

## A binocular fiberscope for presenting visual stimuli during fMRI

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**Abstract**—A binocular pair of fiberscopes relays high-resolution images of CRT displays from an adjacent room to an observer lying in a scanner in functional Magnetic Resonance Imaging (fMRI) studies of visual function. We review the problems that must be overcome by any visual display for use in fMRI, present the specific solution we developed, and discuss its merits. Together, the fiberscope and CRT conveniently display accurately controlled high- and low-contrast wide-field images to an observer in an fMRI scanner.

### INTRODUCTION

Recent studies have shown that functional Magnetic Resonance Imaging (fMRI) can map brain activity during perceptual and cognitive tasks (e.g. Kwong *et al.*, 1992; Cohen and Bookheimer, 1994; Engel *et al.*, 1994). We have been using fMRI, in conjunction with psychophysical measures, to study human visual processing. In our psychophysical studies (e.g. Solomon and Pelli, 1994), we present visual stimuli using computer-driven cathode-ray-tube (CRT) displays, which allow precise control of stimulus contrast, color and timing (Pelli and Zhang, 1991; Pelli, 1997; Brainard, 1997). Most vision research uses CRT displays because they offer high luminance, high spatial resolution, and fine intensity resolution. However, the magnetic-deflection raster scan of CRTs fails in the intense magnetic field of an MRI scanner.

Various alternative displays have been developed, but all are less satisfactory than the direct view of a CRT that is usual in vision labs. With an observer in the bore of the scanner, very little space is left for display equipment, and the long aspect ratio of the bore restricts the observer's view of the outside. Very simple visual stimuli

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(e.g. a flashing uniform field or a static checkerboard pattern) can be displayed by LED goggles or printed material attached to the ceiling of the bore. However, such methods do not allow presentation of images that vary in both space and time. One can operate a CRT outside of the scanner room, escaping the scanner's intense magnetic field. However, even if there were a direct line of sight, the CRT is so far away that it subtends only a small visual angle ( $< 10$  deg) at the eye of an observer in the scanner.

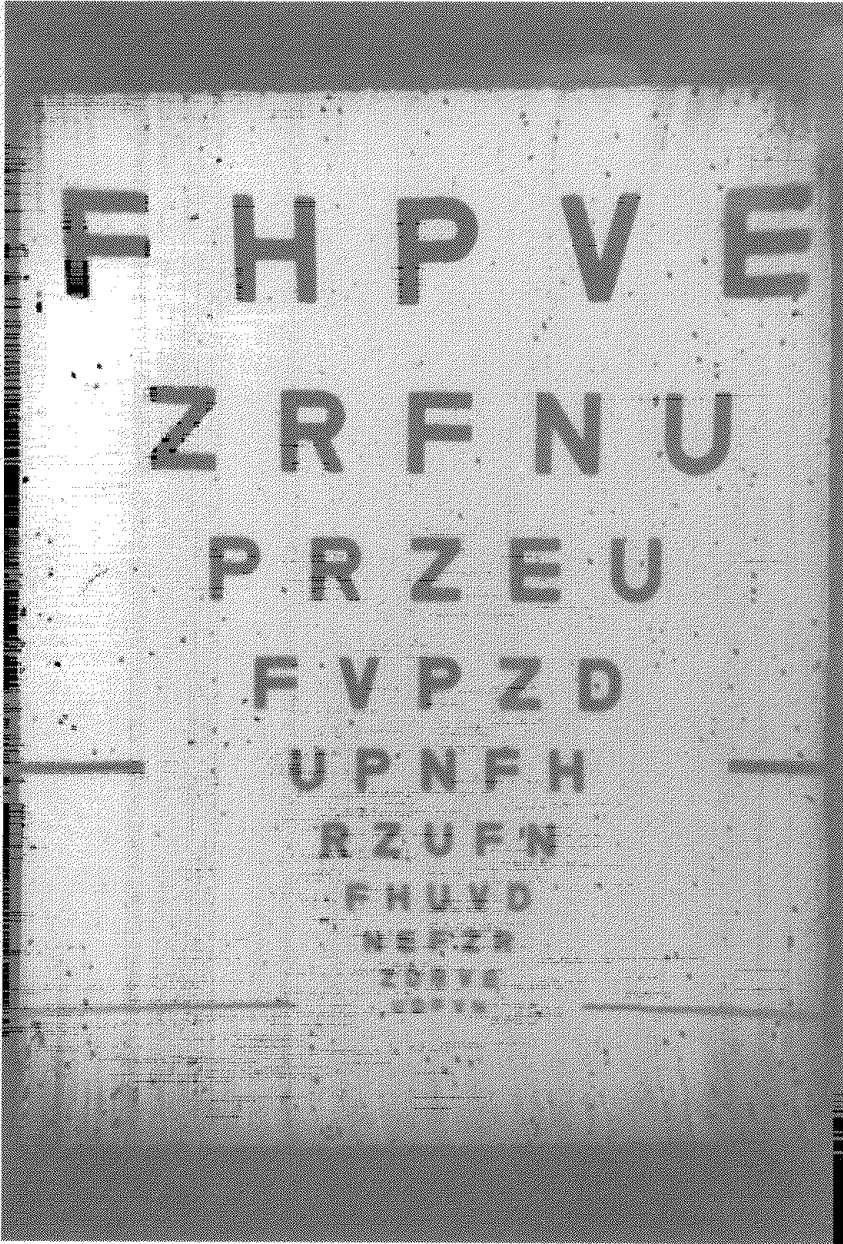
A popular solution (e.g. Tootell *et al.*, 1995) is to put a 45-deg mirror on the ceiling of the bore, allowing the prone observer to look up and see a rear-projection screen onto which a remote video projector displays the video stimulus. The drawbacks of this method include a restricted field of view (due to the long aspect ratio of the bore), difficulty in characterizing the image quality (which is highly dependent on viewing angle), and susceptibility to loss of contrast due to stray light reaching the projection screen.

