Vision Research 85 (2013) 1–4

Contents lists available at SciVerse ScienceDirect

Vision Research

journal homepage: www.elsevier.com/locate/visres

Editorial

Attentional modulation: Target selection, active search and cognitive processing

The papers presented in this special issue are based on the Third International Workshop in Visual Attention that took place in October 2011 at the University of Allahabad in India. This is the second of two parts of a special issue on the topic of ''Visual Attention''. This Editorial highlights the contributions of the papers published in both parts. Part 1 was published in December 2012.

The first in this series of workshops took place in 2003 in a quaint monastery in the Tuscan town of San Miniato, Italy, and the second took place in the Zanjon de Granados, one of the oldest historical buildings in Buenos Aires, Argentina. Each of the previous workshops resulted in Special Issues on Visual Attention, published in 2004 and 2009. This time we gathered in Allahabad, a city of great historic and religious significance in India (October 1–5, 2011; http://sites.google.com/site/visualattention2011).

Our understanding of visual attention has grown tremendously over the last decade. The International Workshops in Visual Attention have played a significant role in advancing the field by providing venues for leaders in the field of attention to present their work and to discuss mechanistic frameworks that begin to capture the broad influence of attention on vision and cognitive processing. For instance, the 2nd International Workshop in Visual Attention held at Buenos Aires in 2007 produced three papers that have revolutionized the field of attention, by incorporating normalization operations into models of attention (Boynton, 2009; Lee & Maunsell, 2009; Reynolds & Heeger, 2009). Normalization is a canonical computation first recognized to occur early in the visual system during the processing of contrast, but it is now considered as an operation that may occur at every level of the cortical hierarchy, and for different mechanisms, including attention.

The third Workshop in the series has continued in this tradition. Scientists met in the historic city of Allahabad, India. Our discussions have furthered our understanding of the role that attention plays in selecting targets of interest and in modulating neural populations relevant to the task, as well as its interaction with cognitive processes involved in learning, memory and reward. The papers published in Part I (2012) and Part 2 (2013) of this special issue represent cutting-edge research of leaders in the field who combine a variety of techniques including psychophysics, eye movements, electrophysiology, neuroimaging and modeling. In this introduction, we group these papers under broad themes such as attention mechanisms, the role of attention in target selection, active visual search and its interaction with other cognitive processes. It is clear, however, that many of the papers contribute to more than one of these themes, which are closely related.

1. Target selection

1.1. Cueing

Many papers in this special issue address the topic of target selection, ranging from classic cueing paradigms with covert attention, to selection during overt attention, around the time of eye movements. Two studies have extended human studies of spatial cueing in covert attention to other species. Eckstein et al. (2013) studied cueing in bees, monkeys as well as humans, and show that all three species take advantage of a spatial cue. Humans show the largest cueing effect, and bees the smallest, although none of the species does as well as the Bayesian ideal observer. However a model that incorporates an additive bias to the sensory response from the cued location is able to capture some of the benefit in performance due to the cue. Lee and McPeek (2013) investigated classic cueing paradigms in monkeys and replicate human data showing spatial and temporal enhancement of covert attention following a cue. Monkeys are better able to make discriminations at the cued location, and the cueing effect of a peripheral cue peaks at 80–100 ms, which is very similar to that found in humans (e.g., Nakayama & Mackeben, 1989).

1.2. Target selection in active vision

Two other studies have looked at spatial attention in the context of active vision, and at enhancement at the location of an upcoming saccade. After an illuminating introduction on the relation between attention and saccades as befits the keynote speaker, the study by Kowler and coworkers examined detection and discrimination at upcoming locations on the path of a saccade sequence (Zhao et al., 2012). Observers are more sensitive to probes at the upcoming saccade goal both in the absence and presence of noise, than to locations that were fixated previously, or locations off the saccadic path. These results are consistent with attention selectively enhancing the representation at the saccade goal and with attention reducing external noise at the saccade goal (Dosher & Lu, 2000a, 2000b). White, Rolfs, and Carrasco (2013) examined how such pre-saccadic shifts of attention are implicitly influenced by the recent history of the target location. Enhancement was greatest when the saccade goal and target shared the same location on the previous trial. More surprisingly, a match between the features of the saccade goal and the target also resulted in an implicit feature-cueing effect on the next trial. Thus, implicit cognitive processes permeate presaccadic attention, so that – contingent on recent experience – it flexibly distributes resources to potentially relevant locations and features.

