33.4: The Impact of Non-Immersive HMDs on the Visual Field

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Abstract

Both binocular and monocular HMDs designed to be used non-immersively were found to create minimal interruption of the visual fields making them safe to wear (but probably not to use) in mobile situations. A small opaque display can be positioned to provide a see through functionality.

1. Objective and Background

Non-immersive head mounted displays (HMDs), those that allow the wearer to interact with their environment while using the HMD, have considerable potential for use in offices, industry and medicine. For example, a worker could walk warehouse aisles collecting goods listed on a HMD that were transmitted from a central computer. In such circumstances the vision through and around the display are important for safety and orientation. While central vision is used to view an object of regard, peripheral (side) vision is critical for safe and efficient mobility. The extent of peripheral vision is known as the visual field.

While manufacturers provide the field of view of HMDs, the impact of HMDs on the visual field have been addressed only minimally in the literature. Most considerations given were to the trade-off between the field size and resolution and the effects of these trade-offs on target search [1-3]. The limitations of these trade-offs are important considerations in immersive HMDs but may be less important in non-immersive HMDs. In fact as noted by Peli [4] and Davis [3], a wide field of view in a HMD may be difficult to use as large eye movements are needed and no head movements can be used to reduce an eccentric eye position. Here we consider in addition to the field of view of the display itself the impact of the whole appliance on the visual fields of the user.

Vision through the HMD display may be reduced or obstructed by the veiling luminance of the display. Vision around the display may be limited by the supporting structure (the body) of the HMD. Between the display and the body is a region that we call the *clearance*, as shown in Figure 1. A HMD may obstruct the view of an object in a particular direction (a scotoma). Non-immersive HMDs may be binocular or monocular, so we examined two examples of each. We show that the impact of the HMD on the visual field depends on a range of factors including HMD design and HMD placement. Interestingly, the scotoma caused by the display may be displaced from the direction of the display. These impacts on the visual field influence the relative safety of use of non-immersive HMDs when planned use requires interaction with the environment and should be considered in HMD design.

2. Methods

Visual fields (extent of vision) were measured on a small group of young (aged 20 to 30 years) normally sighted subjects using standard clinical procedures and instruments [5]. Subjects wore their own spectacles or contact lenses to correct any refractive error. Visual fields were measured without an HMD and with two binocular HMDs and with two monocular HMDs. All evaluated HMDs were non-immersive designs. Care was taken to ensure that the HMDs did not move relative to the head during a measurement session. Visual fields were measured monocularly and binocularly.

The Auto-Plot perimeter (Bausch & Lomb, Rochester, NY) used for most measurements is a mechanical kinetic perimeter that allowed examination of the central 50° (diameter) of the visual field. As shown schematically in Figure 1, small circular spots of light (targets) were projected by the perimeter onto a screen 1 m from the subject. Measurements were conducted in a dimly lit room

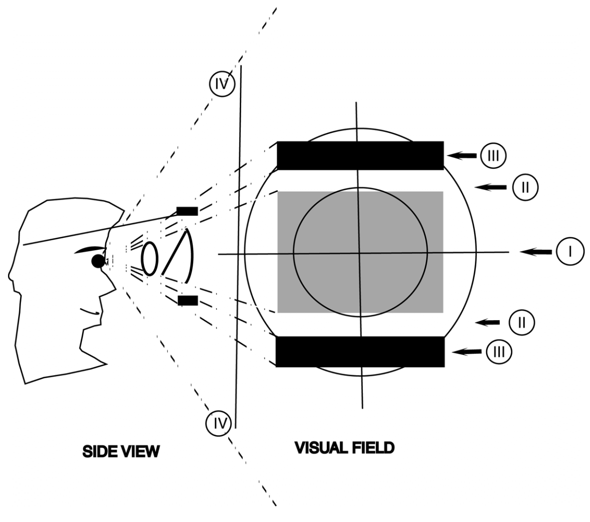

Figure 1. Schematic view of an HMD wearer and the visual field restrictions of a non-immersive HMD. The areas of the visual field of interest are: (I) the gray area is the image of the display projected onto the test screen; (II) clearance is the part of the visual field that surrounds the display and is not blocked by the HMD body; (III) the areas of the visual field, that are blocked by the body and (IV) the natural limits of the visual field e.g. brows.

