component of the ERP: A review. *Psychophysiology, 45*(1), 152–170. https://doi.org/ 10.1111/j.1469-8986.2007.00602.x

Foxe, J. J., & Snyder, A. C. (2011). The role of alpha-band brain oscillations as a sensory suppression mechanism during selective attention. *Frontiers in Psychology, 2*, Article 154. https:// doi.org/10.3389/fpsyg.2011.00154

Gaspelin, N., Leonard, C. J., & Luck, S. J. (2015). Direct evidence for active suppression of salient- but-irrelevant sensory inputs. *Psychological Science*, *26*(11), 1740–1750. https://doi.org/ 10.1177/0956797615597913

Gaspelin, N., & Luck, S. J. (2018). Combined electrophysiological and behavioral evidence for the suppression of salient distractors. *Journal of Cognitive Neuroscience*, *30*(9), 1265–1280. https://doi.org/10.1162/jocn_a_01279

Hanslmayr, S., Axmacher, N., & Inman, C. S. (2019). Modulating human memory via entrainment of brain oscillations. *Trends in Neurosciences*, *42*(7), 485–499. https://doi.org/10.1016/ j.tins.2019.04.004

Hanslmayr, S., Spitzer, B., & Bäuml, K. H. (2009). Brain oscillations dissociate between semantic and nonsemantic encoding of episodic memories. *Cerebral Cortex*, *19*(7), 1631–1640. https://doi.org/10.1093/cercor/bhn197

Hickey, C., Di Lollo, V., & McDonald, J. J. (2009). Electrophysiological indices of target and distractor processing in visual search. *Journal of Cognitive Neuroscience*, *21*(4), 760–775. https://doi.org/10.1162/jocn.2009.21039

Hickey, C., McDonald, J. J., & Theeuwes, J. (2006). Electrophysiological evidence of the capture of visual attention. *Journal of Cognitive Neuroscience*, *18*(4), 604–613. https://doi.org/ 10.1162/jocn.2006.18.4.604

Hilimire, M. R., Hickey, C., & Corballis, P. M. (2012). Target resolution in visual search involves the direct suppression of distractors: Evidence from electrophysiology. *Psychophysiology*, *49*(4), 504–509. https://doi.org/10.1111/j.1469-8986.2011.01326.x

Jannati, A., Gaspar, J. M., & McDonald, J. J. (2013). Tracking target and distractor processing in fixed-feature visual search: Evidence from human electrophysiology. *Journal of Experimental Psychology: Human Perception and Performance, 39*(6), 1713–1730. https:// doi.org/10.1037/a0032251

Jensen, O., Gelfand, J., Kounios, J., & Lisman, J. E. (2002). Oscillations in the alpha band (9-12 Hz) increase with memory load during retention in a short-term memory task. *Cerebral Cortex*, *12*(8), 877–882. https://doi.org/10.1093/cercor/12.8.877

Jensen, O., & Mazaheri, A. (2010). Shaping functional architecture by oscillatory alpha activity: Gating by inhibition. *Frontiers in Human Neuroscience, 4*, Article 186. https://doi.org/ 10.3389/ fnhum.2010.00186

Jensen, O., & Tesche, C. D. (2002). Frontal theta activity in humans increases with memory load in a working memory task. *European Journal of Neuroscience, 15*(8), 1395–1399. https://doi.org/10.1046/j.1460-9568.2002.01975.x

Jonides, J., & Yantis, S. (1988). Uniqueness of abrupt visual onset in capturing attention. *Perception & Psychophysics, 43*(4), 346–354. https://doi.org/10.3758/BF03208805

Kelley, K. (2022). *MBESS: The MBESS r package*. https://CRAN.R-project.org/ package=MBESS

Kerzel, D., & Huynh Cong, S. (2021). Attentional templates are sharpened through differential signal enhancement, not differential allocation of attention. *Journal of Cognitive Neuroscience, 33*(4), 594–610. https://doi.org/10.1162/jocn_a_01677

Kilavik, B. E., Zaepffel, M., Brovelli, A., MacKay, W. A., & Riehle, A. (2013). The ups and downs of β oscillations in sensorimotor cortex. *Experimental Neurology, 245*, 15–26. https://doi.org/10.1016/j.expneurol.2012.09.014

