61.1: Kinematics of Visual Search by Tunnel Vision Patients with Augmented Vision See-Through HMD

Gang Luo and Eli Peli
Schepens Eye Research Institute, Harvard Medical School, Boston, MA 02114, USA

Abstract
An augmented vision see-through HMD, which displays a minified contour view of the real world over the residual visual field of tunnel vision patients, was evaluated in a visual search experiment. Kinematic evaluation of subjects' eye and head movements showed that tunnel vision patients could find and locate targets outside their visual fields faster and more efficiently with the device than without an aid or with an acoustic cue.

1. Objective and background
Tunnel vision is a severe restriction of the peripheral visual field (VF), which may be caused by glaucoma or retinitis pigmentosa (RP). In the USA, about 2% of adults 40 years or older suffer from glaucoma, and an estimated 20 to 33.3 per 100,000 individuals suffer from RP [1,2]. The impact of visual field restriction on mobility becomes very significant when the loss is severe in both eyes (10° residual field or less). At this level patients face significant difficulties with obstacle avoidance and navigation and may need to use a long cane or a guide dog.

To increase the instantaneous field of view of tunnel vision patients, minifying systems may be implemented either as an optical device [3] or as the electronic image remapper [4]; but in all cases they result in loss of resolution, which is generally rejected by the patients. Peli proposed a novel method (based on the principle of spatial multiplexing [5]) that increases the instantaneous field of view without loss of central resolution using an augmented-vision see-through HMD [6, 7]. A prototype of the system we are developing superimposes a minified edge contour of the real world over the patients' natural view in an optical see-through HMD (Figure 1). Patients continue to benefit from the high resolution of their preserved central vision while accessing additional peripheral visual information outside their visual field through the contour image. Although the edge contour is of low resolution, it may provide tunnel vision patients with important information for mobility and critical warning for obstacle avoidance. The system we are developing is based on MicroOptical Engineering Corp's integrated eyeglasses HMD [8].

Before conducting mobility evaluations in which patients walk while wearing the device, we carried out an indoor experiment to study the effect of the HMD on kinematic performance in visual search. Findings should allow us to improve system design and develop a procedure for evaluating adaptation to the device.

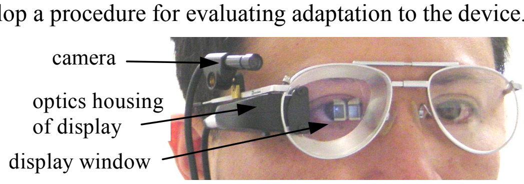


Figure 1. The augmented vision system based on MicroOptical see-through HMD. A wide field camera and an edge detector create contour images to be displayed in a minified manner.

2. Method
2.1 Visual search task
Visual search was performed by subjects sitting 32 inches in front of a rear projection screen spanning 90°(H) by 76°(V). Starting from a fixation point at the center of the screen, subjects were instructed on each trial to find and recognize targets presented outside their visual field (Figure 2). Targets (60) were presented in a random sequence at eccentricities of 20°, 27°, or 35° in arbitrary directions. The background was a so blurred picture with low contrast that the augmented vision system could barely pick up the edges of the background. Sharp pictures of the real world will be used in the future experiments. Each target was composed of a high contrast frame (triangle, square, or circle) inside of which was a random low contrast letter. The target size was either 3° or 5°. The target size and contrast were such that only the frame could be detected and recognized in the minified contour view, but not the letter. High-resolution natural-vision had to be used in order to recognize the letter, which required subjects to actually locate the targets within their central visual field (i.e. to view the target foveally). Subjects were allowed to freely move their eyes and head during the search. Head and eye movement recording began when a target was presented on the screen. As soon as subjects located the target foveally and recognized the letter, they pressed a mouse button, which terminated the recording and the letter vanished. Subjects were then required to state aloud the letter. Any target, which could not be found within 30 seconds, or for which the letter was not correctly identified, was discarded in the analysis procedure.