(0.21 fc: Minolta Illuminance meter TL-1), with a screen luminance of 0.021 cd/m^2 (Minolta LS 110 spot photometer). While the subject maintained a steady gaze at a bright red spot (laser pointer directed at screen) white targets were moved on the screen and the subject reported when the target appeared (or disappeared). The Auto-Plot projects a bright (white) target on the screen. Targets vary in size and are specified as to their diameter in mm on the screen. From the observation distance of 1 m a 1 mm target spans 0.057° or 3.44 arcmin of visual angle. As smaller targets (e.g. 0.5 mm the smallest target available) are more difficult to see than larger targets (e.g. 6 mm) measured scotomata may vary with target size. In dynamic perimetry the target is moved in slowly (about 2 deg/sec) from the area where it is not seen towards the area where it is seen. When the subjects indicate spotting the target the position is marked. On a visual field plot, scotomata (regions in which a target are not seen) are outlined by isopters (lines joining the points that define the scotoma edge) and are commonly hatched or shaded (e.g. Figure 2). A region in which no target can be seen is known as an absolute scotoma and a region in which one target can be seen, but a smaller target cannot be seen is known as a relative scotoma. Note that due to the observer's finite size pupil vingetting causes relative scotomata at the edges of opaque obstructions in front of the eye.

The Sony Glasstron PLM-50 (Sony, Tokyo, Japan) and the Virtual I-O Iglasses (i-O Display Systems, LLC, Sacramento, CA) are binocular HMDs with an open (non-immersive) design. The (QVGA) MicroOptical Clip-on CO-1 and a prototype VGA MicroOptical Integrated EyeGlass (MicroOptical Corp., Westwood, MA) are monocular HMDs. All four HMDs were used in a see-through mode, and visual field measurements were taken with either a black (no power) or with a blank blue screen displayed on the display. Visibility of objects seen through the display may decrease when there is an active display (e.g. patterned, moving) compared to those described here. Except for the MicroOptical Eyeglass, all monocular measurements were of the right eye.

3. Results

Binocular HMDs (Sony Glasstron PLM-50 and Virtual I-0) had a more significant impact on the visual field than monocular HMDs (MicroOptical Clip-on and MicroOptical Eyeglass). Both binocular HMDs blocked some parts of the monocular and binocular visual field (i.e. absolute scotomata), whereas the MicroOptical Clip-on blocked some of the monocular visual field but not the binocular visual field.

The body of the Sony Glasstron PLM-50 caused larger scotomata than the body of the Virtual I-O. The body scotoma in the lower part of the monocular visual field was not found in the binocular visual field of the Virtual I-0, but was found in the binocular visual field of the Sony HMD (Figure 2). The body scotomata in the upper part of both binocular HMDs were comparable in size and shape. Slightly surprisingly, changing to binocular viewing did not substantially reduce those scotomata found monocularly, with either binocular HMD. The body of the Virtual I-0 had little effect along the lateral visual field, while the body of the Sony blocked most of the horizontal meridian beyond the central 42°. The body of MicroOptical Clip-on caused a small scotoma in the visual field (Figure 3) that was not found in the binocular visual field, as the visual field of the other eye was unobstructed. The MicroOptical Eyeglass did not cause a body scotoma.

The optics within the spectacle lens of the MicroOptical Eyeglass caused relative scotomata, as it reduced the see-through contrast in the clearance area (MicroOptical are working to remove this effect). In the binocular field these scotomata may overlap with the physiological blind spot of the other eye in which case a relative scotoma was noted. The blind spot that corresponds with the part of the retina where the optic nerve attaches to the eye (the optic disk), and there are no photoreceptors overlying the optic disk. Internal reflections were also noted with the MicroOptical Clip-on, though they were smaller and less noticeable than those of the Eyeglass.

