Feature guidance by negative attentional templates depends on search difficulty

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Visual Cognition, Special Issue: "Dealing with distractors in visual search" (in press)

Running head: Negative templates and search difficulty
word count: 5039 (main text) + 148 (abstract)

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Abstract

Prior knowledge about an upcoming target can bias attention and facilitate visual search performance. However, whether knowledge about distractors can likewise enhance search, biasing attention away from to-be-avoided items, is less clear. Here, we investigated whether the utilisation of such attentional templates is affected by search difficulty. Results from two experiments revealed search efficiency to be reliably increased when *positive* cues provide information about the upcoming target (relative to *neutral*, baseline cues) irrespective of whether search was easy (low target-nontarget similarity) or difficult (high target-nontarget similarity). By contrast, *negative* cues that inform about a to-be-avoided distractor were found to facilitate performance only during difficult (but not easy) search, that is, when responses were relatively slow. This suggests that, contrary to positive target templates, negative distractor templates can be used effectively only when the search task is difficult, which provides sufficient time for processes of distractor inhibition to operate.

Keywords: attention, visual search, target template, distractor template, inhibition

Introduction

When searching for a target object in our complex and, typically, cluttered natural environment, scanning of the visual array is thought to be aided by an actively maintained internal representation of what we look for, which has been referred to as an 'attentional template'. The idea is that a target template held in visual working memory top-down biases, or 'guides', search towards items in the array that (more or less precisely) match the target description (Desimone & Duncan, 1995; Duncan & Humphreys, 1989). Experiments designed to examine the role of such template representations in guiding attention have typically used visual search tasks, in which observers have to detect a target item in an array of nontargets or 'distractors', importantly, where the target-defining features change from trial to trial. On a given trial, observers are first provided with a cue informing them about some critical target feature (e.g., the target colour), and after a short delay period, a search array is presented to which observers make a speeded response (e.g., indicating whether a target is present or absent). A typical finding in this type of task is that search performance improves when the cue matches the target (relative to a neutral baseline where the cue is non-informative; see Vickery, King, & Jiang, 2005; Wolfe, Horowitz, Kenner, Hyle, & Vasan, 2004; Töllner, Zehetleitner, Gramann, & Müller, 2010). Neurophysiological studies have revealed that maintaining the target representation active during the delay period is associated with an enhanced, sustained activity in lateral parieto-occipital areas (Chelazzi, Miller, Duncan, & Desimone, 1993; Carlisle, Arita, Pardo, & Woodman, 2011) – indicative of some attentional template being set up in working memory that biases search towards the task-relevant object(s).

Complementary to the facilitation of search when observers are provided with target-relevant information, it has been proposed that attentional guidance may also operate through the inhibition of distractor items, that is, objects in the array that should be excluded from scanning (Gaspelin & Luck, 2018, for review). For instance, target detection has proved to be

more efficient when the distractors remain always the same across a block of trials, as compared to when they change randomly from trial to trial (Töllner, Conci, & Müller, 2015). This can be taken to indicate that, in a predictive environment, observers can use nontarget information to effectively exclude the irrelevant items from search. In fact, it has been proposed recently that attentional selection may operate predominantly via down-weighting (i.e., inhibition) of distractor features, rather than the concurrent up-weighting (i.e., activation) of target features (Moher, Lakshmanan, Egeth, & Ewen, 2014; Nie, Maurer, Müller, & Conci, 2016). A potential mechanism of how distractor inhibition may work in search guidance is via the setting-up of a *negative* attentional template that specifies the to-be-avoided, distractor information (Duncan & Humphreys, 1989; Humphreys & Müller, 1993). Instead of enhancing features of the to-be-detected target (as with a *positive* template), a negative template may reduce the activation of features that are associated with to-be-avoided distractors, thereby reducing the distractors' potential to compete for selection. In this view, both positive and negative template representations may help to generate predictions about task-relevant goals in the environment (see Conci, Zellin, & Müller, 2012).

While the inhibition of distractors appears to modulate search in a predictive environment (as in Töllner et al., 2015), experiments that presented a negative, distractor cue prior to the search array on a trial-by-trial basis have thus far revealed rather mixed results. A number of studies found that pre-cueing the colour of a set of nontargets in an upcoming search array can improve task performance – consistent with the idea that observers can set up a negative template ad hoc to inhibit the non-relevant items (Arita, Carlisle, & Woodman, 2012; Reeder, Olivers, & Pollmann, 2017). However, the benefits reported for negative distractor cues are usually smaller than those for positive target cues (Kugler, 't Hart, Kohlbecher, Einhäuser, & Schneider, 2015), and a reliable distractor cueing effect may emerge only after extended practice (Cunningham & Egeth, 2016). This may be taken to indicate that negative templates are harder to utilize than positive templates. In addition, there

are reports (Beck & Hollingworth, 2015; Becker, Hemsteger, & Peltier, 2016) that benefits from negative cues might become evident only when the target and distractor colours appear in separate hemifields within a given search display (as in Arita et al., 2012). Such structured displays might make participants adopt a particular strategy, namely, to quickly convert the negative (distractor colour-set) cue into a positive (target colour-set) cue (which logically involves inferring the target colour as the single colour in the display that is different from the distractor colour). This recoded cue (or the corresponding template) then brings about a rapid spatial shift of attention from the negative to the positive stimulus set. Evidence for such a recoding of the negative into a positive cue has been revealed in a recent eye-movement experiment, which found that, during a given search trial, participants' eyes tended to be captured by distractor items initially, while participants managed to avoid the irrelevant items only later on (Beck, Luck, & Hollingworth, 2018). This type of cue, or template, recoding might explain why negative cues yield smaller benefits than positive cues.