Kiss, M., Van Velzen, J., & Eimer, M. (2008). The N2pc component and its links to attention shifts and spatially selective visual processing. *Psychophysiology, 45*(2), 240–249. https://doi.org/ 10.1111/j.1469-8986.2007.00611.x

Klimesch W. (2012). α-band oscillations, attention, and controlled access to stored information. *Trends in Cognitive Sciences, 16*(12), 606–617. https://doi.org/10.1016/ j.tics.2012.10.007

Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. B. (2017). lmerTest package: Tests in linear mixed effects models. *Journal of Statistical Software, 82*(13), 1–26. https:// doi.org/10.18637/jss.v082.i13

Leber, A. B., & Egeth, H. E. (2006). It's under control: Top-down search strategies can override attentional capture. *Psychonomic Bulletin & Review, 13*(1), 132–138. https://doi.org/ 10.3758/bf03193824

Lenth, R. V. (2022). *Emmeans: Estimated marginal means, aka least-squares means*. https://CRAN.R-project.org/package=emmeans

Liu, T., Stevens, S. T., & Carrasco, M. (2007). Comparing the time course and efficacy of spatial and feature-based attention. *Vision Research*, *47*(1), 108–113. https://doi.org/10.1016/j.visres.2006.09.017

Luck, S. J., Gaspelin, N., Folk, C. L., Remington, R. W., & Theeuwes, J. (2021). Progress toward resolving the attentional capture debate. *Visual Cognition*, *29*(1), 1–21. https://doi.org/10.1080/13506285.2020.1848949

Luck, S. J., & Hillyard, S. A. (1994). Spatial filtering during visual search: Evidence from human electrophysiology. *Journal of Experimental Psychology: Human Perception and Performance, 20*(5), 1000–1014. https://doi.org/10.1037/0096-1523.20.5.1000

Marko, M., Cimrová, B., & Riečanský, I. (2019). Neural theta oscillations support semantic memory retrieval. *Scientific Reports*, *9*(1), Article 17667. https://doi.org/10.1038/s41598-019-53813-y

Mathewson, K. E., Gratton, G., Fabiani, M., Beck, D. M., & Ro, T. (2009). To see or not to see: Prestimulus alpha phase predicts visual awareness. *The Journal of Neuroscience*, *29*(9), 2725–2732. https://doi.org/10.1523/JNEUROSCI.3963-08.2009

McDonald, J. J., Green, J. J., Jannati, A., & Di Lollo, V. (2013). On the electrophysiological evidence for the capture of visual attention. *Journal of Experimental Psychology: Human Perception and Performance*, *39*(3), 849–860. https://doi.org/10.1037/a0030510

Merholz, G., Grabot, L., VanRullen, R., & Dugué, L. (2022). Periodic attention operates faster during more complex visual search. *Scientific Reports*, *12*(1), Article 6688. https://doi.org/10.1038/s41598-022-10647-5

Mertes, C., Wascher, E., & Schneider, D. (2016). From capture to inhibition: How does irrelevant information influence visual search? Evidence from a spatial cuing paradigm. *Frontiers in Human Neuroscience, 10*, Article 232. https://doi.org/10.3389/fnhum.2016.00232

Michail, G., Toran Jenner, L., & Keil, J. (2022). Prestimulus alpha power but not phase influences visual discrimination of long-duration visual stimuli. *The European Journal of Neuroscience*, *55*(11-12), 3141–3153. https://doi.org/10.1111/ejn.15169

Michel, R. (2022). *rmTools: Provides basic r functionalities*.

