Heading detection from optic flow

SIR — The question of whether humans can visually detect the direction of egomotion in the presence of a simulated eye rotation has been the subject of recent debate. Psychophysical studies using slightly different stimulus procedures have yielded very different results when eye rotations in excess of 1 degree s⁻¹ were simulated. But the flow stimuli used in these studies do reveal a qualitatively different pattern of motion when the flow actually arriving on the retina is analysed (Fig. 1). In situations where humans succeed, the retinal flow field is overall centrifugal in structure, whereas in situations where humans cannot correctly detect their direction of heading, it is not.

It has been found independently in the visual cortex of cats and monkeys that most cells in some areas specialized for motion processing favour movements away from the fovea or area centrals. This centrifugal bias is present in cortical areas PMLS (cat) and MT (monkey), and has been hypothetically linked to the processing of optic flow fields during egomotion.

To see whether such an anisotropic distribution of motion detectors could be related to the differences observed in human psychophysics, we introduced a similar anisotropy in a proposed network model of heading detection. The model uses motion detectors similar to cells in PMLS and MT to encode the retinal flow field and in a second stage recovers the direction of heading with populations of cells designed to implement a least-square heading detection scheme. In computer simulations, our model cells respond to various combinations of expanding, contracting, rotating or translating random-dot patterns. Interestingly, similar response properties have been described for a subclass of cells in monkey visual area MSTd, which is a stage of the visual motion network in monkey cortex subsequent to area MT.

When we established an anisotropic distribution of direction preferences in the network's input layer by removing all cells with preferred direction towards the fovea, the network exhibited differences in detecting the direction of heading from different flow field stimuli which were similar to those in humans (Fig. 2). This suggests (1) that the observed differences in humans could be related to a specialization of the heading detection system to centrifugal flow fields; and (2) that an anisotropic distribution of motion detectors seems to be a reasonable design for ground-living mammals, for which the fixation of a stationary object somewhere near the movement trajectory is probably the most common condition of egomotion.

Nevertheless, accurate heading detection might also be of vital importance when a moving target is tracked instead of a stationary object. The experiments of Royden et al. indicate that this is a more difficult task, and we might not be able to perform it had we not the benefit of extraretinal information about our eye.
movements. Undoubtedly, extraretinal information is used by the human heading detection system to make otherwise unsolvable tasks less ambiguous, as has been previously demonstrated for movements towards a vertical plane\textsuperscript{1}. We do not intend to suggest that humans (or animals in general) do not use extraretinal information; our main interest is rather the possible adaptation of the visual system to frequently experienced natural flow fields in the sense of Gibson’s ‘visual ecology’\textsuperscript{11}.

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