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Editorial

Visual attention

For more than a century, psychologists and physiologists such as William James, Wilhelm Wundt, Johannes Müller and Hermann von Helmholtz have proposed that attention plays an important role in perception: it is necessary for effortful visual processing, and may be the "glue" that binds simple visual features into an object. In more recent times, many psychologists, including Ulric Neisser, Anne Treisman and Michael Posner, have developed experimental paradigms to investigate what attention does and what perceptual processes it affects. Over the past few years, there has been a growing interest in the *mechanisms* of visual attention: how visual attention modulates the spatial and temporal sensitivity of early filters; how attention influences the selection of stimuli of interest; how and where the neuronal responses are modulated; how attention and eye movements interact.

In June of last year, about 40 visual scientists (Fig. 1) came together to discuss these issues in a quaint Franciscan monastery in the Tuscan town of San Miniato, near Vinci, home of the great Leonardo (see Fig. 2). The meeting (*San Miniato Workshop on Visual Attention*, 12–16 June 2003: www.percezione.org/Attention2003) brought together visual scientists from many complementary disciplines: psychophysics, primate neurophysiology, oculomotor research, and functional imaging. This special issue on visual attention reports many of the studies presented at the workshop. The topics cover a wide range of aspects of attention, including the properties and mechanisms of the selection processes, the spatial and temporal properties of attention, and the link between eye movements and attention. Many interesting techniques were employed in the various studies, including dual-task interference, noise and masking, contrast thresholds, speed-accuracy trade off, reverse correlation, visual search, neural imaging, and eye-movement monitoring.

Can the visual system select a stimulus?

Eckstein et al. report classification image studies showing that humans successfully select the stimulus at relevant locations and ignore information at irrelevant locations with both a 100% valid location cue and 100% invalid location cues. Solomon shows that an uninformative cue may improve sensitivity at the cued location and that simultaneous cues can improve sensitivity at several locations. Other visual search studies also illustrate that the visual system is able to select cued locations in the presence of noise. Verghese and McKee find that in the absence of a location cue, the observer monitors early detectors at all locations that are well matched to the target attributes. Baldassi and Burr show that when visual search occurs at detection threshold, the filter selection process is somewhat coarse, and observers tend to monitor many irrelevant detectors. More complicated strategies are required when the stimulus identity is not known, but is defined as the odd-man out. Santhi and Reeves report that the decrement in performance for feature search (known attribute) with increasing set size is explained by standard signal detection theory (SDT), but that the improvement in performance for oddity search (unknown attribute) with increasing distractors requires a modification to standard SDT. This set of behavioural studies provides evidence that, although selection may not be perfect, it can occur at early stages of visual processing in order to accomplish specific tasks.

How is this selection accomplished?

Selection is brought about by mechanisms tuned to the spatial and temporal aspects of the image, as well as to visual attributes or features.

Several papers concentrate on the *spatial* aspects of attention. To investigate the spatial profile of external noise exclusion, Dosher et al use concentric rings of noise that overlap the target and show that attention eliminates noise by altering the profile of the template in both spatial and non-spatial dimensions. Using a novel search task, Gobell et al. require observers to report the location of a target appearing at one of many disjoint locations and illustrate that observers can distribute attention to these locations while ignoring intervening unattended locations. The fineness of the attended/unattended locations gives an estimate of the spatial resolution of attentional processes.

Other papers assessed different issues of *temporal dynamics* of attention. Using an orthogonal

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Fig. 1. Attendees of the San Miniato Conference on Visual Attention, taken at "La Pietra", New York University's study centre in Florence.

Fig. 2. Adaptation of "Saint John the Baptist" of Leonardo da Vinci, illustrating the cueing paradigm used by many.

discrimination task as a proxy for detection, Smith et al. find that cueing the target improved both accuracy and response time only in the presence of a mask. Assuming that information was available from the stimulus during a critical window before the mask was presented, they use a diffusion model to show that the cue reduces the time to orient to the stimulus. Enns reports a similar result using a letter identification task and a variety of masks that surround or are superimposed on the target. Precueing target location makes all these masks ineffective when the mask appears about 150 ms after the target, allowing time for the target to be processed. The results of these two studies are consistent with the findings that attention sharpens the temporal window of processing (Lu et al.), and that attention accelerates information accrual (Carrasco et al.). Presenting external noise in temporal contiguity with a target, Lu et al. show that attention excludes external noise by both sharpening the temporal window of processing and by reducing the effect of added noise uniformly across the entire temporal window. Using a speed-accuracy tradeoff procedure, Carrasco et al. find that attention accelerates information accrual more at the locations that are slower in the absence of attention: Attention speeds up processing more along the upper than the lower region of the vertical meridian, and more than along the horizontal meridian, where information accrual is the fastest.