Michel, R., Dugué, L., & Busch, N. A. (2022). Distinct contributions of alpha and theta rhythms to perceptual and attentional sampling. *The European Journal of Neuroscience*, *55*(11-12), 3025–3039. https://doi.org/10.1111/ejn.15154

Miller, E. K., Lundqvist, M., & Bastos, A. M. (2018). Working memory 2.0. *Neuron*, *100*(2), 463–475. https://doi.org/10.1016/j.neuron.2018.09.023

Moher, J., & Egeth, H. E. (2012). The ignoring paradox: Cueing distractor features leads first to selection, then to inhibition of to-be-ignored items. *Attention, Perception, & Psychophysics*, *74*(8), 1590-1605. https://doi.org/10.3758/s13414-012-0358-0

Nothdurft H. C. (2002). Attention shifts to salient targets. *Vision Research*, *42*(10), 1287–1306. https://doi.org/10.1016/s0042-6989(02)00016-0

Palacios-García, I., Silva, J., Villena-González, M., Campos-Arteaga, G., Artigas-Vergara, C., Luarte, N., Rodríguez, E., & Bosman, C. A. (2021). Increase in beta power reflects attentional top-down modulation after psychosocial stress induction. *Frontiers in Human Neuroscience*, *15*, Article 630813. https://doi.org/10.3389/fnhum.2021.630813

Peirce, J. W., Gray, J. R., Simpson, S., MacAskill, M. R., Höchenberger, R., Sogo, H., Kastman, E., Lindeløv, J. (2019). PsychoPy2: Experiments in behavior made easy. *Behavior Research Methods. 51*(1), 195–203. https://doi.org/10.3758/s13428-018-01193-y

Pfurtscheller, G., Neuper, C., Pichler-Zalaudek, K., Edlinger, G., & Lopes da Silva, F. H. (2000). Do brain oscillations of different frequencies indicate interaction between cortical areas in humans?. *Neuroscience Letters*, *286*(1), 66–68. https://doi.org/10.1016/s0304-3940(00)01055-7

Pinheiro, J., Bates, D., DebRoy, S., Sarkar, D., & R Core Team. (2022). *nlme: Linear and nonlinear mixed effects models*. https://CRAN.R-project.org/package=nlme

Pogosyan, A., Gaynor, L. D., Eusebio, A., & Brown, P. (2009). Boosting cortical activity at beta-band frequencies slows movement in humans. *Current Biology*, *19*(19), 1637–1641. https://doi.org/10.1016/j.cub.2009.07.074

Pomper, U., & Ansorge, U. (2021). Theta-Rhythmic oscillation of working memory performance. *Psychological Science*, *32*(11), 1801–1810. https://doi.org/10.1177/09567976211013045

R Core Team. (2022). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. https://www.R-project.org/

Raghavachari, S., Kahana, M. J., Rizzuto, D. S., Caplan, J. B., Kirschen, M. P., Bourgeois, B., Madsen, J. R., & Lisman, J. E. (2001). Gating of human theta oscillations by a working memory task. *The Journal of Neuroscience*, *21*(9), 3175–3183. https://doi.org/10.1523/JNEUROSCI.21-09-03175.2001

Reeder, R. R., Olivers, C. N. L., & Pollmann, S. (2017). Cortical evidence for negative search templates. *Visual Cognition, 25*(1-3), 278–290. https://doi.org/10.1080/13506285.2017.1339755

Richter, C. G., Coppola, R., & Bressler, S. L. (2018). Top-down beta oscillatory signaling conveys behavioral context in early visual cortex. *Scientific Reports*, *8*(1), Article 6991. https://doi.org/10.1038/s41598-018-25267-1

Riddle, J., Scimeca, J. M., Cellier, D., Dhanani, S., & D'Esposito, M. (2020). Causal evidence for a role of theta and alpha oscillations in the control of working memory. *Current Biology*, *30*(9), 1748–1754. https://doi.org/10.1016/j.cub.2020.02.065

Robinson, D., Hayes, A., & Couch, S. (2022). *Broom: Convert statistical objects into tidy tibbles*. https://CRAN.R-project.org/package=broom

Roux, F., & Uhlhaas, P. J. (2014). Working memory and neural oscillations: α-γ versus θ-γ codes for distinct WM information?. *Trends in Cognitive Sciences*, *18*(1), 16–25. https://doi.org/10.1016/j.tics.2013.10.010

Saby, J. N., & Marshall, P. J. (2012). The utility of EEG band power analysis in the study of infancy and early childhood. *Developmental Neuropsychology*, *37*(3), 253–273. https://doi.org/10.1080/87565641.2011.614663

