Abstract  

Background: There is a need for a stereotest with the following properties: (1) Natural viewing conditions, i.e. stimulus contours visible for each eye alone, but no or hardly any cue for monocular detection, and (2) suitability for threshold determination over a wide range of disparities. To comply with these requirements, we developed the Freiburg Stereoacuity Test. Method: The stimulus configuration is shown on a visual display unit (VDU) using phase-difference haploscopy with ferromagnetic liquid crystal shutters. The stereo target consists of a vertical bar that can be presented “in front of” or “behind” a frame. The sizes of the bar and the frame are kept constant relative to the stereo disparity. Anti-aliasing allows for disparities finer than the pixel raster. To mask monocular cues the bar is displaced randomly to the right or left. The stereo threshold was determined in two observers with normal eyes, using first the method of constant stimuli and then the best PEST. Both procedures were repeated with observers wearing scatter transparencies that reduced their visual acuity to about 1/10. In addition, the two observers with insight into the test design and two strabismic patients performed the best PEST procedure with one eye only. Results: With constant stimuli both observers achieved a stereoacuity of 2.6 arcsec and 3.1 arcsec, respectively, taking a hit rate of 75% as the threshold. The best PEST revealed a stereoacuity of 2.5 arcsec and 3.0 arcsec, respectively. The scatter transparencies raised the threshold to 261 and 257, respectively. With one eye only, the two observers with insight into the test design exploited the subtle position cue and reached a coarse pseudostereopsis. The two strabismic patients did not utilise the position cue. Conclusion: The Freiburg Stereoacuity Test allows determination of stereoacuity over a wide range of disparities (1–1000 arcsec). Although the stimuli can be seen with each eye alone, monocular depth cues are sufficiently masked. The Freiburg Stereoacuity Test is available at http://www.ukl.uni-freiburg.de/aug/bach/fst/.

Introduction

Stereopsis is the ability to detect, on the basis of binocular disparity, whether a single small feature, e.g., a line, is in front of or behind other features. Julesz [9] called this ability “local” stereopsis and distinguished it from “global” stereopsis that manifests itself in the ability to see a cluster of disparate random dots, not standing out as single elements, but marking a plane as being in front of or behind a reference plane. Random-dot tests have the advantage that they avoid monocular cues, but they differ considerably from natural viewing conditions. Moreover, in random-dot tests an ambiguity can occur as to which elements belong to each other on the retinae, so
that relatively large disparities are required to provide depth sensation. To avoid these drawbacks we endeavoured to develop a test that allows measurement of “local” stereoacuity over a wide range of disparities. Monocular cues had to be obscured.

Conventional methods for measuring stereoacuity suffer from one or more of the following shortcomings: The number of presentations at each disparity step is small, the threshold is not systematically estimated, and monocular cues are present so that stereoacuity cannot be distinguished from position hyperacuity. Using computer graphics, we avoided these shortcomings and developed the “Freiburg Stereoacuity Test”. Our test resembles the classical three-rod test, but bears three advantages: (1) statistical evaluation is performed online; (2) monocular position information is masked by random lateral offset of the stereo target [17]; (3) the distance between the stereo target and the reference contours is adjusted to mimic typical situations in real life: The reference contours are close to the stereo target when a high stereoacuity is required, e.g., when threading a needle, and the reference contours are distant when gross stereopsis is required, e.g., when pouring a cup of tea. Increasing the distance between the stereo target and the reference contours for large disparities carries the additional advantage that any overlap of the stereo target with the reference contours is avoided.

Methods

The Freiburg Stereoacuity Test

Technical design

The stimulus is presented at a distance of 4.5 m on a visual display unit (VDU), 36 cm wide and 27 cm high, with a resolution of 800x600 pixels and a frame rate of 120 Hz. A high luminance (390 cd/m2) is achieved by a special black-and-white VDU (GD403, Richardson Electronics). The screen is driven from the mainboard graphics card of a standard computer (Macintosh G4). The software for the generation of the stimulus and the interactive determination of the threshold is written in C++.

Nearly complete separation for the right and left eye is achieved by a pair of ferroelectric liquid crystal shutter goggles (FE1, Cambridge Research Systems). The voltage applied to the liquid crystals controls their transparency. The shutter goggles are synchronised to the monitor frequency so that images are presented alternately to the right and the left eye. Each eye receives its image at a frequency of 60 Hz, which is just above flicker fusion frequency. Compared to standard liquid crystal shutters [12], the ferroelectric LCDs switch more rapidly (=50 µs) and have a higher on/off ratio (1:500). In a previous version of the Freiburg Stereoacuity Test [4, 5] the stimuli for the right and left eyes were separated by mirrors instead of shutters.

The stereo target (Fig. 1) consists of a vertical bar that is surrounded by a frame. Outside of the frame a pattern with random black and white squares (edge length 180 arcsec) is displayed. The frame and the squares serve as the reference plane. The vertical bar is presented with a stereo disparity up to 1000 arcsec.

In a display with sharp black-and-white edges the stimulus position would be limited to steps according to the size of the pixels (20 arcsec at a distance of 4.5 m). To overcome this limitation, “anti-aliasing” [2, 16] is applied: The margins of the vertical bar are smoothed with a gradual transition of the luminance following a gaussian profile (Fig. 2). The gaussian profile has a standard deviation of 2 pixels. The profile can be shifted to the right or left in steps of less than 1 arcsec at a distance of 4.5 m. The gradual transition from black to white is acceptable since it merges with the blur of the retinal image brought about by the optics of the eye. The optical point-spread function of the eye resembles a gaussian profile of at least 120 arcsec width at half magnitude [6]. Thus, any shift of a point stimulus changes the relative illumination of a group of neighbouring photoreceptors. The visual system evaluates these changes, making possible a spatial resolution far beyond the grain of the photoreceptors, as exemplified in the various forms of hyperacuity, including stereoacuity [6].

The anti-aliasing technique requires accurate control of the luminance, taking into account the inherent non-linearity of cathode ray tubes. Linearisation of luminance requires a correction with an inverse gamma value [3], which is determined by a simple psychophysical adjustment task: Two fields are presented adjacent to each other. One is the reference field, consisting of a grid with black and white stripes. Viewed out of focus it appears as a homogeneous grey field with a luminance of 50%. The other field consists of a homogeneous grey. Its luminance has to be equalised by the operator to that of the reference field. Any residual non-linearity at both ends of the luminance scale is avoided by using only the 5%–95% range. This can easily be tolerated since a reduction of stereoacuity would be expected only below 50% contrast [10].

The size of the bar and the frame are kept constant relative to the disparity of the bar. The inner frame width is 8 times the disparity and the inner frame height 10 times the disparity. The length of the vertical bar is 70% of the inner frame height so that a gap remains between the top and the bottom of the bar and the inner frame edge. To obtain a sufficient stimulus width and length at small disparities, the frame height is kept at least at 3600 arcsec and the frame width at 800 arcsec. To mask monocular cues the bar is not centred with respect to the frame but placed randomly, trial by trial, to the right or left of the centre by the amount of the