A computational analysis of separating motion signals in transparent random dot kinematograms

JOHANNES M. ZANKER *

Department of Psychology, Royal Holloway, University of London, Egham, Surrey TW20 0EX, UK

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Abstract—When multiple motion directions are presented simultaneously within the same region of the visual field human observers see motion transparency. This perceptual phenomenon requires from the visual system to separate different motion signal distributions, which are characterised by distinct means that correspond to the different dot directions and variances that are determined by the signal and processing noise. Averaging of local motion signals can be employed to reduce noise components, but such pooling could at the same time lead to the averaging of different directional signal components, arising from spatially adjacent dots moving in different directions, which would reduce the visibility of transparent directions. To study the theoretical limitations of encoding transparent motion by a biologically plausible motion detector network, the distributions of motion directions signalled by a motion detector model (2DMD) were analysed here for Random Dot Kinematograms (RDKs). In sparse dot RDKs with two randomly interleaved motion directions, the angular separation that still allows us to separate two directions is limited by the internal noise in the system. Under the present conditions direction differences down to 30 deg could be separated. Correspondingly, in a transparent motion stimulus containing multiple motion directions, more than eight directions could be separated. When this computational analysis is compared to some published psychophysical data, it appears that the experimental results do not reach the predicted limits. Whereas the computer simulations demonstrate that even an unsophisticated motion detector network would be appropriate to represent a considerable number of motion directions simultaneously within the same region, human observers usually are restricted to seeing not more than two or three directions under comparable conditions. This raises the question why human observers do not make full use of information that could be easily extracted from the representation of motion signals at the early stages of the visual system.

Keywords: Vision; motion perception; transparency; direction discrimination; computational modelling; direction distribution; integration.

*E-mail: j.zanker@rhul.ac.uk
1. INTRODUCTION

The basic properties of human motion perception have been analysed in many psychophysical experiments using isolated moving objects or extended homogenous motion patterns (for review, see Sekuler et al., 1990). However, the optic flow generated by moving observers in a three-dimensional world (Gibson, 1979; Nakayama, 1985) is characterised by complex spatial and temporal distributions of motion signals (Zanker and Zeil, 2002). In practice the visual system furthermore has to face dynamic noise superimposed on the pattern of motion signals, which can be due to as many causes as perturbations of the light travelling through optical media, foliage swirling in the wind occluding the view, or the limited transmission fidelity of the neural system itself. A critical test to assess strategies of extracting the behaviourally significant motion information could be the perception of transparent and tessellated motion surfaces, when multiple motion signals can appear in the same or neighbouring regions of the visual field (Smith et al., 1999). The need for well defined psychophysical tasks and stimuli beyond the detection or recognition of motion-defined shapes (Braddick, 1980; Regan, 1991) was partially met by motion-defined stripes, which have been increasingly used in psychophysics during the last 20 years (Van Doorn and Koenderink, 1982; Watson and Eckert, 1994; Zanker, 1996). In a typical configuration these stimuli consist of stripe regions in which randomly distributed dots are moving in alternating directions parallel to the stripe boundaries. Such periodic motion stimuli can be easily segmented by human observers into stripes of coherent motion, as long as the patches are large enough. When the stripes are more narrow, however, they give rise to the sensation of transparent motion, i.e. both motion directions are perceived simultaneously in the complete stimulus field. Finally, with very narrow stripes the stimulus may no longer be discriminated from pure dynamic noise, i.e. dot patterns changing randomly in space and time. The processing of motion-defined gratings in the human visual system was modelled in a previous study (Zanker, 2001) with a biologically plausible motion detector network satisfactorily, predicting the transitions from segmentation to transparency, and from transparency to noise. The same two-dimensional motion detector model (2DMD) has been also used to account for a diverse range of motion processing phenomena (Zeil and Zanker, 1997; Zanker, 2004). Using alternating stripes defined by dots moving in opposite directions, the previous study did not address the issue of how motion many motion directions could be represented simultaneously by the 2DMD model as occupying the same region. This question will be investigated here together with the related question of the minimum difference between two transparent motion directions that still can be separated in the 2DMD output.

When a group of randomly distributed sparse dots is moving coherently in a single direction, one would expect the output of an ideal motion detector network processing this stimulus to be dominated by a sharp peak in the direction distribution at exactly this direction of dot motion. The properties of realistic motion detectors, as well as stimulus ambiguities such as local contour orientation or the interaction