Liquid-crystal-display (LCD) monitors and projectors are not affected by magnetic fields but emit radio-frequency noise that interferes with scanner function, unless this is prevented by special shielding. A LCD monitor could be placed inside the scanner room, and the system might be relatively easy to set up and remove, an advantage in MR facilities that serve both clinical and research purposes. However, current LCD displays have coarse control of contrast and color, making it difficult or impossible to display near-threshold contrast patterns. Note that the 8-bit quantization common in the current RGB graphics cards used to drive CRTs is also too coarse to measure visual contrast thresholds, except by analog or software tricks (Pelli and Zhang, 1991; Tyler, 1997; Bach *et al.*, 1997). Unfortunately, unlike the ease of interposing a custom analog circuit between the video card and the CRT (Pelli and Zhang, 1991), it would be difficult to modify any of the commercial LCDs to achieve a finer intensity resolution. It seems unlikely that LCD displays will exceed 8-bit (per channel) RGB resolution in the near future (e.g. Erhart, 1996). Color plasma displays are now becoming commercially available, but have essentially the same limitations as LCD displays for purposes of generating research-grade visual stimuli (Werner, 1996). There are software-based techniques that sacrifice spatial or colour or temporal resolution in order to improve contrast resolution and are useful for some purposes (Tyler, 1997; Bach *et al.*, 1997).

Here we describe the use of a pair of fiberscopes to relay the image of an ordinary CRT display in an adjacent room to the eyes of an observer lying in the scanner. We have successfully used this system in fMRI experiments (Cornelissen *et al.*, 1995a, b).

## DESCRIPTION OF THE FIBERSCOPE

A fiberscope consists of three parts: first, an objective lens that images the world, in our case the face of the CRT, onto the far end of a coherent image guide; second, the image guide itself; and third, an eyepiece through which the near end of the image guide is viewed. The 1000-by-800 optical fiber image guides (about \$8000 each from Schott Fiber Optics, South Bridge, MA, USA) have high enough resolution (Fig. 1) to view a  $640 \times 480$  pixel monitor without significant loss of detail. From the display



**Figure 1.** Eye chart viewed through a fiberscope. The letters in the bottom row are just readable through the fiberscope, though not in this photograph. With the usual 10 $\times$  eyepiece power, the 1000  $\times$  800 fiber image guide subtends 35  $\times$  28 deg of visual field. The black dots are broken fibers.

in the next room, the 4.5-m long image guides go through a hole in the shielded wall of the MRI room to reach the observer lying in the scanner. We present the same stimuli on the same monitors that we used in our psychophysical studies, which