0042-6989/$ - see front matter © 2013 Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.visres.2013.05.001

Two papers address the topic of how the attention works with eye movements to select targets. Krauzlis, Dill, and Fowler (2012) examined whether pursuit and saccadic eye movements are driven by a common target selection mechanism, or whether pursuit follows targets selected by saccades as suggested in some previous studies. In an elegant study that involved microstimulation of primate superior colliculus, they show that pursuit of a row of moving dots is only transiently disrupted by microstimulation that induces a saccade to another target moving in the opposite direction. These results indicate that both pursuit and saccades are driven by a common target selection mechanism. Further exploring the link between attention and eye movements, Patsukhov et al. (2013) investigated the role of another eye movement – microsaccades – in a covert attention task. They used microsaccades to reveal the spatial and temporal deployment of attention in a RSVP task. Microsaccades occurred continuously and were aligned with the axis along which the two RSVP streams could occur. In addition, the rate and direction of microsaccades varied to reflect changes in attentional demand: either the shift of attention to a new target location or the attentional blink that follows target detection. The authors concluded that attentional allocation shapes microsaccadic activity continuously.

1.3. Visual search

Target selection often comes up in the context of a real world task such as visual search where the observer may be looking for a particular target, or for an unknown target that is the odd-ball. The four papers on visual search take novel approaches to the topic. Arun (2012) presents an insightful way of looking at visual search, by characterizing performance in terms of the reciprocal of search time. The elegance of this approach is that this quantity is proportional to the discriminability of the target from the distractors, and that it serves as a useful distance metric of the similarity of objects in search space. Vincent (2012) takes another perspective on visual search and examines whether observers incorporate the statistics of target occurrence into their active search. His data show that observers do incorporate these statistics into their choice of saccadic targets, including whether target location is random or biased to a location, and whether or not the target location repeats on consecutive trials. Saccades are also influenced to an extent by the location of the target on the previous trial.

Verghese (2012) examined saccade strategy in a search task, using a novel paradigm with an unknown number of targets. The task was to actively search a brief, noisy display and to identify all target locations. Search time was limited, so saccades needed to be efficient to maximize the information gained, implying that selecting uncertain locations was much more informative than selecting likely target locations. Observers in this task were inefficient and consistently executed saccades to likely target locations, over uncertain locations. This raises the question of whether saccade strategy is truly efficient at maximizing information as suggested by other studies (Najemnik & Geisler, 2005), or whether the strategy to saccade to locations that look most like the target is a result of visual experience with salient objects or single targets of interest. Torbaghan et al. (2012) examined the question of saccade priority in a task with multiple targets. Monkeys were trained to search for multiple targets, one of which was rewarded. The animals developed a foraging strategy where they made saccades to successive target locations to obtain a reward. On half the trials, they were rewarded for making a rapid saccade to a probe that appeared during their foraging behavior. Saccade latency to the probe depended on its location; latency was shortest if it was a target location that had not been visited, intermediate for a distractor location, and slowest for a previously fixated target, indicating an inhibition of a previously fixated location. These results are consistent with target locations receiving high priority for saccades, particularly when they are associated with potential reward.

2. Attention mechanisms

2.1. Feature-based attention

Following on the findings in neurophysiology, neuroimaging and psychophysics that the effect of attention on the neural population is to multiplicatively increase response gain, or increase contrast gain, or to add an additive boost to the response (e.g., Buracas & Boynton, 2007; Pestilli, Ling, & Carrasco, 2009; Reynolds & Chelazzi, 2004), several studies have investigated the conditions that lead to these modulations. Consistent with the predictions of Reynolds and Heeger's (2009) Normalization Model of Attention, Herrmann et al. (2010) showed that spatial attention increased response gain when the attention field was small relative to the area responding to the visual stimulus, whereas spatial attention increased contrast gain when the attention field was broad relative to the visual stimulus, i.e. when the spatial location of the target was uncertain. Here, Herrmann, Heeger, and Carrasco (2012) address the mechanism of feature-based attention. Observers were cued to attend globally to a specific feature value, or a range of feature values. They found that in orientation discrimination, feature attention always increased response gain, regardless of whether the uncertainty of the attended feature was low or high. Liu, Becker, and Jigo (2013) also addressed the issue of feature uncertainty and showed that the decrement in performance when observers attend to multiple, discrete feature values, is similar to the uncertainty effects found in spatial attention, when the target can occur in one of multiple discrete, locations.

2.2. Spatial attention

Yeshurun and Sabo (2012) investigated the effect of transient attention on the detection of a brief contrast increment on a pedestal that is presented in the periphery. The pedestal was either steady or pulsed along with the increment to test the hypothesis that the latter favors the parvocellular pathway, because the luminance transient that occurs with the pulsed pedestal would saturate the magnocellular pathway. Their results show that transient attention improved contrast detection on the pulsed pedestal, but not on the steady pedestal, indicating that transient attention favors the parvocellular system.

Bressler et al. (2013) showed that the way in which endogenous (voluntary) attention enhances targets as a function of eccentricity is consistent with the role of attention in target selection. Functional imaging in humans revealed that attention amplifies the bold response, but that the degree of modulation is eccentricity dependent. Central targets were enhanced more than peripheral targets in early visual, ventral, and lateral occipital cortex, while peripheral targets were enhanced more in dorsal areas, including the homolog of area MT. These results shed light on how the dorsal stream might be designed to orient to new peripheral targets, whereas the early visual areas and the ventral stream enhance the target that is currently acquired.

