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LABORATORY STUDY

A novel apparatus for testing binocular function using the 'CyberDome' three-dimensional hemispherical visual display system

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Abstract

Purpose **Virtual reality has recently been highlighted as a promising medium for visual presentation and entertainment. A novel apparatus for testing binocular visual function using a hemispherical visual display system, 'CyberDome', has been developed and tested.**

Methods **Subjects comprised 40 volunteers (mean age, 21.63 years) with corrected visual acuity of −0.08 (LogMAR) or better, and stereoacuity better than 100 s of arc on the Titmus stereo test. Subjects were able to experience visual perception like being surrounded by visual images, a feature of the 'CyberDome' hemispherical visual display system. Visual images to the right and left eyes were projected and superimposed on the dome screen, allowing test images to be seen independently by each eye using polarizing glasses. The hemispherical visual display was 1.4 m in diameter. Three test parameters were evaluated: simultaneous perception (subjective angle of strabismus), motor fusion amplitude (convergence and divergence), and stereopsis (binocular disparity at 1260, 840, and 420 s of arc). Testing was performed in volunteer subjects with normal binocular vision, and results were compared with those using a major amblyoscope.**

Results **Subjective angle of strabismus and motor fusion amplitude showed a significant correlation between our test and the major amblyoscope. All subjects could perceive the stereoscopic target with a binocular disparity of 480 s of arc.**

Conclusions **Our novel apparatus using the CyberDome, a hemispherical visual display system, was able to quantitatively evaluate binocular function. This apparatus offers clinical promise in the evaluation of binocular function.**

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Keywords: binocular function; virtual reality; hemispherical visual display system

Introduction

Binocular function is the basis for the development of many physiologic visual functions and must be intact for higher visual function. Normal binocular function (stereopsis) is the goal of treatment in paediatric ophthalmology for children with strabismus and amblyopia. The major amblyoscope is currently used to evaluate binocular and potential binocular function. The prototype of the major amblyoscope, based on a stereoscope, was first developed in 1868.[1] Since then, various improvements have been made, but the basic configuration remains the same. During this time, marked advances have been made in other instruments used in clinical ophthalmology, leaving the impression that devices used to evaluate binocular vision seem somewhat outdated.

Marked advances in information technology, including television, movies, computers, and video games have permeated every aspect of our daily lives. These constant visual stimuli no longer seem extraordinary. Computer technology and graphics have gone beyond the three-dimensional images to the realm of virtual reality. Devices to evaluate binocular function that maintain the interest of modern children must also be developed. This report describes the use of virtual reality technology for clinical evaluation of binocular function.

Materials and methods

Subjects

Subjects comprised 40 volunteers without ocular disorders other than refractive error (mean age, 21.63 years). Corrected visual acuity was −0.08 (LogMAR) or better, and visual acuity with both eyes open was −0.08 (LogMAR) or better. Near stereopsis was evaluated with the Titmus stereo test to confirm that all subjects showed stereopsis of less than 100 s of arc. Simultaneous perception (subjective angle of strabismus), fusion (motor fusion: convergence and divergence), and stereopsis were preliminarily evaluated using a major amblyoscope (Synoptophore; Clement Clarke International, UK). All subjects provided written informed consent before participating in this study, and the tenets of the Declaration of Helsinki were followed.

Test apparatus

A virtual reality display system, the CyberDome1400 (Panasonic Electric Works Co., Ltd, Japan), was used in this study. The CyberDome1400 is a hemispherical visual display system for widescreen projection.[2] Two liquid crystal projectors are used to display polarization images at horizontal and vertical viewing angles of 100° on a dome-shaped screen with a diameter of 1.4 m. Corrected images are reflected by a flat mirror in front of the projectors, and the compact image is projected on the dome screen. Figure 1a and b depict the display and system configuration. Synchronous processing is performed by two slave computers and one master computer to project a three-dimensional image. Projector angle of view, screen configuration, and placement represent input parameters for software used for image correction to provide a distortion-free image on the dome screen.