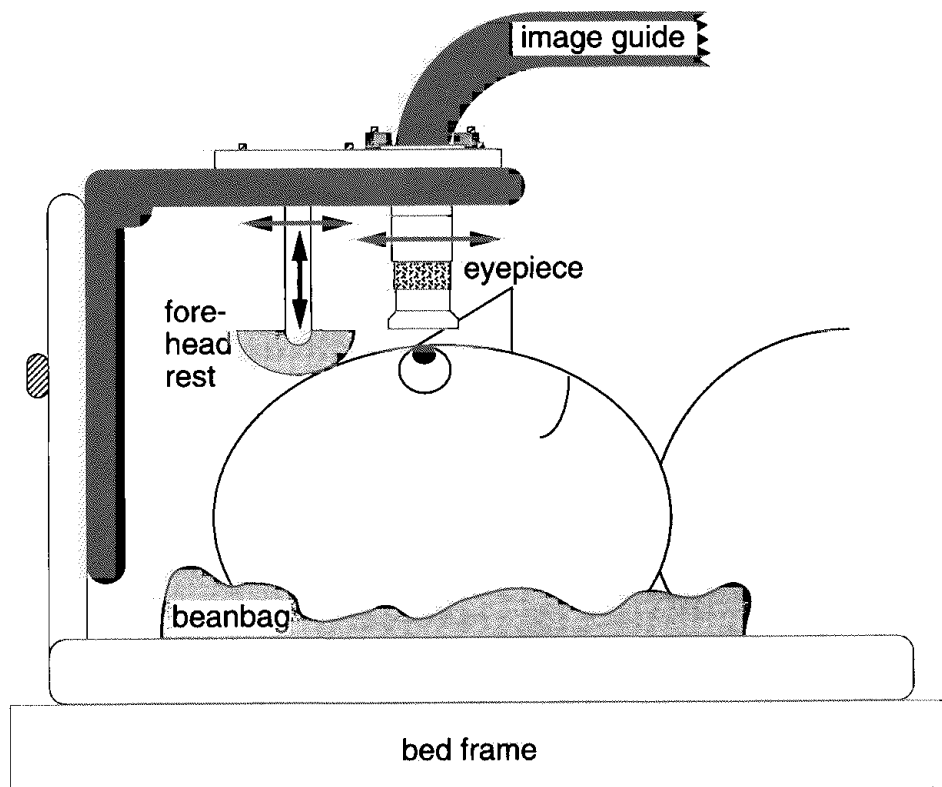
makes it easier to compare psychophysical data with those obtained in fMRI. We use two image guides, one for each eye, in order to maximize brain stimulation, and to avoid the rivalry and suppression that would result from using monocular stimulation (Bolanowski and Doty, 1987). In our experiments to date, both image guides relay images of the same monitor, but one could easily use two monitors for stereo display.

Fiberscopes have some disadvantages. The 4.5-m image guides attenuate the luminance by a factor of 3, attenuating more at shorter wavelengths (giving the white CRT's image a yellowish cast), and cause some contrast loss through light leakage between fibers. Even so, the optical modulation transfer function (MTF) is quite satisfactory. The contrast gain is 1 at zero frequency (by definition) and is still 0.5 at 4 cyc deg<sup>-1</sup> and drops to 0.25 at 8 cyc deg<sup>-1</sup> (with a 10× eyepiece). It is relatively easy to measure these distortions and compensate for them. (Contrast gain was measured by comparing visual thresholds with and without the fiberscope.) The glass optical fibers break if bent too sharply. Broken fibers result in black spots in the image (see Fig. 1). However, such spots are stable and probably make little contribution to the results, since fMRI experiments typically measure the difference between an experimental and a control condition. In several years of use of our fiberscopes, there has been no noticeable increase in the number of breaks beyond those produced during manufacture.

Fiberscopes for fMRI must satisfy several requirements. The fiber-optic image guides must reach from the observer's head, in the bore of the scanner, to the display in the next room. The image guides and eyepieces must not contain any ferrous or conductive materials, so as not to disturb the scanner's magnetic field. (A dynamic magnetic field induces eddy currents in any conductive loop, which in turn create a secondary magnetic field. Disturbance of the magnetic field may result in field inhomogeneities with resultant distortion of images and artifacts that may compromise overall image quality.) Each of our image guides consists of 1000 × 800 optical fibers (each 10 μm in diameter) that together form a 10 × 8 mm bundle. The fibers are protected by a flexible plastic jacket.

Inside the scanner, a plastic eyepiece holder rests on the bed frame and supports the eyepieces (Fig. 2). The holder, which is made of non-ferrous materials (mainly PVC), fits inside the scanner's bore over the observer's head. It is easy to set up and remove, and allows adjustment of the eyepiece position to accommodate various head sizes, eye positions, and interpupillary distances. The holder does not interfere with the use of the MR scanner's surface coil, which we place over the occipital area to image visual cortex. The eyepieces are suspended in the holder above the observer's eyes. To prevent the observer's eyes from touching the eyepieces, a bar is positioned slightly above the observer's forehead. If the observer raises her head, she will push against this bar with her forehead, rather than poke her eyes. Other directions of head motion are restrained by an immobilizing, deflatable polystyrene-filled beanbag ('Olympic Vac-Pac', Olympic Medical, Seattle, WA, USA).