Salahub, C., & Emrich, S. M. (2021). Drawn to distraction: Anxiety impairs neural suppression of known distractor features in visual search. *Journal of Cognitive Neuroscience*, *33*(8), 1504-1516. https://doi.org/10.1162/jocn_a_01743

Sauseng, P., Griesmayr, B., Freunberger, R., & Klimesch, W. (2010). Control mechanisms in working memory: A possible function of EEG theta oscillations. *Neuroscience and Biobehavioral Reviews*, *34*(7), 1015–1022. https://doi.org/10.1016/j.neubiorev.2009.12.006

Sawaki, R., & Luck, S. J. (2010). Capture versus suppression of attention by salient singletons: Electrophysiological evidence for an automatic attend-to-me signal. *Attention, Perception, & Psychophysics, 72*(6), 1455–1470. https://doi.org/10.3758/APP.72.6.1455

Sawaki, R., & Luck, S. J. (2011). Active suppression of distractors that match the contents of visual working memory. *Visual Cognition, 19*(7), 956–972. https://doi.org/10.1080/13506285.2011.603709

Schmidt, R., Herrojo Ruiz, M., Kilavik, B. E., Lundqvist, M., Starr, P. A., & Aron, A. R. (2019). Beta oscillations in working memory, executive control of movement and thought, and sensorimotor function. *The Journal of Neuroscience*, *39*(42), 8231–8238. https://doi.org/10.1523/JNEUROSCI.1163-19.2019

Schroeder, C. E., & Lakatos, P. (2009). Low-frequency neuronal oscillations as instruments of sensory selection. *Trends in Neurosciences*, *32*(1), 9–18. https://doi.org/10.1016/j.tins.2008.09.012

Sherman, M. T., Kanai, R., Seth, A. K., & VanRullen, R. (2016). Rhythmic influence of top-down perceptual priors in the phase of prestimulus occipital alpha oscillations. *Journal of Cognitive Neuroscience*, *28*(9), 1318–1330. https://doi.org/10.1162/jocn_a_00973

Slowikowski, K. (2021). *Ggrepel: Automatically position non-overlapping text labels with 'ggplot2'*. https://CRAN.R-project.org/package=ggrepel

Spitzer, B., & Haegens, S. (2017). Beyond the status quo: A role for beta oscillations in endogenous content (re)activation. *eNeuro*, *4*(4), Article ENEURO.0170-17.2017. https://doi.org/10.1523/ENEURO.0170-17.2017

Staudigl, T., & Hanslmayr, S. (2013). Theta oscillations at encoding mediate the context-dependent nature of human episodic memory. *Current Biology*, *23*(12), 1101–1106. https://doi.org/ 10.1016/j.cub.2013.04.074

Stenner, M. P., Bauer, M., Haggard, P., Heinze, H. J., & Dolan, R. (2014). Enhanced alpha-oscillations in visual cortex during anticipation of self-generated visual stimulation. *Journal of Cognitive Neuroscience*, *26*(11), 2540–2551. https://doi.org/10.1162/jocn_a_00658

Stilwell, B. T., Egeth, H., & Gaspelin, N. (2022). Electrophysiological evidence for the suppression of highly salient distractors. *Journal of Cognitive Neuroscience*, *34*(5), 787–805. https:// doi.org/10.1162/jocn_a_01827

Theeuwes J. (1993). Visual selective attention: A theoretical analysis. *Acta Psychologica*, *83*(2), 93–154. https://doi.org/10.1016/0001-6918(93)90042-p

Theeuwes, J. (2010). Top–down and bottom–up control of visual selection. *Acta Psychologica*, *135*(2), 77-99. https://doi.org/10.1016/j.actpsy.2010.02.006

Töllner, T., Conci, M., & Müller, H. J. (2015). Predictive distractor context facilitates attentional selection of high, but not intermediate and low, salience targets. *Human Brain Mapping*, *36*(3), 935–944. https://doi.org/10.1002/hbm.22677