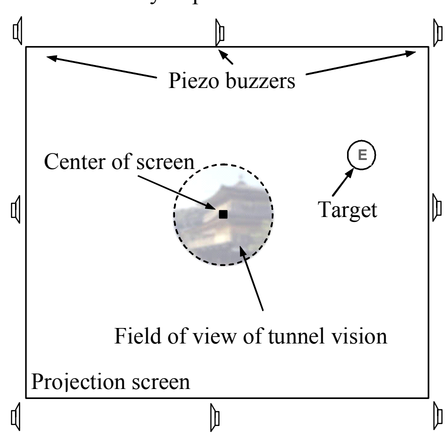


Figure 2. Illustration of the visual search task setup. The target, a low contrast letter (shown as letter E) in a high contrast frame (shown as a circle), was displayed outside patients' restricted visual fields (shown by the dashed circle). In acoustic cue experiments, target presentation was accompanied by a modulated sound from one of the 8 buzzers.

 ISSN/0004-0966X/04/3502-1578-$1.00+.00

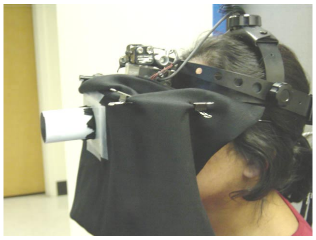


Figure 3. A normally sighted subject with a veil and a paper tube to simulate tunnel vision. In this case the camera was mounted outside the veil and the eye tracker inside the veil.

Four normally sighted subjects with simulated tunnel vision (15°) using a paper tube (Figure 3) and 3 tunnel vision patients (whose residual visual fields ranged from 7° to 10°) participated in the experiment. Visual search performance was assessed in three conditions: 1) without any aid, 2) with an acoustic cue and 3) with the minified contour cue. The acoustic cue was a modulated sound from one of eight piezoelectric buzzers placed around the projection screen (Figure 2), which indicated the approximate direction of a target, but not its eccentricity. The augmented view was implemented with 6× minification and provided a cue for both direction and eccentricity of targets. However, the displayed eccentricity was scaled down by the minification.

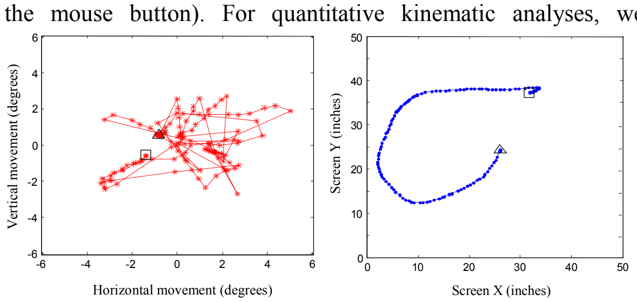
2.2 Recording of eye and head movement

A head-mounted eye tracker (ISCAN, Burlington, MA) and magnetic motion tracker (Ascension, Burlington, VT) were used to measure eye-in-head rotation and head position during visual search at a rate of 60 Hz. Search time and eye/head movement trajectories were analyzed.

Eye movements were measured and analyzed in terms of eye-in-head rotation in degrees. The eye-tracking device had a nominal accuracy of 0.3° over ±20° range and was calibrated using a 5-point scheme. Head movements were measured in terms of primary gaze point on the screen (as if the eye were fixed at the primary position). Head tracking was calibrated using a technique developed by Barabas et al. [9]. Examples of eye-in-head position and head position recordings are shown in Figure 4.

2.3 Pre-processing of movement data

Figure 5 shows an example of movement data (horizontal and vertical) during one visual search trial. Flat segments can be seen at the beginning and end of the movement for both eye and head. The flat segment at the beginning represents a reaction time delay. The flat segment at the end includes both time for fine visual discrimination of the low contrast letter and reaction time (to press the mouse button). For quantitative kinematic analyses, we



(a) (b)

Figure 4. Examples of eye-in-head position (a) and head position (b) of a tunnel vision subject during visual search without a visual aid. The triangle indicates the start point and the square the end point.

