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Editorial

Editorial: Visual Search and Selective Attention

1. Visual Search and Selective Attention

Visual search is one of the most successful paradigms employed in research on selective attention. In the prototypical search task, observers are presented with displays containing variable numbers of items one of which, the target, may differ from the other items, the distractors. Observers indicate, as rapidly and as accurately as possible, whether or not a target objects is present in the display. One reason for the method's amazing success is its versatility: there appears to be no limit to the possible ways in which search tasks can be adapted to investigate the various facets of selective visual processing.

One classical distinction is that between simple feature and feature conjunction search. The presence or absence of a target differing from distractors by a conspicuous feature, such as one differently colored item among color-homogenous context items, is discerned quickly and efficiently. Search reaction times (RTs) in feature search tasks are independent of the number of display items, suggesting that feature information is processed in parallel across the display. By contrast, detection of a target defined by a conjunction of features, such as a particularly colored and oriented object among context objects some of which share the target's color but not its orientation, while others share the target's orientation but not its color is difficult. Search RTs increase with increasing numbers of display items and the functions relating RT to the number of display items suggest that search involves serial processing. The distinction between feature and feature conjunction is reflected in the two-stage processing architecture of Anne Treisman's seminal Feature Integration Theory: features are registered in topographically organized maps of analyzers, which subserve the detection of feature targets; and focal attention is required to integrate independent feature representations into coherent object representations for conjunction search. John Duncan and Glyn Humphreys, in their Attentional Engagement Theory, placed the emphasis on the roles of similarity between target and distractors and similarity among the distractors. These two types of similarity regulate the competition of search items for access to a limited-capacity visual short-term memory (VSTM) which permits conscious report. The more dissimilar the target is relative to the distractors (and the more similar the distractors are, which permits them to be de-selected as a group), the faster it will gain access to the VSTM. Jeremy Wolfe and his colleagues, in their Guided Search Theory, also assume that the dissimilarity of the target relative to the distractors determines how rapidly it is selected. Based on topographic feature representations (as assumed in FIT), feature contrast signals are computed in parallel separately for each display location, for the various visual dimensions (color contrast, orientation contrast, etc.). These signals are then integrated by units in an overall-saliency map, which guides the allocation of selective (focal) attention: that location is selected which achieves the highest activation on the saliency map, and visual information from this location is gated through to capacity-limited processes of object recognition. In feature search, the target is detected efficiently because it is the only item generating a strong saliency signal. In conjunction search, by contrast, the target signal differs less from those associated with distractors, and, given noise in the saliency computation, several peaks on the saliency map may need to be scanned one after the other until a detection decision can be made.

While most researchers agree on the general functional architecture of attentional selection in visual search, there a number of issues that are subject to strong controversies. In order to debate these open issues and also to foster an exchange between the various disciplines, or approaches, contributing to our understanding of them (psychophysics, functional brain imaging, electro- and neurophysiology, neuropsychology, and computational modeling), we conceived the "Visual Search and Selective Attention" Symposium. Following the first meeting (in 2003 at Lake Ammersee near Munich, Germany; organizers: Hermann J. Müller and Joseph Krummenacher), which was attended by leading scientists in the field, we edited a collection of the (Symposium and related) papers which appeared in a special issue of Visual Cognition (2006). Given the success of this meeting, we organized the second installment of the Symposium (in 2008 at Lake Murten, near Fribourg, Switzerland; organizers: Joseph Krummenacher and Hermann J. Müller). The current special issue collects a selection of papers that are based on this second meeting.

2. Questions at issue

While it is commonly assumed that the processes associated with the generation of feature representations and saliency signals are stimulus-driven and automatic in nature, a body of recent work shows that performance in search tasks is modulated by past stimulus characteristics. Specifically, processing of a target is facilitated if it is defined by the same visual features, or in the same dimension, as on the preceding trial(s). Maljkovic and Nakayama coined the term 'priming of pop-out' to describe this effect of inter-trial facilitation. Müller and colleagues reported inter-trial effects that depended on repeating the target-defining dimension across trials, whereas feature repetition within the repeated dimension had negligible effects. They took this pattern of inter-trial effects to ar-

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gue that dimension-specific feature contrast signals are 'attentionally' weighted prior to being integrated by overall-saliency units, where an increase in the weight for the current target-defining dimension is associated with a decrease in the weight for the non-defining dimensions. The weight set established on a trial is persistent, giving rise to the inter-trial dynamics. Essentially, this 'dimension-weighting' account assumes that the weighting modulate processing at a pre-selective coding stage (while not ruling out that there may also be modulations at post-selective stages). While the existence of dimension-based modulation is uncontested, some researchers have challenged to notion of a pre-selective locus of dimension weighting. Cohen and colleagues and Theeuwes and colleagues suggested that dimension-based effects arise at the post-selective level of response selection and response generation. Empirical evidence has been provided for both positions, and the papers of the present section contribute further to the debate whether inter-trial priming, or weighting, operates prior to selection (and therefore affects selection) or whether it operates exclusively on post-selective stages of response selection and generation.