A comparison of trial-by-trial positive (target) cueing and negative (distractor) cueing studies reveals that the respective studies exhibit a potentially important difference concerning search difficulty: Reliable positive cueing effects have typically been reported in studies with relatively easy searches, evidenced by relatively short reaction times (RTs) taken to detect and respond to the target (around 750 msec; e.g. Carlisle et al., 2011; Wolfe et al., 2004). By contrast, studies reporting substantial negative cueing effects often used rather difficult search tasks that resulted in much slower RTs (usually around 1200-1900 msec; see Arita et al., 2012; Reeder et al., 2017). Moreover, increased negative cueing effects were also reported when search became slower due to an increase in display size, that is, with the number of to-be-avoided nontarget items (Cunningham & Egeth, 2016). These differences may be taken to indicate that the efficient use of a positive versus a negative attentional template may crucially depend on search difficulty: positive cueing appears to become evident already with easy searches, whereas negative cueing effects reveal robust benefits

only with difficult searches. This potential difference in search difficulty was systematically investigated in the current study.

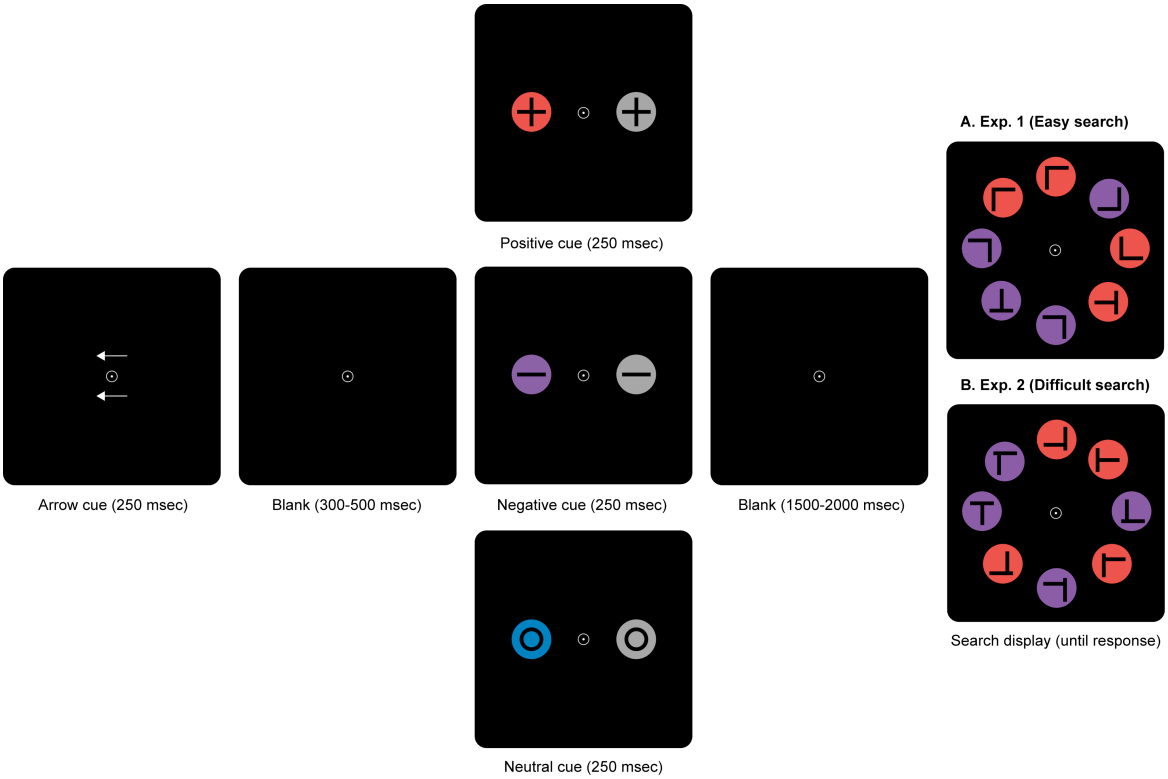

Figure 1. Example trial sequence in Experiments 1 (A, easy search – low target-nontarget similarity) and 2 (B, difficult search – high target-nontarget similarity): A given trial started with the presentation of an arrow cue, which indicated the side on which (after a short delay) the task-relevant colour cue would subsequently appear. After another brief delay, the actual search display was presented, which required observers to detect the target "T" (presented in the examples in the right display hemifield) and report its left/right pointing direction. Positive (+), negative (-) or neutral (o) cues were presented in separate (blocked) experimental parts. The cues displayed (i) the colour of the target set (positive), (ii) the colour of the nontarget/distractor set (negative) or (iii) a colour that did not appear in the subsequent search display (neutral).