2.3. Object-based attention

Watson et al. investigated object-based attention in the context of models of visual attention. In their task they measured the speed with which attention spread along a contour, depending on its contrast. They manipulated the contrast of the target contour relative to distractor contours and found that attention spreads along an object best when it was defined by a unique contrast, and that there was an additional benefit when the target contrast was higher than that of the distractors. These results are not consistent with pure response or contrast gain, but favor a response gain mechanism, whose effects are most evident at higher contrasts.

3. Attention and other cognitive mechanisms

3.1. Reward and learning

Two studies specifically address the issue of reward and how it modulates target selection. Theeuwes and Belopolsky (2012) show that a target associated with a high monetary reward in a training phase, attracts saccades even when it is irrelevant to the task at hand, indicating that past reward can influence saccade strategy. In a review of previous work from their laboratory, Chelazzi et al. (2013) investigated the learning associated with reward. They show that the influence of reward on modulating visual selective attention occurs both when performance and outcome in a task are actively monitored, and when there is an implicit association between objects in the environment (whether attended or ignored) and the more-or-less rewarding events that accompany them.

3.2. Learning and memory

The link between the neural substrates underlying implicit learning, attention and memory is borne out by Geisbrecht, Sy, and Guerin (2013). Participants were better able to detect the target when it occurred in a familiar context, than in a new context. Event-related functional magnetic resonance imaging revealed that activity in the hippocampus as well as in visual and parietal cortex was modulated by learned visual context even though participants' indicated no explicit knowledge of the learned context. The results suggest that implicit contextual learning is mediated by neural mechanisms involved in attention and memory. In a review of the link between perceptual learning and attention, Byers and Serences (2012), note that perceptual learning can occur both in the presence and absence of attention, but that attention plays role as gatekeeper by determining to what extent perceptual learning is expressed, depending on task demands.

3.3. Attention and load

Two papers address the interaction of attention and task load. Anobile et al. (2012) investigated the ability to make numerosity judgments in conjunction with attentional demanding tasks. The tasks included a visual, auditory or tactile discrimination tasks. Interestingly they discovered that subitizing (the ability to quickly and accurately report the number of items for small numbers, $n \leqslant 4$) is much more susceptible to attentional load, regardless of whether the other task is in the visual domain, or in another sensory domain. In comparison, the ability to estimate numbers (for $n > 4$) was only affected when the secondary task was in the visual domain. The study by Baijal et al. (2013) offers a potential explanation for this effect. They hypothesize that tasks that require estimation based on large number of elements (distributed attention) use a compressed representation with a relatively low memory load whereas tasks that require identification of the properties of individual elements (focused attention) have a load that is proportional to the number of elements. Using contralateral delay activation of the EEG as a measure of working memory load, they show that estimation of mean size of a number of disks generates a CDA that is independent of the number of the disks, whereas the identification of a particular disk generates a CDA that increases with the number of disks. In the context of Anobile et al. (2012), it is possible that subitizing requires attention to individual elements and represents a high memory load, which makes it susceptible to attentional demands.

In addition to the important contributions to the advancement of our understanding of visual attention, the International Workshops on Visual Attention have always aspired to hold meetings at non-traditional international locations with the aim of providing an opportunity to students from these countries to interact with leading scientists in the field. In this context, the 3rd Attention Workshop was a tremendous success allowing for interactions with over 20 students from the University of Allahabad, the Indian Institute of Science, the National Brain Research Center, Benares Hindu University, the National Institute for Mental Health and Neurosciences, the University of Calcutta, the Defense Institute of Psychological Research, the Indian Statistical Institute, and the University of Hyderabad.

We thank those who attended the workshop, whose presentations and discussions made it such a success, and particularly those who have also contributed to this special issue. We hope that the papers in the special issue will motivate many discussions and future endeavors in the study of attention.

Acknowledgments

We are grateful to Narayanan Srinivasan, the local organizer, for his hospitality and generosity, to the Centre of Behavioural and Cognitive Sciences, University of Allahabad, Allahabad, for providing the venue for the workshop, the Office of Naval Research Global (Grant No. N62909-11-1-1068) for their financial support, and to Vision Research for publishing this special issue.

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Workshop Organizer and Special Issue Editor
Marisa Carrasco
New York University, NY, USA
E-mail address: marisa.carrasco@nyu.edu

Workshop Organizer and Special Issue Editor
Miguel Eckstein
University of California, Santa Barbara, USA
E-mail address: eckstein@psych.ucsb.edu

Workshop Organizer and Special Issue Editor
Rich Krauzlis
National Institutes of Health, Bethesda, USA
E-mail address: richard.krauzlis@nih.gov

Workshop Chair and Special Issue Editor
Preeti Verghese
Smith Kettlewell Eye Institute, San Francisco, USA
E-mail address: preeti@ski.org