3. Overview of the articles of the special issue

Wolfe, Palmer, and Horowitz analyzed entire reaction time distributions to interpret behavior in visual search tasks. They base their argument on the finding that search reaction time functions are in a continuum between very efficient to inefficient. They argue that a number of theories are able to model patterns of mean reaction times, but that it is hard to model entire reaction time distributions. Analyzing RT distributions obtained in three search tasks (efficient, inefficient, intermediate) shows that target-absent distributions overlap with target-present distributions to a larger degree than would be expected if search termination were simply based on a threshold of elapsed time. The authors argue that RT distribution analyses should be employed to constrain models of visual search.

Hopf, Boehler, Schoenfeld, Heinze and Tsotsos investigated the characteristics of the spatial focus of attention, which has been likened to a spotlight, zoom lens, gradient, or center-surround profile. Neuromagnetic recordings are reported that suggest that the spatial profile of the attention focus depends on the perceptual demands of the task. Search requiring spatial scrutiny to discriminate the target produces a zone of neural attenuation in the surround of the target, whereas search without spatial scrutiny produces a gradient. Increasing the demands on target discrimination does not affect surround attenuation. Surround attenuation sets on with a substantial delay relative to the initial feed-forward sweep of visual information. The authors propose the generation of center-surround profiles arises as a consequence of top-down selection.

Lefebvre, Jolicœur, and Dell'Acqua, examined a special kind of search task, curve tracing, by means of the sustained posterior contralateral negativity (SPCN). The SPCN is sensitive to target location and is thought to reflect encoding and active retention of stimulus (location) in (VSTM), but was also observed during ongoing stimulation. Observer's task was to determine the color of a disc at the end of the target line. The target line was defined as the only line (out of four possible lines) the starting point of which was spatially pre-cued. The to-be-followed target line traversed visual space by starting above the horizontal meridian and ending below the horizontal meridian or vice versa. The lateralized SPCN (target line presented in the left or right hemifield) was found to be more pronounced (in terms of amplitude) in trials in which the line started below the horizontal meridian relative to when it started above the meridian – a finding reflecting a known characteristic of the SPCN. In accordance with a spread-of-attention model the SPCN amplitude to target lines starting below the horizontal meridian remained stable while processing below and above-meridian parts of the target line. A spotlight model would have predicted a decreasing SPCN amplitude once the curve crosses the horizontal meridian from below. The authors concluded that covert spread attention was deployed to the target curve during the tracing task.

Zirnsak, Lappe and Hamker examine the pattern and functional role of dynamic changes of the receptive field (RF) at the time of an impending saccade. RF dynamics (observed, e.g. in lateral intraparietal cortex, superior colliculus, and frontal eye field) were interpreted as predictive remapping, that is, prior to saccade onset, cells respond to stimuli presented in their 'future' receptive field. Other effects of RF dynamics (e.g. in V4) involve the shrinkage and shifting of RFs towards the saccade target. In order to account for the various findings on RF dynamics, the authors analyzed predicted RF shifts within the framework of a computational model of peri-saccadic perception based on oculomotor re-entry signals in extrastriate visual cortical maps. In contrast to the assumption that the different types of RF dynamics observed in V4 are fundamentally different from dynamics observed in other brain areas, the authors show that the different forms of RF changes can be attributed to the same neural mechanisms.

Elazary and Itti present a Bayesian model of visual search that takes account of the fact that observers employ bottom-up and top-down processes to expedite search and recognition of targets. They show that by adding a Bayesian network that modulates saliency representations, their model's performance is significantly improved relative to comparable models.

Analyzing behavioral measures and event-related brain potentials (ERP), *Eimer, Kiss and Cheung* show that, in search for color singletons presented among homogeneous distractors, the onset of an ERP marker for spatially selective attention (the N2pc component) was delayed when target and distractor colors were swapped across trials. The authors conclude that priming of features across trials influences the latency of focal-attentional processing of the target – supporting the assumption that priming of pop-out primarily arises at early, perceptual levels of processing, and ruling out post-perceptual explanations of intertrial priming effects.