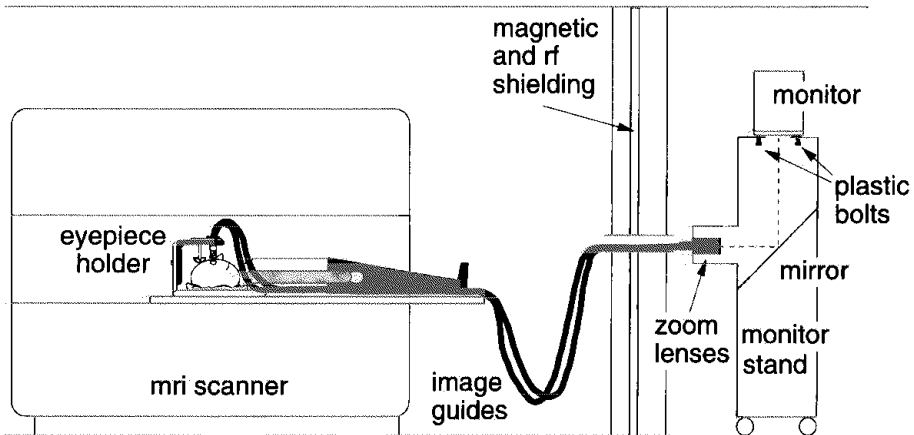
The field of view (expressed as the angle subtended at the observer's eye) depends on the choice of eyepiece power. We have done most of our work with 10× wide-field microscope eyepieces ( $f = 16$  mm, American Optical), which display the 10 × 8 mm image guide as a 35 × 28 deg field. We replaced the eyepiece's metal housing by



**Figure 2.** Schematic drawing of the eyepiece holder. The holder can be adjusted to accommodate different head sizes, eye positions, and interpupillary distances. The arrows indicate four of the adjustments. (The adjustment for interpupillary distance is not shown.) The forehead rest protects the observer's eyes from contact with the eyepieces. The beanbag immobilizes the observer's head. We place the MR scanner's surface coil over the occipital area to image visual cortex. The holder and image guides could be used with other coils as well, provided there is enough room.

plastic. Eyepieces with 5 $\times$ , 15 $\times$ , and 20 $\times$  magnification are readily available as well, yielding approximately proportional fields of view ranging from 17  $\times$  14 deg to 64  $\times$  51 deg. The lower power of the 5 $\times$  eyepiece results in a smaller field of view but increases the density of the fibers in the observer's visual field (1000/17 deg = 59 fibers/deg), allowing display of higher spatial frequencies (up to 29 cyc deg<sup>-1</sup> without aliasing). The higher-power eyepieces restrict us to lower spatial frequencies, but over a larger field. A disadvantage of the 20 $\times$  eyepieces is their reduced eye relief: long eye lashes may brush against the eyepiece, to the possible annoyance of the observer.

We built a monitor stand (Fig. 3) to hold any of the several different monitors used by researchers needing visual stimuli in their fMRI research here. The monitor is positioned face-down, its glass face resting on four plastic bolts at a fixed distance from the two objective lenses (J6  $\times$  11 video zoom lenses, Sony) that image the monitor screen onto the image guides. This scheme easily accommodates a wide variety of monitors, yet allows quick alignment. The objective lenses are positioned



**Figure 3.** Schematic drawing of the fiberscope in use. The monitor stand accommodates practically any monitor. The monitor's glass face rests on four plastic bolts at a fixed distance of 1.0 m from the two objectives (video zoom lenses), which image the monitor screen via a 45 deg front-surface mirror onto the ends of the image guides. The zoom lenses are adjusted to make the image of the CRT fill the face of the image guide. The guides pass through a pipe that penetrates the 3-inch-thick steel-plate magnetic shield and the copper-foil radio-frequency shield in the walls of the scanner room. (The pipe is a waveguide. It prevents radio frequencies from entering the otherwise electrically shielded room.) The eyepiece holder suspends the other end of the image guides in front of the observer's eyes.

at an optical distance of 1.0 m from the monitor (bouncing off a 45 deg front-surface mirror) and converge slightly in order to direct them at the same point on the screen. The focal length (zoom) of the objective lenses is adjusted to make the image of the CRT fill the  $10 \times 8$  mm face of the image guide. (As noted above, the size of the visual field is controlled by the choice of eyepiece power.) A pair of such stands would allow presentation of independent images to the two eyes. Because the fiberscopes operate independently of the monitor, they can be used to view anything, including real three-dimensional objects, in stereo.

## CONCLUSION

For fMRI study of visual function, fiberscopes allow the use of the traditional workhorse of vision research—the CRT monitor. Together, the fiberscope and the CRT conveniently display accurately controlled high- and low-contrast wide-field images to an observer in an fMRI scanner.

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