Tuladhar, A. M., ter Huurne, N., Schoffelen, J. M., Maris, E., Oostenveld, R., & Jensen, O. (2007). Parieto-occipital sources account for the increase in alpha activity with working memory load. *Human Brain Mapping*, *28*(8), 785–792. https://doi.org/10.1002/hbm.20306

Van Boxtel, G. J. M., et al. (2021). *gsignal: Signal processing*. https://github.com/gjmvanboxtel/gsignal

van Zoest, W., Huber-Huber, C., Weaver, M. D., & Hickey, C. (2021). Strategic distractor suppression improves selective control in human vision. *The Journal of Neuroscience, 41*(33), 7120–7135. https://doi.org/10.1523/JNEUROSCI.0553-21.2021

Vatterott, D. B., & Vecera, S. P. (2012). Experience-dependent attentional tuning of distractor rejection. *Psychonomic Bulletin & Review*, *19*(5), 871–878. https://doi.org/10.3758/s13423-012-0280-4

Vickery, T. J., King, L. W., & Jiang, Y. (2005). Setting up the target template in visual search. *Journal of Vision*, *5*(1), 81–92. https://doi.org/10.1167/5.1.8

Vigué-Guix, I., Morís Fernández, L., Torralba Cuello, M., Ruzzoli, M., & Soto-Faraco, S. (2022). Can the occipital alpha-phase speed up visual detection through a real-time EEG-based brain-computer interface (BCI)?. *The European Journal of Neuroscience*, *55*(11-12), 3224–3240. https://doi.org/10.1111/ejn.14931

Wang, C., Rajagovindan, R., Han, S. M., & Ding, M. (2016). Top-down control of visual alpha oscillations: Sources of control signals and their mechanisms of action. *Frontiers in Human Neuroscience*, *10*, Article 15. https://doi.org/10.3389/fnhum.2016.00015

Ward L. M. (2003). Synchronous neural oscillations and cognitive processes. *Trends in Cognitive Sciences*, *7*(12), 553–559. https://doi.org/10.1016/j.tics.2003.10.012

Weiss, S., & Mueller, H. M. (2012). "Too many betas do not spoil the broth": The role of beta brain oscillations in language processing. *Frontiers in Psychology*, *3*, Article 201. https://doi.org/10.3389/fpsyg.2012.00201

Wen, W., Hou, Y., & Li, S. (2018). Memory guidance in distractor suppression is governed by the availability of cognitive control. *Attention, Perception & Psychophysics*, *80*(5), 1157–1168. https://doi.org/10.3758/s13414-018-1511-1

Wianda, E., & Ross, B. (2019). The roles of alpha oscillation in working memory retention. *Brain and Behavior*, *9*(4), Article e01263. https://doi.org/10.1002/brb3.1263

Wickham, H. (2016). *ggplot2: Elegant graphics for data analysis*. Springer-Verlag New York. https://ggplot2.tidyverse.org

Wilke, C. O. (2020). *Ggtext: Improved text rendering support for 'ggplot2'*. https://CRAN.R-project.org/package=ggtext

Wolfe J. M. (2021). Guided Search 6.0: An updated model of visual search. *Psychonomic Bulletin & Review*, *28*(4), 1060–1092. https://doi.org/10.3758/s13423-020-01859-9

Wykowska, A., & Schubö, A. (2010). On the temporal relation of top-down and bottom-up mechanisms during guidance of attention. *Journal of Cognitive Neuroscience*, *22*(4), 640– 654. https://doi.org/10.1162/jocn.2009.21222

Wykowska, A., & Schubö, A. (2011). Irrelevant singletons in visual search do not capture attention but can produce nonspatial filtering costs. *Journal of Cognitive Neuroscience*, *23*(3), 645– 660. https://doi.org/10.1162/jocn.2009.21390

Xie, Y. (2015). *Dynamic documents with R and knitr* (2nd ed.). Chapman; Hall/CRC. https:// yihui.org/knitr/

Zhu, H. (2021). *kableExtra: Construct complex table with 'kable' and pipe syntax*. https:// CRAN.R-project.org/package=kableExtra

Zhuang, X., & Papathomas, T. V. (2011). Cue relevance effects in conjunctive visual search: Cueing for location, color, and orientation. *Journal of Vision*, *11*(7), Article 6. https:// doi.org/10.1167/11.7.6