Olivers and Hickey also address the issue of the locus of intertrial effects. The rationale of their study is based on the idea that the occurrence and magnitude of intertrial priming at the perceptual level depends on the perceptual ambiguity of the display. In a compound task, perceptual ambiguity was manipulated by presenting or not presenting a distractor that resembled the target; both target (e.g. red or green) and distractor (e.g. yellow or blue) were defined on the color dimension. Equal proportions of distractor present and absent trials and target repetition and change trials were presented in random order; the effects of target repetitions and changes on manual RTs in distractor and no-distractor conditions were compared. While priming effects were found to be larger if a distractor was present, target repetition vs. change did not affect performance. ERP data revealed latency and amplitude modulations of the P1 and N2pc components, arguing for a perceptual locus of intertrial priming. In line with the assumption of a perceptual locus, priming effects were shown to increase with increasing similarity between the target and the distractor.

Töllner, Zehetleitner, Gramann, and Müller tested a prediction of the dimension-weighting account, namely, that effects of semantic pre-cueing of the target-defining dimension (in a compound-search task) originate, at least in part, at pre-selective stages of saliency coding. Observers were presented with a semantic dimensional pre-cue on a trial-by-trial basis. RT and ERP data were analyzed. The results revealed validly cued targets to produce faster reactions and both shorter peak latencies and larger amplitudes of the N2pc component compared to invalidly cued targets. Crosstrial changes of the target dimension were mirrored by delayed N2pc latencies, compared to dimension repetitions. Response changes were reflected by enhanced amplitudes of the lateralized readiness potential (LRP). The authors take this set of findings to argue that top-down dimensional set modulates pre-selective processing mechanisms.

Effects of the task requirements, detection versus discrimination, were investigated in a behavioral study by *Krummenacher, Grubert, and Müller*. In more detail, they compared a standard search task with a non-search task (single display item presented at a fixed position). In each task, the target was defined by certain (across trials variable) color or orientation features, whereas other (combined color and orientation) features were designated as non-target-defining. The results showed the type and locus of inter-trial effects to depend on the task: in search tasks (requiring simple target detection), inter-trial effects are largely dimension-specific and arise at an early, pre-selective processing stage; by contrast, in non-search tasks (requiring target discrimination), effects show feature-specificity and arise at a post-selective stage where target features are processed serially.

Lamy, Yashar, and Ruderman also assume that there exist different loci of intertrial effects; they argue that tapping into different time points of information processing in feature search tasks reveals different types of effect. By changing the colors of targets and distractors at different times during the trial, they found evidence for modulation at an early, selection-based processing stage and a later, response-based stage. Based on their findings, they propose a dual-stage account as an adequate explanation of intertrial effects.

Kumada examines the effects of attentional capture on the search process. Attentional capture refers to the phenomenon that focal attention is automatically attracted by the most salient item of the search display, and the author examined whether or not the search following capture was in any way affected by this event. Observers searched for an orientation singleton target; in a proportion of trials, a distractor singleton of same orientation but a different color relative to the target was presented. The results showed that while on trials without distractor singleton search remained unaffected by the number of non-targets, RTs on singleton distractor trials increased with increasing non-target number. The author argues that the singleton distractor induces serial search, because search order is lost as a result of attention capture. Loss of search order, according the author's account, is due to the attenuation of activation represented on the task-relevant feature map; attenuation is required for attention to disengage from the distractor location, and the consequence of attenuation is that the target's location is not longer represented by a prominent peak of saliency.

Braithwaite, Watson, Andrews, and Humphreys investigate the issue of whether presenting visual search displays at isoluminance affects attentional guidance in color subset search and preview search conditions. They report a subset search advantage for color groups under isoluminant conditions – an effect not found under non-isoluminant conditions. In preview search, preview benefits were observed in the non-isoluminant condition; that is, search efficiency was increased in preview search compared to the search baseline without preview of the items. In the isoluminant condition, however, search efficiency for preview search was only increased relative to baseline performance under extended preview durations. Additionally, at isoluminance an effect of target color was observed; i.e. preview benefits were found if the target was defined in a different color as the preview items and preview costs were evident in trials in which the target possessed the same color as the preview items. The authors concluded that at isoluminance more time is needed (extended preview duration) to bias search for a target against the preview items (negative color carry-over from the preview display to the target). Overall, according the authors, the results of a subset advantage for color and the color carry-over effects indicate stronger weighting of color in isoluminant displays.

Kristjánsson and Vuilleumier tested spatial within-trial spatial working memory in dynamic and static visual search tasks in patients with contralesional spatial neglect following brain damage in the right hemisphere. Whereas in the static condition the items remained at the same place during the entire trial, in the dynamic search condition, all the display items, including the target, changed their location every 110 ms. Search performance of neglect patients was compared to performance of a group of controls with right-hemisphere damage who did not show neglect. In neglect patients, search for stimuli in the left hemifield was disrupted in both the static and dynamic condition. Search was disrupted in dynamic search conditions in both neglect patients and controls, but disruption by item relocation was restricted to the right visual field in neglect patients. The authors interpret the finding that item relocation does not disturb in the left even more as indicating that the neglect patients' spatial working memory of their left visual space is already disrupted.

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