To implement variations of search difficulty, we adopted a cueing paradigm previously used by Reeder et al. (2017). In our variant of the task, the search displays required observers to respond to a left/right oriented 'T' target presented among randomly oriented 'L'-shaped nontarget items and an up/down oriented distractor 'T'. A systematic variation of the offset at the junction of the 'L' nontargets resulted in either a relatively low target-nontarget similarity that was expected to permit a rather easy, fast search (Experiment 1,

Figure 1A), or in a rather high target-nontarget similarity, likely rendering search relatively difficult and, thus, slow (Experiment 2, Figure 1B; see also Duncan & Humphreys, 1989; Conci, Gramann, Müller, & Elliott 2006; Conci, Müller, & Elliott, 2007). Prior to the visual search displays, observers were presented with a colour cue that indicated either the target colour (positive cue), the colour of the to-be-ignored distractor (negative cue), or a neutral colour cue which did not appear in the actual search display and thus served as the baseline for potential cueing effects in the positive- and negative-cue conditions (see an example trial sequence in Figure 1). Based on previous results (see above), we expected benefits of positive cueing to manifest independently of search difficulty, while any benefits of negative cueing may be dependent on search difficulty, with a substantial benefit expected only in the difficult search condition.

Experiment 1

Experiment 1 was performed using a variant of the paradigm reported by Reeder et al. (2017), implementing a relatively low target-nontarget similarity, so that search should be relatively easy (Figure 1A). On each trial, we presented an initial positive (target), negative (distractor) or neutral (baseline) colour cue followed by the actual search display (see examples cues in Figure 1 and a search array in Figure 1A). If participants can effectively prepare to orient towards a given target colour when presented with a positive cue, then we would expect them to produce a reliable RT benefit (relative to the neutral cue). Moreover, a reliable RT benefit for the negative cue (again, relative to the neutral cue) would indicate that observers are also able to inhibit the colour of an upcoming distractor.

Methods

Participants: Sixteen observers (7 male, mean age: 25.56 years) participated in the experiment for payment of €9.00 per hour. All participants had normal or corrected-to-normal

vision and all but one were right-handed. All observers provided written informed consent, and the experimental procedure was approved by the ethics committee of the Department of Psychology, Ludwig-Maximilians-University Munich.

Apparatus and stimuli: The experiment was controlled by a Windows 7 computer, using Matlab routines and Psychophysics Toolbox extensions (Brainard, 1997; Pelli, 1997). All stimuli were presented on a black background (0.02 cd/m^2) on a 20-inch monitor (1920 x 1080 pixel screen resolution, 85-Hz refresh rate) at a viewing distance of approximately 70 cm. The experiment was conducted in a dimly lit and sound-attenuated experimental cabin.

All stimuli consisted of coloured circles (with a radius of 1.9° of visual angle) that could be displayed in one of six isoluminant colours (red, blue, pink, green, turquoise, and grey; luminance: 11.02 cd/m^2). At the centre of each coloured circle, an alphanumeric character was presented, which was composed of black lines. The characters subtended 1.06° x 0.98° of visual angle. In the initial cue displays, two coloured circles with identical characters – either '+', '–', or 'o' – were presented. The subsequent search display in turn consisted of 8 circles, one of which contained a target 'T' that was rotated randomly by 90° either to the left or right, and one distractor "T" that was presented randomly at a 0°, or 180° rotation (i.e. pointing up- or downwards). The T-shaped target and distractor were always presented in opposite hemifields at one of the six lateral positions, with an equal probability of the target (and the distractor) appearing in the left and the right display half. The remaining six circles in the search display presented nontarget "L", shapes that were rotated randomly by 0°, 90°, 180°, or 270°.

As depicted in Figure 1, the cue display consisted of two circles presented 2.5° to the left and right from the central fixation point (radius: 0.9°). One lateral circle was presented in grey colour, and the other lateral circle was presented in one of the five remaining colours. Both circles always contained the same character, presenting either positive (+), negative (–),

or neutral (o) cue symbols (see below for further details). The subsequent search display then consisted of 8 circles, which were equally spaced around an imaginary circle with a radius of 5.5° of visual angle. There were always only two colours displayed in a given search layout, with four circles of each colour being randomly assigned to the possible display locations (except that the shapes that contained the two T's were always presented in opposite hemifields, see above). The two colours from the search display were selected from the set of five colours (red, blue, pink, green, and turquoise). The target T and three nontarget Ls were always presented in one colour, and the distractor T (see above) and the three remaining nontarget Ls in the other colour.