Test method

Subjects, after complete correction of refraction, wore polarized glasses and viewed the test images on the dome screen at a distance of 1 m in front of the eyes. Simultaneous perception (subjective angle of strabismus), fusion (motor fusion: convergence and divergence), and stereopsis were evaluated. These results were compared with the preliminary results obtained using the major amblyoscope. Size of target images was fixed at 5° of arc. Subjects were able to move the images using a joystick. Figure 2a shows the test apparatus setup.

Target images for simultaneous perception were a lion and cage. The lion was presented to the right eye and the cage was presented to the left eye. Subjects were asked to stop moving the joystick when the lion entered the cage. The value at this time was measured as the subjective angle of strabismus (°). In all subjects, the lion was presented to the right eye, the cage was presented to the left eye, and measurements were performed with the left eye fixed. The target image for fusion was a dolphin.

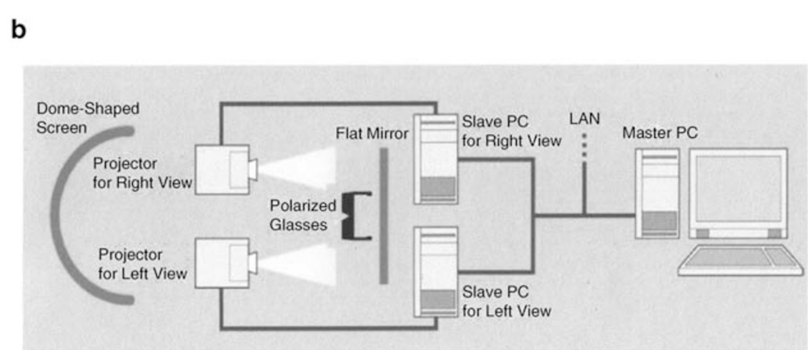

Figure 1 (a) The CyberDome1400. (b) System configuration.

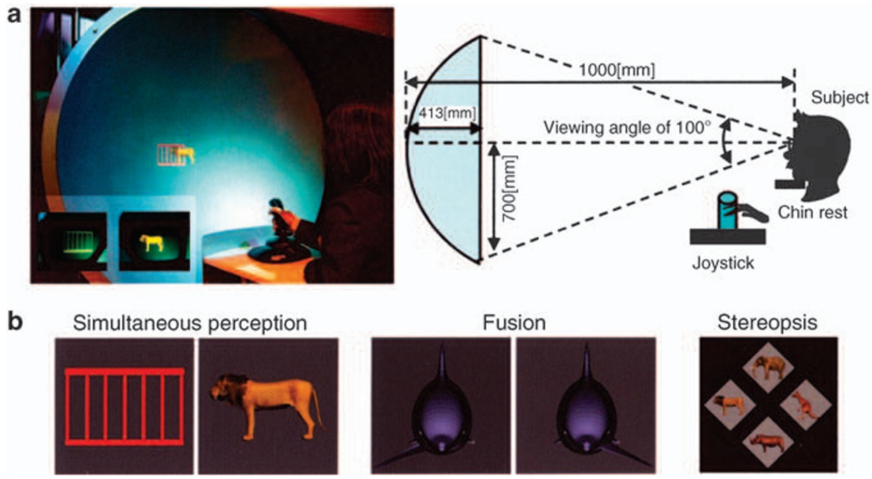

Figure 2 (a) Test apparatus setup: Subjects can intuitively move the display image using a left–right joystick. Polarizing glasses provide binocular vision. (b) Test images for simultaneous perception, fusion, and stereopsis displayed by novel apparatus using the CyberDome1400.

