

Binocular influences on global motion processing in the human visual system

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Abstract

This study investigates four key issues concerning the binocular properties of the mechanisms that encode global motion in human vision: (1) the extent of any binocular advantage; (2) the possible site of this binocular summation; (3) whether or not purely monocular inputs exist for global motion perception; (4) the extent of any dichoptic interaction. Global motion coherence thresholds were measured using random-dot-kinematograms as a function of the dot modulation depth (contrast) for translational, radial and circular flow fields. We found a marked binocular advantage of approximately 1.7, comparable for all three types of motion and the performance benefit was due to a contrast rather than a global motion enhancement. In addition, we found no evidence for any purely monocular influences on global motion detection. The results suggest that the site of binocular combination for global motion perception occurs prior to the extra-striate cortex where motion integration occurs. All cells involved are binocular and exhibit dichoptic interactions, suggesting the existence of a neural mechanism that involves more than just simple summation of the two monocular inputs.

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1. Introduction

Over the past decades, our understanding of the properties of global motion processing (i.e., the integrated direction or speed of a number of elementary, local motions) and its neural substrate (Morgan & Ward, 1980; Siegel & Andersen, 1988; Williams & Sekuler, 1984) has increased considerably. For example, it has been established that the processes that serve to integrate local motions into global percepts of translation and optic flow, can utilize both first-order and second-order image cues (Baker & Hess, 1998; Ledgeway & Hess, 2000) and operate in both central and peripheral vision (Dumoulin, Baker, & Hess, 2001). Furthermore there is much evidence to suggest that the mechanisms mediating global motion perception sum inputs across a wide spatial frequency range (Bex & Dakin, 2002) and have extensive

areal (Burr, Morrone, & Vania, 1998; Downing & Movshon, 1989) and temporal (Burr & Santoro, 2001; Downing & Movshon, 1989) summation.

It is presently assumed that the cortical mechanisms underlying global motion analysis are extra-striate because of the large areas over which local motion summation takes place (Burr et al., 1998; Downing & Movshon, 1989). For example, cells in area MT are well-suited to this task as they have large receptive fields, with multiple spatially localized local motion inputs, that are thought to provide the basis of such summation (Movshon, Adelson, Gizzi, & Newsome, 1985). Moreover lesions to this area in monkey (Newsome & Pare, 1988) and its homolog in man (Baker & Hess, 1991) disrupt the ability to encode the direction of global motion. There is also a strong correlation between behavioural performance and cellular responses in this area (Britten, Shadlen, Newsome, & Movshon, 1992) in that performance can be modified in a predictable manner by microstimulation of these cells (Salzman, Murasugi, Britten, & Newsome, 1992).

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The current, widely accepted, view of global motion processing is that it involves at least two processing stages: (1) an initial stage of local motion detection that is contrast-sensitive and (2) a subsequent stage of motion integration that is relatively contrast-invariant (Morrone, Burr, & Vaina, 1995). The first stage has been identified with cells in area V1, whereas the second stage has been identified tentatively with cellular responses in area MT (Movshon et al., 1985; Rodman & Albright, 1989). The available neurophysiological evidence suggests that motion detectors in V1, that respond to local motion in a manner consistent with contrast-energy analysis (Movshon & Newsome, 1996), send their outputs to area MT where there is evidence for cells with broader spatial and orientational responses (Movshon et al., 1985).

It is clear from a number of different standpoints that binocularity plays an important role in global motion processing. For example, the motion after-effect to global motion exhibits, on average, 96% interocular transfer, suggesting a higher level of binocularity than typically found in V1 (Raymond, 1993). Binocular disparity can facilitate global motion direction discrimination (Greenwood & Edwards, 2006; Hibbard & Bradshaw, 1999; Snowden & Rossiter, 1999). Also, developmental conditions in which the binocular function has been compromised due to unilateral amblyopia exhibit anomalous global motion processing for both the affected and fellow fixing eye, suggesting an abnormality at a binocular site (Giaschi, Regan, Kraft, & Hong, 1992; Ho et al., 2005; Simmers, Ledgeway, Hess, & McGraw, 2003). However the extent of the binocular advantage for the perception of global motion and the level at which it arises, is presently indeterminate.

As local motion detection is assumed to be monocular (Georgeson & Shackleton, 1989; Lu & Sperling, 2001), one possibility is that binocular summation for global motion arises beyond V1, perhaps within extra-striate area MT itself where the majority of cells are binocular (Maunsell & Van Essen, 1983; Zeki, 1978). Alternatively as a sizeable population of directionally selective cells in V1 are binocular (Hubel & Weisel, 1968), and there is debate concerning a binocular input to motion perception, it is possible that the V1 cells that project to MT are themselves binocular. Consequently the binocularity of global motion processing in MT could be largely inherited from its first stage (V1) inputs.

In the context of spatial vision, the extent of the binocular advantage for simple form detection is known to be modest, being of the order of 1.4 (Campbell & Green, 1965). On the other hand, for large field low spatial frequency stimuli in motion it can be as large as a factor of 2 (Rose, 1980). The locus of this binocular advantage in sensitivity is unresolved but could arise in either striate or extra-striate cortex, or even a combination of the two. Therefore, in the present study we sought to assess the extent and the site of the binocular advantage for global motion perception in human vision.

To address these issues we measured the relationship between the global motion coherence threshold and stimulus modulation depth (contrast) for stochastic stimuli undergoing translational, radial and circular motion under a range of viewing conditions.

2. Experiment 1. Global motion thresholds under monocular and binocular viewing

In Experiment 1 global motion coherence thresholds versus contrast functions were measured under monocular and binocular viewing conditions using a similar technique to Simmers et al. (2003). If there is a binocular viewing advantage such that thresholds can be measured over a lower contrast range than for monocular viewing (characterized by a lateral shift of the threshold versus contrast function along the contrast axis), this would suggest the locus of this phenomenon is a contrast-dependent site, namely V1. If on the other hand binocular viewing results in a uniform improvement in global motion performance, compared with monocular viewing, at all contrasts tested (characterized by a vertical shift of the threshold versus contrast function along the threshold axis) this would implicate a contrast-invariant site in extra-striate cortex (cf. MT or MSTd).

2.1. Methods

2.1.1. Observers

Three observers took part in Experiment 1. CVH was one of the authors and JT and JB were volunteers naïve to the purpose of the experiment. All had normal or corrected-to-normal visual acuity and normal binocular vision.

2.1.2. Apparatus and stimuli

Stimuli were generated using a *Macintosh G4* and presented on a *Sony Multiscan G520* monitor with an update rate of 75 Hz which was gamma-corrected with the aid of internal look-up tables. The mean luminance of the display was approximately 50 cd/m². Stimuli were presented within a circular window at the centre of the display which subtended 12° at the viewing distance of 92 cm.

Global motion stimuli were either translational, radial or rotational random-dot kinematograms (RDKs). Dots were presented on a homogenous mid-grey background (mean luminance of 50 cd/m²) that filled the entire circular display window. The luminance modulation (Michelson contrast) and hence the visibility of the dots could be varied by increasing the luminance of the dots, with respect to the background, according to the following equation:

Dot luminance modulation

$$= (L_{\text{dots}} - L_{\text{background}}) / (L_{\text{dots}} + L_{\text{background}}), \quad (1)$$

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