Relevant perceptual factors in stereoscopic displays: image disparity, convergence distance, and focus length

STEREOPSIS, DEPTH, AND 3-D

◆ **Disparity information in the peripheral visual field for pattern perception**

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Although it is known that stereo-acuity declines with increasing eccentricity of the targets, it is not clear how we use disparity information in the peripheral visual field for pattern perception. To examine this question, we investigated pattern perception by restricting the area that presented stereo or luminance information in the periphery.

We measured the reaction time for recognising a letter defined by binocular disparity or by luminance in a random-dot display. We restricted the area containing the specific information (disparity or luminance) using an eye-contingent window technique. Disparity or luminance information was thus present only inside a window centred on the fixation point. Observers viewed the display with free eye movement. The magnitudes of the disparity and luminance contrast were chosen so as to give the same reaction times when the area containing the pattern information was not restricted. Eye movements were measured by a limbus-tracking system and the signal was fed into a computer for real-time control of the window position.

The reaction time increased as the window size decreased. The increase in reaction time, however, was steeper for the stimuli defined by disparity than for the stimuli defined by luminance. We conclude that disparity information in the periphery is used for recognising a pattern and is more effective than luminance information for a given window size.

◆ **Estimation of lengths and angles of kinematically induced amodal rods**

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In previous experiments computer-generated stimuli consisting of two dots moving on semi-elliptical paths, either on inner or on outer halves of ellipses, induced percepts of amodal rods rotating or oscillating in 3-D space, with the two stimulus dots as the visible endpoints. The task was to estimate the length and the angle of inclination of the perceived rod in a specified position. Results of the experiments were only in partial accord with the frontoparallel principle (Johansson and Jansson, 1968 *Perception & Psychophysics* **4** 165–170). A geometrical model was proposed to explain the perceived characteristics of the rod. The model was tested in two experiments. In the first experiment the length and the angle of inclination of the perceived rod were varied. Subjects were sensitive to changes of length and angle. Furthermore, when they overestimated the length, they underestimated the angle. In the second experiment the curvature of the semi-elliptical paths was increased. Compared to the first experiment, estimations of lengths increased but estimation of angles were not significantly different.

◆ **Relevant perceptual factors in stereoscopic displays: Image disparity, convergence distance, and focus length**

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Traditionally, visually relevant factors in stereoscopic displays have been investigated within a performance-oriented framework, focusing on the veridicality of depth perception. However, for some applications, most notably in the areas of broadcasting and entertainment, an appreciation-oriented approach seems to be more relevant. Within this framework, we investigated the influence of image disparity, convergence distance, and focus length on the subjective assessment of depth, naturalness of depth, and quality of depth (or preference).

Twelve observers with normal or corrected-to-normal vision and good stereopsis viewed a fully randomised presentation of stereoscopic still images that varied systematically in image disparity (six levels of camera base difference: 0, 4, 8, 12, 16, and 24 cm), convergence distance (two levels: 1.30 m and 2.60 m) and focus length (two levels: 10 mm and 20 mm). Each observer was asked to rate, in separate counterbalanced sessions, his/her impression of depth, naturalness of depth, and quality of depth.

The results indicate that observers prefer a stereoscopic presentation of images over a monoscopic presentation. A clear optimum was found at 4 cm image disparity for subjective judgments of naturalness and of quality. Depth judgements increased up to an image disparity of 12 cm, a result that is in line with earlier psychophysical literature. There was an effect of focus length only at extreme image disparities. An effect of convergence distance was also found that can be

adequately explained by rescaling to match the effective visual disparities. Although there was a strong linear correlation between naturalness and quality ($r = 0.96$), a small but systematic deviation could be observed. This deviation was best modelled by a linear quality model that incorporates both naturalness and depth.

◆ **Illusory contours do not capture stereopsis—they just constrain the depth spreading**
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If vertical cut-out sectors defining a Kanizsa square are given crossed disparity, the illusory figure appears in depth. Such an illusory figure can pull the background pattern inside the illusory figure to the same depth. It has been assumed that illusory contours are necessary for this phenomenon, which is called stereo capture (Ramachandran, 1986 *Perception & Psychophysics* **39** 361 – 373). However, we noticed that the vertical cut-out sectors of the inducing figures ('pacmen') are not the only structures that can capture the background texture. The rows of background dots that are enclosed between the disparate vertical cut-out sectors also have unambiguous stereoscopic depth. Thus it might be possible that the disparate rows alone capture the background texture. To investigate our hypothesis we created a stereogram in which the inducing figures were removed. It consisted of a dotted background texture and four areas devoid of dots. The dotless areas corresponded to the areas which were occluded by the original inducing figures. Because of this, the top and bottom rows inside the central area were in crossed disparity.

According to our results (a) depth capture also occurred without illusory contours; (b) when illusory contours were not present, the depth of the disparate rows spread more often to other areas. Usually the depth spread first to the central area of the figure and after that horizontally to other areas of the figure. Therefore, we conclude that illusory contours do not capture stereopsis—they just constrain the depth spreading.

◆ **Effects of stereo and motion manipulations on measured presence in stereoscopic displays**
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Methods of assessing presence, a sense of 'being there' within a displayed virtual environment, include post-test subjective measures, discrimination tests, and monitoring reflexive responses. Each is limited—either they do not provide a measure of temporal variation, are not feasible with current display technology or are overly content-specific.

A measure of presence derived from the method of continuous evaluation (ITU-R, Recommendation BT.500-7, revised, "Methodology for the subjective assessment of the quality of television pictures", 1995) has been used to overcome these limitations. The results of two experiments are presented. Those of the first experiment established that the methodology is usable under the optimal viewing conditions for the 20 inch stereoscopic TV display upon which our stimuli were presented. It compares within-subject variation on continuous TV picture quality ratings under two viewing conditions—at six picture heights in the light (standard for quality evaluations) and at two picture heights in the dark (optimal stereo TV viewing). The second experiment investigated the effects of manipulations of the visual parameters of stereo, scene motion, and observer-based motion on participants' presence evaluations within edited sections of a stereoscopic film. The results provide support for theories predicting that the extent of sensory information available to a participant is one of the factors determining presence.

◆ **Continuous assessment of presence in stereoscopic displays**
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Presence, a sense of 'being there' evoked by a display, can be regarded as a concept of central importance in the evaluation of broadcasting and entertainment services in general and virtual reality applications in particular. Subjective methods of assessing presence that have either been used or proposed to date do not provide a measure of temporal variation in observers' presence. To overcome this limitation, we have applied the method of continuous assessment (ITU-R, BT 500-7) to the measurement of presence. Thirty observers (twelve at IPO, eighteen at UoE) with normal