The fin of the dolphin was a check mark. The fusion image was presented at the subjective angle of strabismus (°) measured in testing for simultaneous perception. Subjects used a joystick to move the image towards convergence and divergence, and the breakpoint for fusion was measured. Target images for stereopsis were animals. Four images were presented with binocular disparity used for one. Binocular disparity of the stereoscopic image was 1260, 840, and 420 s of arc. Subjects were asked to identify the image perceived stereoscopically. Figure 2b shows the test images for simultaneous perception, fusion, and stereopsis.

Statistical analysis

Data were examined using Pearson's correlation coefficient. The results were found to be significant (Pearson's = 0.687, 0.856, and 0.682, $n = 40$, $P < 0.05$).

Results

Evaluation of binocular function could be performed in all subjects. For simultaneous perception (subjective angle of strabismus), test results with the novel apparatus using the CyberDome showed a good correlation with results from the major amblyoscope ($r = 0.687$, $P < 0.0001$; Figure 3). Mean subjective angle of strabismus was $-0.505 \pm 0.985°$ with the CyberDome and $-1.107 \pm 1.843°$ with the major amblyoscope. Motor fusion amplitude for convergence showed a strong correlation between the CyberDome and major amblyoscope ($r = 0.856$, $P < 0.0001$; Figure 4). Motor fusion amplitude for divergence also showed a correlation between the CyberDome and major amblyoscope ($r = 0.682$, $P < 0.0001$; Figure 5).

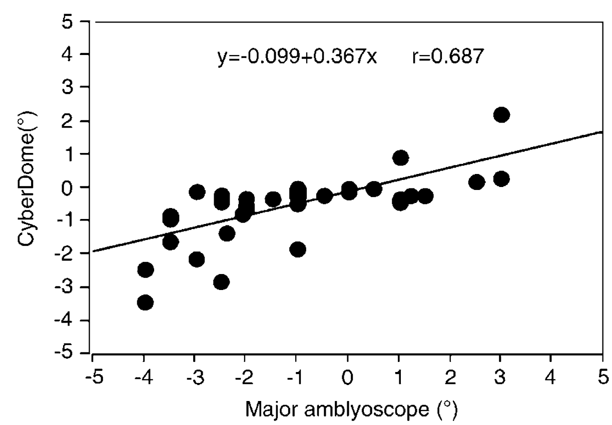

Figure 3 Scatterplot showing the subjective angle of strabismus measured by CyberDome plotted against that by the major amblyoscope. The line of equivalence (y = x) is designated by a solid line.

Discussion

We evaluated a novel apparatus using the CyberDome1400 (CyberDome) to assess binocular function. Despite some difference in binocular separation, test results (simultaneous perception, and fusional amplitude (convergence and divergence) showed good correlations between the CyberDome and major amblyoscope. Although stereopsis can be evaluated quantitatively using Braddick slides, this application is not routinely performed, and our apparatus allows simple quantitative evaluation. Measurement was performed with a binocular disparity

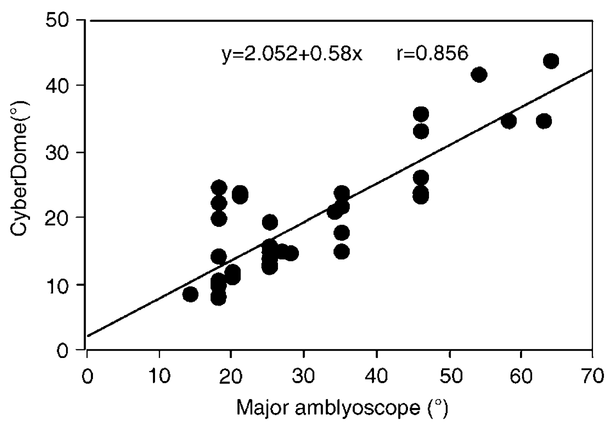

Figure 4 Scatterplot showing the magnitude of motor fusional amplitude (convergence side) measured by CyberDome plotted against that by major amblyoscope. The line of equivalence (y = x) is designated by a solid line.