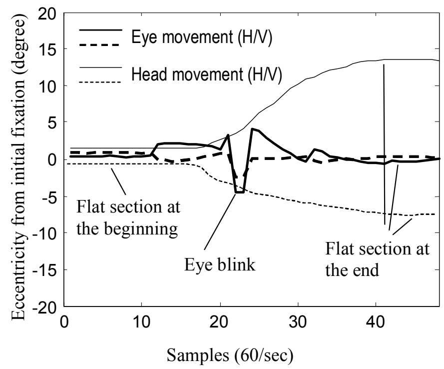


Figure 5. Horizontal and vertical traces of eye and head movements in one trial.

extracted the period between the initial eye/head movement and the point at which visual discrimination occurred, discarding the flat segments. The start of a movement was defined as the first point when the speed of either the eye or head exceeded a given threshold, and the end of a movement was defined as the last point when the speeds of both eye and head decreased below thresholds. Head movement recordings were generally continuous, and could be analyzed directly. However eye movement recordings usually suffer data loss and invalid data due to blinks, narrowing of the palpebral aperture, or range limitations of the eye tracking device, etc. Therefore, the eye movement data had to be preprocessed to remove invalid data before further analysis.

Invalid eye data due to blinks were detected first. During a blink there is an apparent fast vertical drop of eye position followed by a fast bouncing back with occasional zero data between due to loss of pupil tracking. A blink mask was designed based on these features. Three sizes of mask were used in the current analysis. By convolution with the blink masks, eye blink data could be located and replaced with estimations (linear interpolated values). Pupil size was used to detect other invalid data. When the pupil size significantly changed, it was likely that the recorded pupil position was not reliable. The eye position data were therefore set to be zero, and again the gap was filled by means of linear interpolation. Lost data (zero data) for any other reason were also estimated by means of interpolation.

Before kinematics analyses, the quality of the data recording for each trial was verified. If invalid data exceeded a certain amount (10% in current analysis), that trial was discarded. If significant invalid data occurred at the beginning or the end a trial, the trial was also discarded because the start point and end point of the movement could not be determined reliably. Finally, 16% (average across sessions) of targets were excluded from analysis due to too many invalid data, or failure to find target.

2.4 Kinematics analysis

Kinematic performance of visual search was evaluated based on search time and kinematic efficiency. We defined a measure of efficiency, the cumulative deviation as illustrated in Figure 6. The dashed curve represents an eye/head trajectory during visual search. S is the start point, E is the end point and AB is a step between two consecutive sample points in the middle of the path. At point A, the straight path to the end would be vector AE, but the actual step the subject takes is AB. Vector AC is the component of AB in the direction that makes the eye/head point directly towards the end point, and Vector CB is the component of

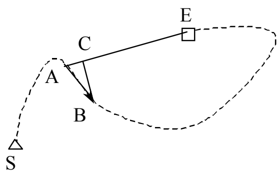


Figure 6. The cumulative deviation was calculated by summing the magnitude of CB at each sampling point along the search trajectory.

AB that deviates orthogonally from the straightforward direction. The cumulative deviation is calculated by summing the magnitude of all deviating components (like CB) at all the sampling points along the path. The more indirect the path, the larger the cumulative deviation. If a path goes straight to the end, the cumulative deviation is zero regardless of eccentricity.

3. Results

Figure 7 shows the averaged search time and cumulative deviation for the four normally sighted subjects with simulated tunnel vision in the three visual search conditions (without any aid, with acoustic cue, and with minified augmented contour cue). Both types of cues improved performance, resulting in decreased search times (especially at 20º eccentricity) and lower cumulative deviations of eye and head at all eccentricities.