Procedure and design: Figure 1 presents an example trial sequence. Each trial started with the presentation of a central fixation point and two arrow cues (arrow length: 1.2°, placed 0.8° above and below the central fixation) for 250 msec, indicating the side on which the task-relevant colour cue would appear next. After a subsequent delay period with a blank screen (and the fixation point) presented for 300-500 msec (randomized), one of three possible lateralized cues were presented, again for 250 msec, which displayed a task-relevant colour on the side cued by the arrows, and a non-informative, grey circle on the other side. Left/right cue positions and the five task-relevant colours (red, blue, pink, green, and turquoise) were fully counterbalanced across conditions and presented in random order across the entire experiment. After the presentation of the colour cue display (with characters inside the circles indicating whether the cue was positive, negative, or neutral), a blank screen (with a fixation point) appeared again for a period of 1500-2000 msec (randomized). Next, the search display (Figure 1A) was presented until a response was provided. Observers were required to detect the target T and report its left/right pointing direction by responding via the left/right mouse key, respectively. They were instructed to respond as quickly and as accurately as possible. In case of an erroneous response, a white minus sign appeared for

1000 msec on the computer screen. Each trial was followed by a blank interval, presented for a random period of 950-1050 msec.

As depicted in Figure 1, the colour cue could be one of three possible types: positive, negative, or neutral. When observers were presented with a positive (+) cue, the task-relevant colour shown would indicate with 100% validity the colour of the target item presented in the subsequent search display. In contrast, the negative (–) cue colour would be 100% predictive of the to-be-ignored distractor item. In the neutral (o) cue condition, a pseudo-randomly selected colour was presented in the cue that matched neither the colour of the target nor that of the distractor in the subsequent search array. Note that all five task-relevant colours (red, blue, pink, green, and turquoise) appeared with equal probability in all three cueing conditions.

The experiment used a within-participants design with the single factor cue type (positive, negative, neutral). There were 1080 trials in total, which were subdivided into three parts (of 360 trials each), each corresponding to one possible type of cue. The three (cue-type) parts were presented in counterbalanced order across participants. The blocking of the cue type was chosen because previous work had revealed negative cues to be particularly effective with this mode of cue presentation (Cunningham & Egeth, 2016). Note however, that despite of presenting the cue type blocked, the actual cue colours varied from trial to trial. Observers were instructed to actively use the presented cues. Before the start of each part of the experiment, observers were provided with 30 unrecorded trials for practice.

Results

To determine whether the various types of cue modulated performance, a repeated-measures analysis of variance (ANOVA) was performed on the mean error rates and RTs with the single factor cue type (positive, negative, neutral). We additionally report the Bayes factors (BF_{10}) estimated based on comparable Bayesian statistics using JASP (JASP Team, 2017). The Bayes factor provides the ratio with which the alternative hypothesis is favoured

over the null hypothesis: larger BF_{10} values argue in favour of the alternative hypothesis, with values above 3 denoting 'substantial evidence' in favour of the alternative hypothesis; by contrast, values less than 1 favour the null hypothesis; see Dienes (2011).

Errors: Overall, participants made relatively few erroneous responses (6.1%), with statistically comparable error rates in the positive, negative, and neutral-cue type conditions, $F(2,30) = 0.78$, $p = .46$, $BF_{10} = 0.26$.