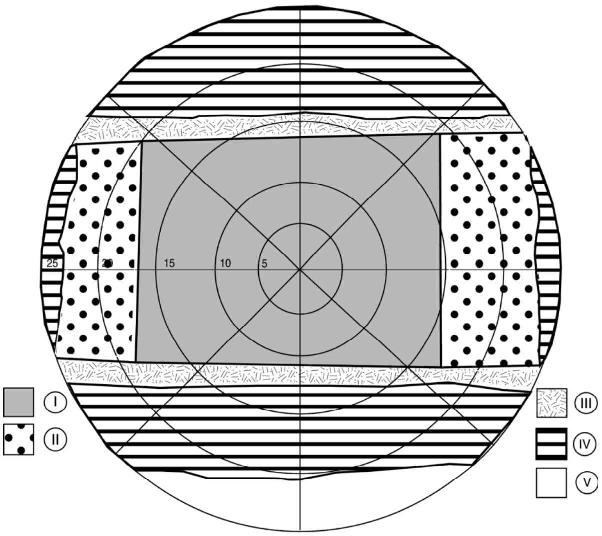

Figure 2. Binocular visual field with a Sony Glasstron PLM-50 wearer measured with the B&L Auto-Plot perimeter (with blue screen on). The areas of interest are: (I) relative scotoma caused by display, targets smaller than 6 mm were not seen in this region; (II) clearance, a relative scotoma, targets smaller than 2 mm were not visible; (III) clearance, a relative scotoma, targets, smaller than 6 mm were not visible; (IV) absolute scotoma caused by the HMD body; and (V) below the HMD body, all target sizes were visible. Note that the absolute scotoma extends up to the limit of the field and much further than shown laterally.

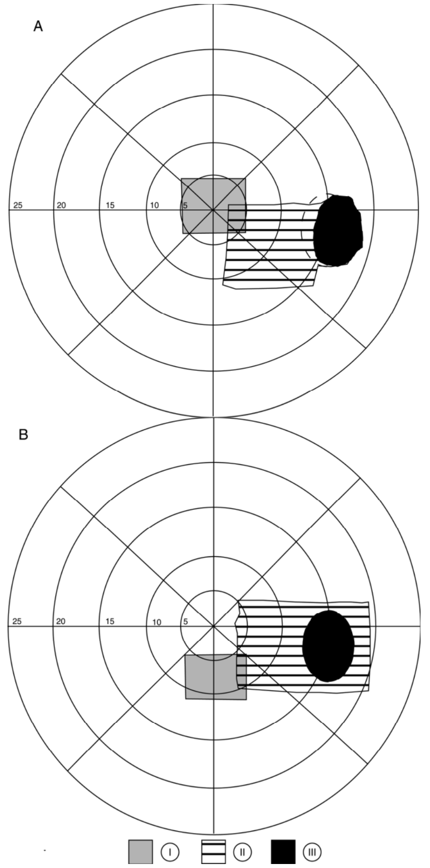

Figure 3. Monocular visual fields of the right eyes of two subjects each wearing the MicroOptical Clip-on HMD. In each case there was almost complete separation between (I) the display and (II) the relative scotoma created by the optics and the screen of the HMD. The locations of these elements depended on the position of the HMD relative to the eye. The absolute scotoma (III) is the physiological blind spot. (A) Subject JB, vertex distance of 34 mm, (I) the display was located in the center; and (II) a relative scotoma, shown here for a 1 mm white target, shifted down and to the right. (B) Subject IF, vertex distance of 26 mm, (I) the display was located below the center; and (II) a relative scotoma, shown here for a 1 mm white target, shifted up and to the right. Other measurements were taken, where the display and the optical scotoma were aligned or had different displacements.

As shown in Table 1, the measured angular size of the HMD displays compared reasonably well with the nominal field of view (i.e. as specified by the manufacturers). Notably, the displays of the binocular HMDs were larger than those of the monocular HMDs. The Sony Glasstron had the largest display, however it was difficult for most wearers to see the entire display at once. Only when the HMD was close to the eyes were all edges of the Sony display visible at once. Subjects wearing glasses could not see all corners of the display at the same time, either the upper or the lower edges being strongly vignetted. Thus the larger field of view of the Sony was usually not fully usable.

The distance between eye and the HMD (vertex distance) affects the size of the scotoma. This distance is a consequence of facial physiognomy and, where available, adjustments of the HMD. For example, in the two visual fields of the MicroOptical Clip-on shown in Figure 3, the vertex distances for two subjects were 26 mm and 34 mm, resulting in scotomas of different sizes when wearing the same HMD.

Clearance, a see-through part of the visual field visible between the HMD body and the display, was found with both binocular HMDs but not with either monocular HMD. As shown in Figure 2, clearance may be a relative scotoma (due to reduced transmittance). As targets 2 mm and larger were visible in the clearance of the Sony Glasstron, the relative scotoma was less dense than that of the display (Figure 2).