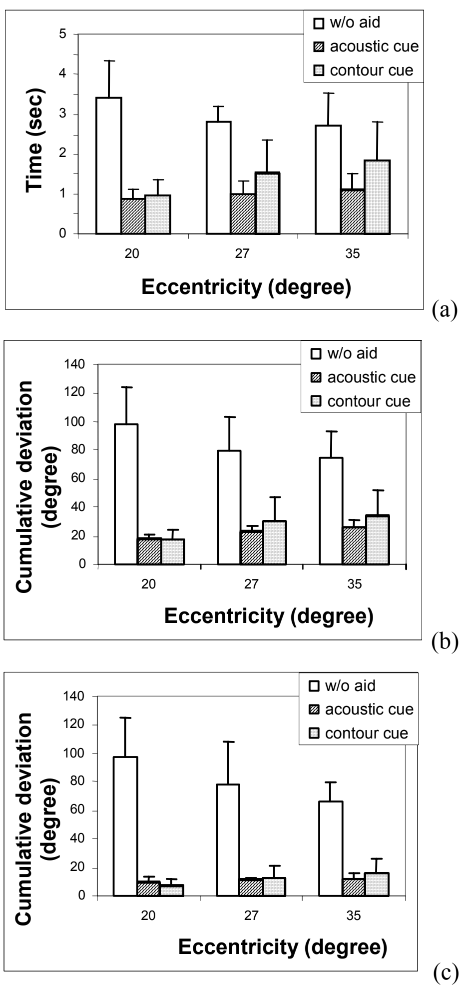


Figure 7. Averaged search time (a), cumulative deviations of eye (b) and head movement (c) of 4 normally sighted subjects with simulated tunnel vision. Error bars are 1 SD.

When tunnel vision patients initially performed the visual search task with the augmented vision system, they reported difficulties in establishing the correspondence between the real target location and the target contours seen on the display. Normally sighted subjects did not report such difficulties. We determined the reason was that the patients had difficulty in determining the center of the display, actually a reference point, as their visual fields were smaller than the field of view of the display. So they could not figure out the orientation of a real target with respect to its edge image. A physical center mark was therefore added at the center of the display. Patients commented that it became substantially easier to locate targets by bringing the center mark onto the displayed target contours (using head movements) and then switching their attention to the real world to foveate the target (camera calibration is needed for this technique to work).

Figure 8 shows the results of one patient (VF=10°), who demonstrated a big improvement in both search time and cumulative deviations with the minified contour cue. His performance was generally better with the contour cue than the

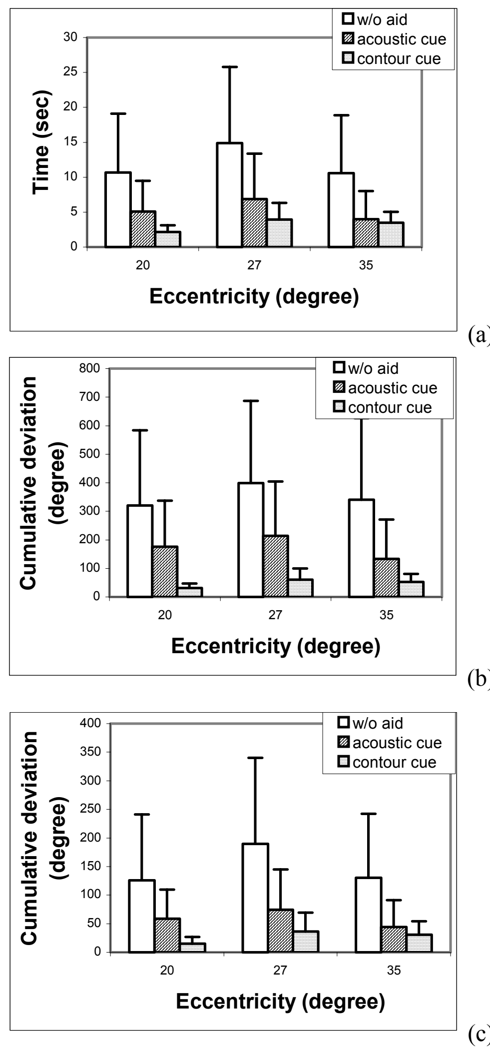
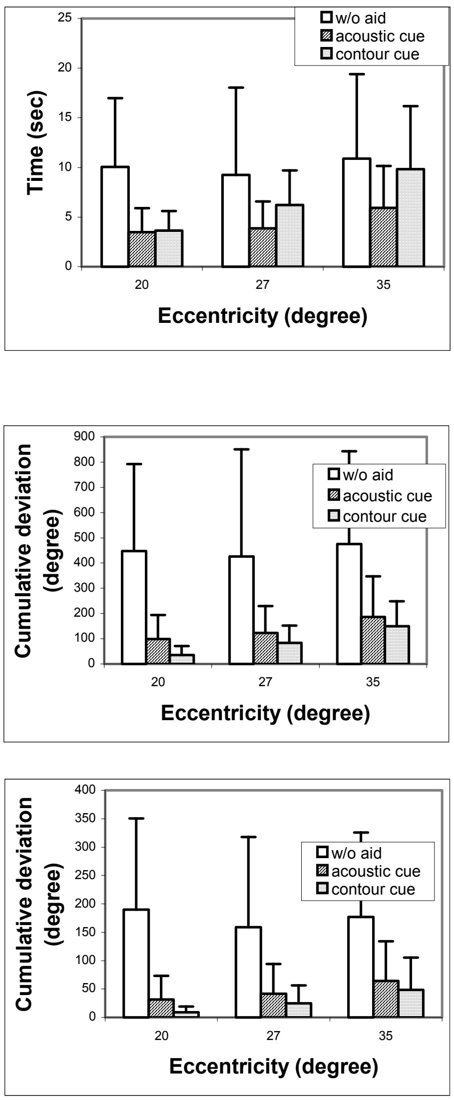