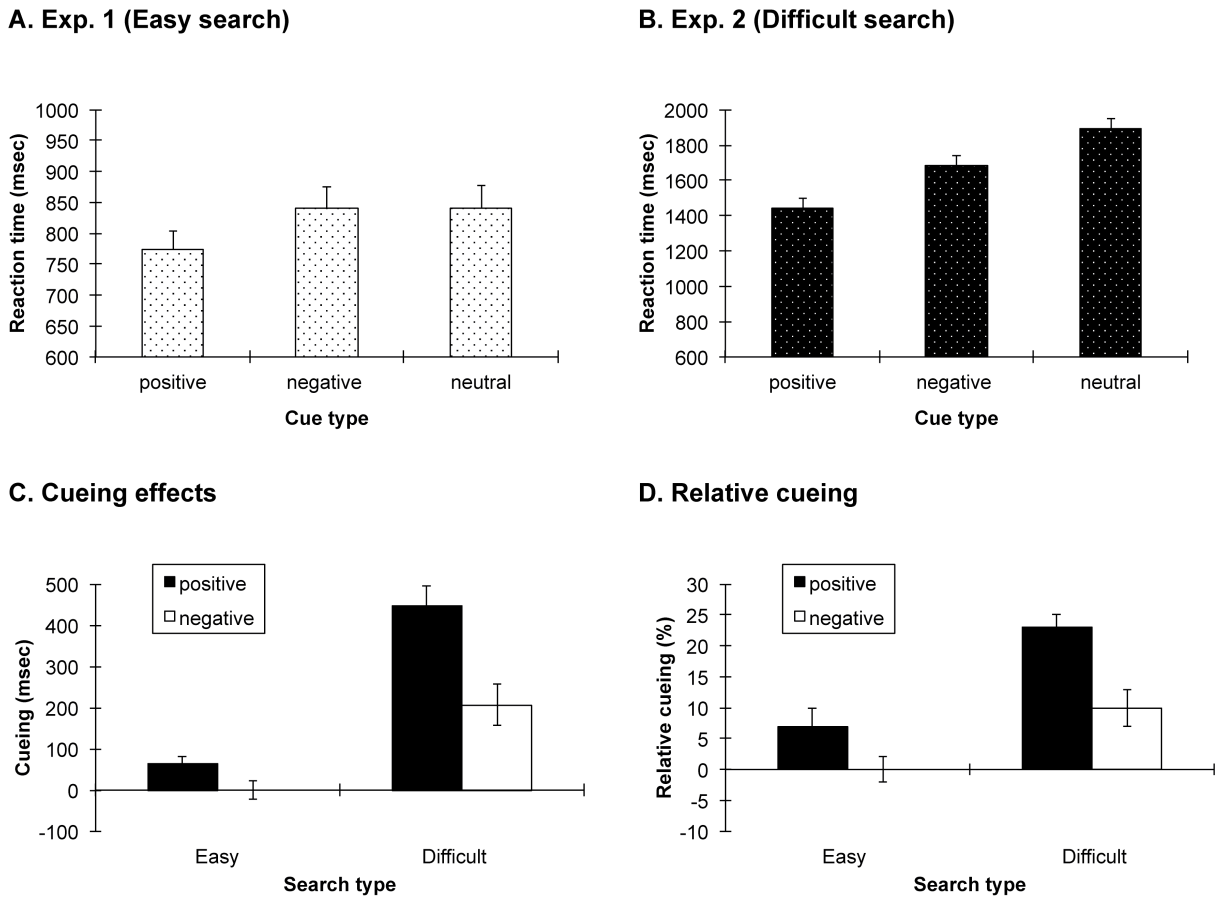

Figure 2. Mean reaction times (with associated standard error bars), as a function of cue type in Experiments 1 (A) and 2 (B). Panels C and D depict the corresponding [relative] cueing effects for positive (positive RT – neutral RT) and negative (negative RT – neutral RT) cues in the easy and difficult search tasks (Experiments 1 and 2, respectively).

RTs: Mean RTs for each observer and condition were calculated, excluding error responses and RTs deviating more than 3 standard deviations from the mean. Overall, less than 1.3% of all trials were excluded by this outlier criterion. The mean correct RTs as a

function of cue type are presented in Figure 2A. The RT ANOVA revealed a significant main effect, $F(2,30) = 7.90$, $p < .003$, $BF_{10} = 19.43$: positive cues led to substantially faster RTs (by 65 msec) compared to neutral cues, $t(15) = 2.86$, $p < .02$, $BF_{10} = 4.62$ (775 versus 840 msec), whereas negative cues failed to produce an RT difference relative to neutral cues, $t(15) = 0.02$, $p = .98$, $BF_{10} = 0.25$ (840 versus 840 msec). This indicates that in Experiment 1, prior knowledge of the target colour enhanced performance, whereas knowledge of the upcoming distractor colour was not at all effective in improving performance.

Discussion

Experiment 1 replicated previous findings that observers can substantially benefit from a cue that informs them about the colour of an upcoming visual search target (Carlisle et al., 2011; Vickery et al., 2005; Wolfe et al., 2004; Töllner et al., 2010). However, information about the colour of an upcoming distractor did not differ from the neutral cue condition (baseline). This indicates that observers were unable to set up a negative attentional template coding distractor-related features. Of note, the mean search RTs in Experiment 1 were ~800 msec, indicative of search being relatively easy, as in previous experiments that also reported reliable target-related cueing effects (e.g. Carlisle et al., 2011; Wolfe et al., 2004). Thus, together with these findings, the results of Experiment 1 are consistent with our hypothesis, namely, that comparably easy searches are facilitated by a positive, target-related cue, but not by a negative, distractor-related cue.

Experiment 2

Experiment 2 was designed to examine whether a negative cueing effect would eventually be observed when the search task is made relatively difficult. Experiment 2 essentially repeated Experiment 1, except that the target-nontarget similarity (in the search displays) was increased in order to slow target detection. This was achieved by (now)

presenting the nontarget 'L' shapes with a small offset (see Figure 1B), thus rendering the nontargets more similar to the task-relevant target 'T'. Despite this change, the basic composition of the display was identical to the setup described above for Experiment 1. If negative cueing becomes evident in particular in difficult search tasks, the conditions realized in Experiment 2 were expected to give rise to reliable RT benefits for negative, as well as for positive, cues.

Methods

Apparatus, stimuli, design, and procedure were comparable to Experiment 1, except that the nontarget items were slightly modified to increase the search difficulty, by increasing the target-nontarget similarity. This was achieved by presenting each nontarget item with a small offset (of approximately 30%) at the junction of the 'L's, which made them more similar to the target 'T' and created a relatively difficult search task (see Figure 2B for an example display). A new group of sixteen naïve participants (6 male, age *M*= 24.00 years, *SD*= 4.27) took part in this experiment. All observers had normal or corrected-to-normal vision and all were right-handed. All other details were the same as in Experiment 1.

Results

Errors: Experiment 2 again revealed few erroneous responses (5.4%), without any difference between the positive, negative and neutral cue types, $F(2,30) = 1.46$, $p = .24$, $BF_{10} = 0.43$.