An important feature of a non-immersive HMD is see-through transmittance (the relative brightness of the environment seen through the display). See-through transmittance affects display contrast, however a low see-through transmittance brightness may cause relative scotomata, such that objects that are small or have a low luminance may be not visible. The see-through transmittance of the two binocular HMDs depended strongly on whether the display was powered, but this was not true of the monocular HMDs (table 1). Without power very small targets were visible through all displays except the Sony Glasstron which required targets 2 mm or larger. With power (i.e. displaying a blue screen), again the Sony Glasstron required larger targets (6 mm or larger) than the Virtual I-O. Even at the highest see-through transmittance of the Sony Glasstron, the environment seen through the display was dimmer than through the (fixed transmittance) Virtual I-O display. Though we found no measurable difference between with- and without-power for the two monocular HMDs the environment viewed through the MicroOptical Eyeglass was dimmer than through the MicroOptical Clip-on when used in the see-through mode. As with monocular HMDs the other eye sees objects unobstructed when viewing binocularly, the see-through targets in table 1 are reported for the monocular visual field.

An interesting effect was noted with the MicroOptical Clip-on. Depending on the position of the HMD relative to the eye, the scotoma can completely overlap the display, or the scotoma can be displaced relative to the display. In other words, the display can be opaque or see-through. Consequently, as shown in table 1, the smallest target visible through the display depends on the placement of the HMD. This characteristic permits a see-through functionality in a device that was built as an opaque display. This could be an advantage in applications that

Table 1. The measured field of view of the display was consistent with the nominal field of view as reported by the manufacturer. The depth of the relative scotoma created by the display was greater when the display was illuminated (with-power) than when without power. A relative scotoma defined by a 0.5 mm target is minimal as this was our smallest target. For the monocular HMDs, these measurements were made monocularly,

	Horizontal field of view (degrees)		Smallest white target visible through the display (mm)	
	Nominal	Measured	without power	with power
Sony Glasstron (PLM-50)	30	33	1	6
Virtual I-O (I-glasses)	27	25	0.5	3
MicroOptical Clip-on (CO-1)	10	10	0.5	12 / 0.5 *
MicroOptical Integrated EyeGlass	16	17	0.5	0.5

* For the MicroOptical Clip-on, the visibility through the display depended on the positioning of the HMD as described in the text.

may benefit from see-through, but could be detrimental to functionality when high contrast is necessary. In the example shown in Figure 3B the scotomata was displaced to overlay the blind spot. Under these conditions the scotoma includes an area of the eye that does not have vision anyway. But more important, usually the other eye covers the scotomata caused by the MicroOptical Clip-on HMD. Thus position of the display and its consequence to the separation of the screen and the scotoma should be explained and training in their control should be provided to users.

4. Impact

When using a non-immersive HMD the user could and sometimes might be expected to interact with the environment while mobile. Most such devices are distributed with a strong warning against their use while operating motor vehicles or heavy machinery. However, many are clearly designed to be mobile and thus would be expected to be operated by users who are walking or otherwise interact with other equipment and devices. In such situations the visual field available for the user is important both for safe operation, avoiding obstacles and for fast and efficient navigation through the environment and locating objects needed for task performance. These issues are clearly on the mind of designers of such devices as is evident by the results reported above. While the binocular HMDs caused scotomata in the binocular visual field, the monocular HMDs provided essentially an open environment with minimal field obscurations when used with both eyes open. While such open designs clearly provide the necessary field of view required for detecting large obstacles and threats, the ability to attend to the peripheral field when attending to the display is certainly reduced. Thus the open designs we measured do not prove in any way that it is safe to operate such displays while walking and moving around. Although vision is not obstructed, attention might not be easily divided between the display and the environment; thus it might not be safe to move around while operating the display. However, it appears that with proper design sufficiently open visual field may be available such that a user may safely move from one place to another without a need to remove the display. An option to eliminate display imagery may be of benefit both to visibility and attention when moving.

We demonstrated also that with small displays such as the MicroOptical Clip-on, care in the positioning of the device might control the location of the scotomata created by the display. Further the finite size of the eye's pupil permits separation of the display and the scotoma enabling the use of a nominally opaque display as a see-through display. The users of such displays should either be trained or get clear instruction on the issues relating to such operation. With training, it is possible that mobile computing displays could be used safely and efficiently and provide rapid and convenient access to information on the go.

6. Acknowledgements

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7. References

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