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Table 1: Descriptives

Appendix

Abstract

Internal representations of looked-for objects facilitate scanning of our complex environment and therefore improve visual search. Accordingly, performance in visual search was found to benefit from positive templates containing information about upcoming targets, and besides that, to depend on the precise pre-stimulus phase of neural alpha- and theta oscillations. However, until now, it is unclear if negative templates, containing information about upcoming distractor features, can equally improve search by causing proactive suppression of distractors. Besides, it is discussed whether salient distractors automatically attract attention (as suggested by stimulus-driven models), or if specific behavioral goals can prevent this automatic capture (as suggested by goal-dependent models).

In light of these discussions, the present experiment (N=29) aimed to examine the effect of neural oscillations on attentional templates in visual search, by instructing participants to either search for or suppress a specific, trial-by-trial changing orientation in a subsequent search display that was presented at different stimulus onset asynchronies (SOAs).

We hypothesized to find alpha- or theta oscillations in hit rate and RTs associated with positive and negative templates in our visual search experiment. Since we could only find non-significant trends towards such oscillations, and mainly for the hit rate, our findings do not fully support these assumptions. However, together with previous studies, our results may provide important insights regarding the experimental- and stimulus design for future studies aiming to examine the effect of neural oscillations on attentional templates in visual search.

Keywords: visual search, alpha oscillation, theta oscillation, positive template, negative template, proactive suppression, distractor, reaction time, hit rate

Zusammenfassung

Interne Repräsentationen gesuchter Objekte erleichtern das Durchsuchen komplexer Umgebungen. Dementsprechend verbessern positive Suchschablonen, die Informationen über das Aussehen gesuchter Objekte enthalten, die Suchleistung, wobei sich eine Abhängigkeit von der genauen prä-stimulus Phase der neuronalen Alpha- und Theta-Oszillationen zeigt. Bislang ist jedoch unklar, ob negative Suchschablonen, die Informationen über aufkommende Distraktoren enthalten, ebenfalls zu einer Verbesserung der Suchleistung führen können, indem sie eine proaktive Unterdrückung der Distraktoren bewirken. In diesem Zusammenhang wird außerdem diskutiert, ob auffällige Distraktoren automatisch die Aufmerksamkeit auf sich ziehen (wie reizabhängige Modelle annehmen), oder ob bestimmte Verhaltensziele diese automatische Anziehung der Aufmerksamkeit verhindern können (wie zielabhängige Modelle annehmen).

Vor diesem Hintergrund untersuchte das vorliegende Experiment (N=29) den Effekt neuronaler Oszillationen auf Aufmerksamkeitsschablonen bei der visuellen Suche. Die Teilnehmer*innen wurden instruiert, eine gezeigte Orientierung in einem nachfolgenden Suchbildschirm entweder zu suchen oder zu unterdrücken, der nach unterschiedlichen Intervallen präsentiert wurde. Die für den jeweiligen Durchgang relevante Orientierung änderte sich dabei in jedem Durchgang.

Es wurde angenommen, dass sich der Einfluss der Alpha- oder Theta Oszillationen auf die positiven beziehungsweise negativen Aufmerksamkeitsschablonen in Schwankungen der Leistung bei Antwortzeiten und Trefferquoten widerspiegelt.

Diese Annahmen konnten jedoch nur teilweise bestätigt werden, da wir nur nicht-signifikante Trends für derartige Oszillationen finden konnten und diese hauptsächlich in der mittleren Trefferquote auftraten. Zusammen mit früheren Studien können von unseren Ergebnissen jedoch wichtige Erkenntnisse für das Versuchs- und Stimulusdesign zukünftiger Studien abgeleitet werden, die die Effekte neuronaler Oszillationen auf Aufmerksamkeitsschablonen bei der visuellen Suche untersuchen.

Schlüsselwörter: visuelle Suche, Alpha-Oszillation, Theta-Oszillation, positive Aufmerksamkeitsschablone, negative Aufmerksamkeitsschablone, proaktive Unterdrückung, Distraktor, Reaktionszeit, Trefferquote