Interocular orientation disparity and the stereoscopic perception of slanted surfaces

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Abstract—The orientation threshold for two-dimensional filtered noise stimuli was estimated using forced-choice procedures with both dioptric and dichoptic viewing. In the dioptric case the two patterns were co-rotated. In the dichoptic case the stimuli were counter-rotated to produce an orientation disparity, which yields a percept of slant about the horizontal axis orthogonal to the cyclopean line of sight. Dioptric thresholds increased with the orientation bandwidth of the stimuli. In contrast, dichoptic thresholds were essentially constant across a wide range of conditions. In all cases, dichoptic orientation acuity was much finer than conventional estimates. In a second experiment, the dichoptic threshold was estimated for patterns superimposed on a depth pedestal. Acuity was affected significantly by the presence of the pedestal, and was an inverse function of pedestal amplitude. The results suggest that stereoscopic slant caused by dichoptic counter-rotation arises because of neural processing of the overall pattern of disparities of position produced by counter-rotation, rather than specialised encoding of orientation disparity.

Keywords: Orientation disparity; tilt and slant perception; stereopsis.

INTRODUCTION

The spatial separation of the two eyes in the horizontal plane ensures that each enjoys a unique viewpoint of the visual world. This separation leads to differences, or disparities, between the retinal images of binocularly viewed objects that do not lie at the fixation point. The most obvious and simple form of disparity is that of horizontal position. By definition, objects that do not lie on the horopter lie in different visual directions, and therefore such objects do not stimulate corresponding retinal points in the two eyes. It has been demonstrated convincingly that under a rather limited range of conditions these disparities of position are a

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sufficient cue for object identification, can induce the perceptual impression of solidity (‘stereopsis’), and can create convincing three-dimensional depth without diplopia (Julesz, 1971).

It is possible to identify types of what have been termed ‘higher order’ disparities (in that they are neither point-wise nor local) in addition to the more conceptually straightforward disparity of position. These other disparities arise from the ordered distribution across space of point-wise disparities of position, two of the main variants of which have been shown to be those based on interocular differences in contour orientation, and those based on object deformation (Howard and Rogers, 1995). The higher order disparities are most easily illustrated with targets that are composed exclusively of linear elements, such as grids and ruled lines. In these cases the deformations can be demonstrated in a relatively simple manner.

Orientation disparity presents a particularly interesting case. The two-eyes images of vertical lines that have been ruled on a coronal plane will counter-rotate in the two eyes if the plane is slanted from vertical, as a simple consequence of the viewing geometry (Ogle, 1950, pp. 103–104). We adopt the terminology for surface orientation that specifies slant as the angle between the surface normal and the (cyclopean) line of sight, and tilt as the direction of slant given by the angle between the projection of the surface normal onto the fronto-parallel image plane and the horizontal (Marr, 1982; Stevens, 1983a, b; van Ee et al., 1999). Unless specifically stated otherwise, for convenience we use the term ‘slant’ to refer to the specific case of a rotation of a coronal plane around the horizontal axis.

The amount and direction of the inter-ocular counter-rotation for a given slant depends on several factors, such as the sign of the slant, and the location of the target line with respect to the point of fixation (Koenderink and van Doorn, 1976). Further, and in manner that complements the more general analysis of the viewing geometry, it has been demonstrated that dichoptic presentation of inclined lines in a stereoscope will yield a convincing impression of depth and perspective (Braddick, 1979). This is closely analogous to the seminal demonstrations of depth from positional disparity that can be obtained with random-dot stereograms (Julesz, 1971). These findings have been extended by a series of other investigations of stereoscopic slant, which are claimed to provide psychophysical evidence for the proposition that orientation disparity is an effective and independent cue to depth that can be exploited by the visual brain following stereoscopic fusion (e.g. Ninio, 1985; Gillam and Rogers, 1991; Gillam and Ryan, 1992; Cagenello and Rogers, 1993).

The proposal that the brain might possess mechanisms that are specialised for encoding orientation disparity enjoys some support from physiological investigations of the response properties of single neurones in area 17 of the cat (Blakemore et al., 1972; Nelson et al., 1977; LeVay and Voigt, 1988) area 18 of the cat (LeVay and Voigt, 1988), area 21a in the cat (Wieniawa-Narkiewicz et al., 1992; Wang and Dreher, 1996), and the striate cortex (area V1) of the monkey (Hänny et al., 1980). In all of these studies, single neurones have been found that are not only tuned