RTs: Error responses and outliers (2.2% of all trials) were again excluded from the RT analysis. Figure 2B presents the mean correct RTs as a function of cue type in Experiment 2. The RT ANOVA again revealed a significant cue-type effect, $F(2,30) = 41.54$, $p < .001$, $BF_{10} = 5.764e +6$. Positive colour cues again generated a large and reliable RT benefit (of 446

msec), compared to the neutral cue condition, $t(15) = 9.12$, $p < .001$, $BF_{10} = 90380.04$ (1446 versus 1892 msec). Importantly, the negative cue now also expedited RTs (by 207 msec) relative to neutral cues, $t(15) = 4.07$, $p < .002$, $BF_{10} = 38.21$ (1686 versus 1892 msec). This pattern shows that, in a difficult search task (with high target-nontarget similarity), target detection is (substantially) facilitated not only by prior knowledge of the target colour, but also by knowledge of the distractor colour.

Between-experiment comparisons: To directly compare performance between the two experiments, the mean cueing effects were subjected to a mixed-design ANOVA with the factors cue type (positive, negative; within-participants) and search difficulty (low in Experiment 1, high in Experiment 2; between-participants). Cueing effects were calculated by subtracting the RTs in the positive and, respectively, the negative cueing condition from the neutral (baseline) condition – see Figure 2C for a depiction of the effects. This analysis revealed significant main effects of cue type, $F(1,30) = 37.25$, $p < .001$, $BF_{10} = 1247.63$, and of search type, $F(1,30) = 38.01$, $p < .001$, $BF_{10} = 9912.83$: the cueing effects were overall larger with positive than with negative cues (256 versus 104 msec) and larger in the difficult than in the easy search condition (326 versus 33 msec). Moreover, the interaction was significant, $F(1,30) = 12.31$, $p < .002$, $BF_{10} = 17.81$: in the difficult search condition, the effect of positive cueing was 240 msec larger than that of negative cueing, as compared to only 65 msec in the easy search condition (both p's $< .001$, $BF_{10} > 38.28$).

A final analysis was performed in order to take into account the large difference in overall search RTs between the two experiments (mean RTs were 818 versus 1675 msec, in the easy versus difficult conditions implemented in Experiments 1 and 2, respectively). To this end, *relative* cueing effects, which quantify the cueing benefit in % relative to the neutral baseline condition, were calculated (see Figure 2D) and submitted to a mixed-design, cue-type x search-difficulty ANOVA. This analysis again revealed both main effects to be significant: cue type, $F(1,30) = 38.87$, $p < .001$, $BF_{10} = 11073.37$, and search type, $F(1,30) =$

20.50, $p < .001$, $BF_{10} = 178.11$. That is, across experiments, positive cues yielded a larger benefit than negative cues (15% versus 5%), and the benefits were overall larger in the difficult than in the easy search (17% versus 3%). Of note, the interaction was not significant, $F(1,30) = 2.82$, $p = .10$, $BF_{10} = 0.95$, indicative of – in relative terms – comparable magnitudes of benefits engendered by positive cues (larger benefits) and, respectively, negative cues (smaller benefits) in easy and difficult search tasks.

Together, the between-experiment comparisons show that the benefits are overall larger (some three times in relative terms) when the target colour (versus the distractor) colour was pre-cued and when search is difficult (vs. easy). Importantly, however, negative cueing benefits – although of a similar relative magnitude in easy as in difficult search – may only be revealed when the search task is difficult and (absolute) RTs correspondingly slow.

Discussion

The increase in target-nontarget similarity in Experiment 2 led to a substantial slowing of the mean search RTs (from ~800 msec in Experiment 1 to ~1600 msec in Experiment 2). Such an inefficient search did not only reveal a reliable effect of positive, target cueing (as in Experiment 1), but also a - in fact: substantial - effect of negative, distractor cueing (with both the mean search RTs and the size of the positive and negative cueing effects roughly replicating Reeder et al., 2017). This is in line with our initial predictions, confirming that, with inefficient search, observers can successfully set up and effectively use a negative attentional template (coding distractor information) for search guidance, as well as a positive template (coding target information).

General Discussion

The current study, of two experiments, investigated whether search difficulty modulates the effective use of complementary attentional templates for top-down search

guidance, namely: a *positive* template that up-modulates the processing of target-related information, and a *negative* template that down-modulates the processing of distractor-related information in the search array. Experiment 1 showed that in a relatively easy search condition with low target-nontarget similarity, positive (target) cues significantly facilitated search (by 65 msec), while negative (distractor) cues produced no reliable benefits relative to the neutral baseline (0-msec difference). By comparison, implementing a relatively difficult search (high target-nontarget similarity) in Experiment 2 resulted in large and reliable cueing effects not only with positive (446 msec), but also with negative cues (207 msec). This shows that observers can prepare to guide attention to an upcoming target irrespective of the difficulty of the task, while they can effectively use advance information about the distractors only when the task is rather difficult.