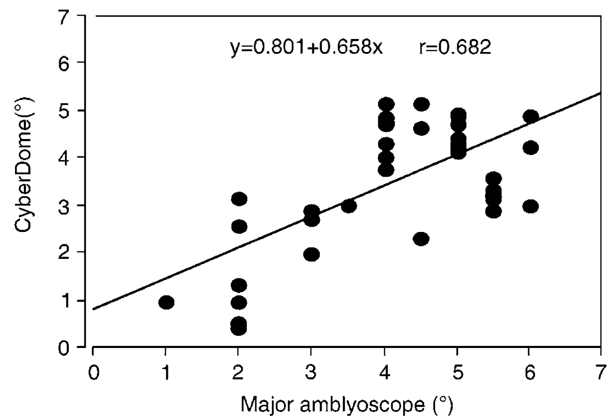

Figure 5 Scatterplot showing the magnitude of motor fusional amplitude (divergence side) measured by CyberDome plotted against that by major amblyoscope. The line of equivalence (y = x) is designated by a solid line.

of 1260, 840, and 420 s of arc, but measurement at different disparities is possible with a change in settings. This research showed that assessing binocular functions with the CyberDome produces results comparable to those found using the major amblyoscope in participants with no ocular defects and normal levels of vision and binocularity.

Evaluation of binocular function using the CyberDome offers three advantages. Firstly, each test device is associated with a difference in binocular separation. The CyberDome uses polarizing glasses, whereas binocular separation is provided by a lens barrel in the major amblyoscope. Thus, the binocular vision with the CyberDome more closely approximates visual experience in our daily lives compared with the major amblyoscope. Our testing of simultaneous perception showed a smaller subjective angle of strabismus with the CyberDome ($-0.505 \pm 0.985°$) than with the major amblyoscope ($-1.107 \pm 1.843°$). Binocular separation is thus less and vision is more realistic with the CyberDome (polarizing glasses) than with the major amblyoscope. Secondly, width of the visual field differs. The diameter of the CyberDome is 100°, whereas the diameter of the major amblyoscope is 19°, actual value), so the CyberDome provides a wider visual field. Thirdly, the CyberDome allows testing with an amusing game-like experience. Subjects can adjust the image and sounds using a PC-controlled system. Subjects can enjoy participating in the testing process using the joystick to move images.

In 1966, Aulhorn[3] used imaging technology to develop the phase-difference haploscope for evaluation of binocular function. The haploscope uses rapidly rotating sectors, at a 90°-phase difference, in front of each eye and a pair of right and left projectors with synchronized sectors to provide binocular vision. In addition to natural binocular viewing, a third projector presents a background image to both eyes to simulate more natural vision for testing. The configuration of the CyberDome apparatus in our study was different, but target images are projected on a screen and subjects simultaneously view movement of the target images. Many of the basic principles thus resemble those of the phase-difference haploscope. Our novel apparatus evaluates the same test parameters as the major amblyoscope, and represents the next generation of devices to evaluate binocular function, using modern virtual reality technology, to provide a more realistic visual experience than previously possible with the phase-difference haploscope.

Eastgate *et al*[4] recently presented a treatment system for amblyopia using modified virtual reality technology. This device enables not only treatment of amblyopia, but also the ability to measure binocular vision, such as simultaneous perception, fusion, and stereopsis in our device. We need to incorporate the function of a treatment system for amblyopia in our device, and this issue is currently being pursued. In addition, the advantages of our novel apparatus using the CyberDome1400, including a virtual reality system and a dome screen, offer an improvement in visual testing equipment. This can be useful not only to assess binocular function, but also to assess a variety of other subjective visual functions, such as visual acuity, visual field (ie, the dome screen used in our system), eye position and movement (eg, the Hess screen test). In the future, we aim to develop a multipurpose ophthalmic test system that combines numerous conscious ophthalmic tests.

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