Others investigated the effect of attention on basic *temporal aspects* of processing. Melcher et al. measured the temporal integration time for detecting a motion signal in noise and show that attention prolongs the time over which summation between two motion pulses can occur. The increase in temporal summation appears to occur at a cost to temporal resolution. Yeshurun demonstrates that directing spatial attention to a target indeed impairs temporal resolution and that this impairment seems to involve the magnocellular pathway.

Mechanisms of selection

At what level of representation does attention act? Previous research has shown that in addition to selection by location, attention selects targets at the level of features, objects, or more complex representations such as surfaces. This special issue has a number of articles that illustrate the flexibility of the selection mechanisms.

Some papers examine the selectivity of attention, and whether this is related to *attributes* or *features*. Using a dual-task interference paradigm, Morrone et al. show selective attention at the level of individual attributes (colour and luminance contrast): Peripheral sensitivity is impaired when the dual task involves the same attribute at the center and the periphery, but it is unaffected when the dual tasks involve different attributes. Pashler et al. conclude that attentional selection is not biased towards high contrast as suggested by biased competition theory. Observers are able to ignore the high contrast distractors when the low contrast stimulus is the target, especially if target identity is maintained in blocks of trials.

Other authors address attention to objects and suggest that the entire stimulus or object is selected as a whole, together with all its constituent features. Wolfe et al. show that a picture of the target serves as an excellent cue in a conjunction search task where the target identity is unknown before the start of the trial. Word cues are much less effective. Sanborn et al. illustrate that attention can operate at many levels of processing of word identification, depending on the nature of the task. Sohn et al. test an important prediction of object-based attention: that attention spreads between the features that define an object. They provide evidence for attentional modulation spreading from the colour of a globally defined stimulus to its motion.

What is the functional connection between selection mechanisms and eye movements?

Recent evidence points to a strong link between attention and saccadic eye movements. The findings of Krauzlis et al. suggest that neurons in the superior colliculus play an active role in target selection. Stimulus–related activity in the superior colliculus represents possible targets, and the saccade target is selected by comparing the likelihood of the target at the current fixation location to the likelihood at one of the other locations. Schall examined target-related activity in the frontal eye fields, which are upstream of the superior colliculus and are known to play a role in saccade target selection. Target-related activity occurs at the site of the oddly coloured stimulus even when the animal is not planning a saccade to that location, showing that the frontal eye fields may be involved in covert shifts of attention that occur without accompanying eye movements. In an experiment mimicking natural eye movements, Gersch et al. examined the pattern of attentional allocation during a sequence of saccades to fixed locations. They found increased sensitivity primarily at the goal of the next saccade and decreased sensitivity for points between the current fixation and the location of the next saccade. The results of Theeuwes and Goodijn also suggest that attentional selection plays an important role in the sequence of eye movements. Observers are much slower to make saccades to the location of a most recent saccade, demonstrating an inhibition of return to a recently selected target location.

Concluding remarks

Over the past few decades, considerable progress has been made in understanding visual attention. Attention should no longer be considered a fuzzy concept invoked to account for higher-level cognitive effects. We now have a fairly good idea of the basis of attentional selection, its spatial and temporal characteristics, its effects on various aspects of visual performance, and some clues about the underlying neural substrate. The success of this research is undoubtedly due to the convergent information gained from various techniques—psychophysical, electro-physiological, oculomotor, functional imaging, and computational. Hopefully scientists from these various disciplines will continue to collaborate throughout the next decades to further our understanding of the mechanisms of attention, which affect almost all aspects of visual processing.

Finally, we would like to thank those who attended the workshop and made it such a success, and particularly those who have also contributed to this volume.

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