Previous studies that tested trial-by-trial negative cueing have so far reported rather mixed findings that either do (Arita et al., 2012; Cunningham & Egeth, 2016; Reeder et al., 2017) or do not (Beck & Hollingworth, 2015; Beck et al., 2018; Becker et al., 2016) support the notion of an inhibitory template. The current experiments replicate the basic findings of Reeder et al. (2017), while also showing that reliable negative cueing effects may be obtained even when the layout of the search display does not afford rapid spatial redirection of attention from one hemifield that contains items possessing distractor-related features to the other hemifield that contains items possessing target-related features (such as in experiments in which the items in each hemifield are grouped by target and, respectively, distractor color; e.g., Arita et al. 2012; Beck & Hollingworth, 2015). However, effective (or, at least, statistically resolvable) negative cueing appears to depend on the difficulty of the search task, which clearly differs from the effects of positive cueing that are revealed in easy (Carlisle et al., 2011) as well as difficult (Reeder et al., 2017) search tasks. This may be taken to point to crucial differences in how the different types of cue are processed.

A likely explanation for the observed cueing modulation as a function of search difficulty may be that, with the negative cues, observers may have used a strategy that relies on shifting weight towards non-cued items, rather than actually suppressing the cued items (Beck & Hollingworth, 2015; Becker et al., 2016). This account assumes that observers are able to effectively prepare for an upcoming target colour, for instance, by setting up an appropriate target template, which in turn yields a large and reliable positive cueing effect in both easy and difficult searches. However, with negative cues, some additional processing would be required to quickly recode the to-be-avoided distractor features into to-be-detected target features at the onset of the search array on a given trial (Beck et al., 2018). This recoding process presumably takes time and requires cognitive resources (especially when colours in the search display are presented in a heterogeneous layout). As a result, a reliable benefit of negative cueing would be observable only if the search difficulty provides an appropriate temporal buffer to enable efficient recoding. Moreover, owing to the demands of translating negative into positive features, distractor-cueing effects would become smaller than comparable target-cueing effects. Of note, this 'recoding' explanation does not assume that attentional guidance involves some active inhibition of the irrelevant items; instead, guidance is assumed to mainly operate through facilitation of target-related information. This is at odds with major theoretical models of attentional selection, which posit that search is guided by both facilitatory and inhibitory mechanisms (Desimone & Duncan, 1995; Duncan & Humphreys, 1989; Humphreys & Müller, 1993).

An alternative explanation for the differential positive and negative cueing effects in easy and difficult search tasks would assume that observers can indeed set up both facilitatory, positive (target-related) and inhibitory, negative (distractor-related) templates to guide search. However, while a positive template can be readily established, negative cues may require more elaborate processing to bring about effective inhibition of the cued (distractor) features. For instance, negative cues may require both suppression of a prepotent (automatic) shift of

attention towards the cued features (e.g., Tsal & Makovski, 2006) and concurrent inhibition of items possessing these features (in this regard, the situation may be similar to the spatial inhibitory processes involved in the anti-saccade task; see Munoz & Everling, 2004, for a review). Assuming that this conflict cannot be resolved in an 'all-or-nothing' fashion on each and every trial, the degree to which negatively cued features are effectively suppressed would depend on the average balance of (achieved) inhibition to facilitation across all negative-cue trials. In other words, statistically (across all trials), net effective inhibition would always be suboptimal, and the resulting effect of negative cueing would be less than that achievable with positive cueing (even if one were to assume a-priori that the maximum achievable inhibition would be equivalent to maximum facilitation). Thus, from this perspective, facilitatory and inhibitory template representations may both be established in working memory, but they would differ crucially in terms of the net (inhibitory and facilitatory) top-down effects they could attain in search guidance.

Complementary to these specific accounts of why negative cueing manifests especially with difficult searches (i.e., either in terms of "feature recoding" or "elaborate inhibition" – see above), another reason might lie in observers' motivation to make effective use of the cues. For instance, in difficult search, making active use of the cue may yield a pronounced performance benefit (e.g., 326 msec overall in Experiment 2), as compared to only a small benefit in easy tasks (e.g., 33 msec in Experiment 1). In other words, the to-be-expected benefit in the difficult versus easy search task may, at least in part, increase the motivation to make use of the cues provided, be they positive or negative. However, such motivational factors are unlikely to explain the 'qualitative' difference in negative cueing that we observed between our easy search task (in which there was no negative cueing at all) and the difficult task (in which there were substantial negative cueing benefits).

Overall, our findings indicate that the effects of both positive and negative attentional templates depend on search difficulty. For instance, the between-experiment comparison of

relative cueing effects showed that more difficult searches lead to larger cueing effects than easier searches, independently of variations in the level of overall search RTs. This may indicate that observers compensate for search difficulty by generating a more refined template representation. This is consistent with evidence from event-related potentials, that an increase in search difficulty leads to an enhanced template representation in working memory (Schmidt & Zelinski, 2017; see also Töllner, Conci, Rusch, & Müller, 2013) – suggesting that more precise tuning of a given template to the cued items leads to improved attentional guidance (Chen, Schnabl, Müller, & Conci, 2018). On this background, our findings suggest that a given template representation can be dynamically adjusted as a function of the external stimulus conditions to optimize attentional selection in visual search (Geng, DiQuattro, & Helm, 2017).

Acknowledgements

This work was supported by project grants from the German research foundation (Deutsche Forschungsgemeinschaft, DFG; FOR 2293).

References

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, 580–584.

Beck, V. M., & Hollingworth, A. (2015). Evidence for negative feature guidance in visual search is explained by spatial recoding. Journal of Experimental Psychology: Human Perception and Performance, 41, 1190–1196.

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, 645–662.

Becker, M. W., Hemsteger, S., & Peltier, C. (2016). No templates for rejection: A failure to configure attention to ignore task-irrelevant features. Visual Cognition, 23, 1150–1167.

Brainard, D. H. (1997). The psychophysics toolbox. Spatial Vision, 10, 433–436.

Carlisle, N. B., Arita, J. T., Pardo, D., & Woodman, G. F. (2011). Attentional templates in visual working memory. The Journal of Neuroscience, 31, 9315-9322.

Chelazzi, L., Miller, E. K., Duncan, J., & Desimone, R. (1993). A neural basis for visual search in inferior temporal cortex. Nature, 363, 345– 347.

Chen, S., Schnabl, L., Müller, H. J., & Conci, M. (2018). Amodal completion of a target template enhances attentional guidance in visual search. i-Perception, 9(4), 1-10.

Conci, M., Gramann, K., Müller, H. J., & Elliott, M. A. (2006). Electrophysiological correlates of similarity-based interference during detection of visual forms. Journal of Cognitive Neuroscience, 18, 880-888.

Conci, M., Müller, H. J., & Elliott, M. A. (2007). The contrasting impact of global and local object attributes on Kanizsa figure detection. Perception & Psychophysics, 69, 1278-1294.

Conci, M., Zellin, M., & Müller, H. J. (2012). Whatever after next? Adaptive predictions based on short- and long-term memory in visual search. Frontiers in Psychology, 3: 409.

Cunningham, C. A., & Egeth, H. E. (2016). Taming the white bear: Initial costs and eventual benefits of distractor inhibition. Psychological Science, 27, 476-485.

Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. Annual Review of Neuroscience, 18, 193–222.

Dienes, Z. (2011). Bayesian versus orthodox statistics: Which side are you on? Psychological Science, 6, 274-290.

Duncan, J., & Humphreys, G. W. (1989). Visual search and stimulus similarity. Psychological Review, 96, 433–458.

Gaspelin, N., & Luck, S. J. (2018). The role of inhibition in avoiding distraction by salient stimuli. Trends in Cognitive Sciences, 22, 79-92.

Geng, J. J., DiQuattro, N. E., & Helm, J. (2017). Distractor probability changes the shape of the attentional template. Journal of Experimental Psychology: Human Perception and Performance, 43, 1993–2007.

Humphreys, G. W., & Müller, H. J. (1993). SEarch via Recursive Rejection (SERR): A connectionist model of visual search. Cognitive Psychology, 25, 43–110.

JASP Team. (2017). JASP (Version 0.8.2) [Computer software].

Kugler, G., ’t Hart, B. M., Kohlbecher, S., Einhäuser, W., & Schneider, E. (2015). Gaze in visual search is guided more efficiently by positive cues than by negative cues. PLoS One, 10(12): e0145910.

Moher, J., Lakshmanan, B. M., Egeth, H. E., & Ewen, J. B. (2014). Inhibition drives early feature-based attention. Psychological Science, 25, 315–324.

Munoz, D. P., & Everling, S. (2004). Look away: the anti-saccade task and the voluntary control of eye movement. Nature Reviews Neuroscience, 5, 218–228.

Nie, Q.-Y., Maurer, M., Müller, H. J., & Conci, M. (2016). Inhibition drives configural superiority of illusory Gestalt: Combined behavioral and drift-diffusion model evidence. Cognition, 150, 150-162.

Pelli, D. G. (1997). The VideoToolbox software for visual psychophysics: Transforming numbers into movies. Spatial Vision, 10, 437–442.

Reeder, R. R., Olivers, C. N. L., & Pollmann, S. (2017). Cortical evidence for negative search templates. Visual Cognition, 25, 278–290.

Schmidt, J., & Zelinski, G. J. (2017). Adding details to the attentional template offsets search difficulty: Evidence from contralateral delay activity. Journal of Experimental Psychology: Human Perception and Performance, 43, 429–437.

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, 935-944.

Töllner, T., Conci, M., Rusch, T., & Müller, H. J. (2013). Selective manipulation of target identification demands in visual search: The role of stimulus contrast in CDA activations. Journal of Vision, 13(3): 23, 1–13.

Töllner, T., Zehetleitner, M., Gramann, K., & Müller, H. J. (2010). Top-down weighting of visual dimensions: Behavioral and electrophysiological evidence. Vision Research, 50, 1372-1381.

Tsal, Y., & Makovski, T. (2006). The attentional white bear phenomenon: The mandatory allocation of attention to expected distractor locations. Journal of Experimental Psychology: Human Perception and Performance, 32, 351-363.

Vickery, T. J., King, L.-W., & Jiang, Y. V. (2005). Setting up the target template in visual search. Journal of Vision, 5(1), 81–92.

Wolfe, J. M., Horowitz, T. S., Kenner, N. M., Hyle, M., & Vasan, N. (2004). How fast can you change your mind? The speed of top-down guidance in visual search. Vision Research, 44, 1411–1426.