Figure 8. Search time (a) and cumulative deviations of eye (b) and head (c) movement of a tunnel vision patient whose kinematic performance improved with the minified contour cue at all tested eccentricities. Error bars are 1 SD.

acoustic cue, especially at 20° eccentricity. However, the other two patients (VF=7°, 10°) did not achieve as much of an improvement in search time as the first one did. Figure 9 shows the results of one of them. Like the first patient, they could find targets with much less deviation using the minified contour cue than without an aid (Figure 9b, c); however search times did not improve for targets at 35° eccentricity (Figure 9a). This may indicate that while wearing the augmented vision system they did not aimlessly search for targets at large eccentricity with their natural vision, but instead they spent some time on watching the contour display. An obvious difference between the first patient (Figure 8) and the other two (Figure 9) is that the first patient had about 10 hours more experience with the augmented vision system. We hypothesize that training would help patients to improve search times at larger eccentricities.



(a)

(b)

(c)

Figure 9. Results of search time (a) and cumulative deviations of eye (b) and head (c) movement of one of the two patients whose search times with the minified contour cue did not improve at 35° eccentricity. Error bars are 1 SD.

4. Impact

The visual search experiments reported here suggest that the augmented vision system may expand the functional visual field of tunnel vision patients, and that kinematic visual search performance may be improved with the device. It is well known that acoustic information is often used as a substitute for visual information by patients with impaired vision. Our results suggest that the augmented vision system could be as helpful as hearing in locating objects outside residual visual field. Patients felt that the system was promising as an aid to mobility, and expressed great interest in participating in real world mobility experiments using the device.

In the minified contour view, rendering of the direction, size and distance of real objects is unnatural. They cannot be spontaneously perceived correctly by patients without an adaptation process. Although kinematic performance does not necessarily translate to mobility, it may reflect a patient's adaptation to the minified contour view. The evaluation of kinematic performance described here will be used in a future mobility study as a measure of the efficiency with which the system is used.

5. Acknowledgements:

Supported in part by NIH grant # EY12890. MicroOptical developed the HMD and DigiVision the edge detector.

6. References

[1] Robinson, B., et al., "The prevalence of selected ocular diseases and conditions." Optometry and Vision Science, 74(2), 79-91 (1997).

[2] Pagon, R.A., "Retinitis pigmentosa." Survey of Ophthalmology, 33, 137-177 (1988).

[3] Szlyk, J.P., et al., "Use of bioptic amorphic lenses to expand the visual field in patients with peripheral loss." Optometry and Vision Science, 75(7), 518-524 (1998).

[4] Loshin, D.S. and R.D. Juday, "The programmable remapper: Clinical applications for patients with field defects." Optometry and Vision Science, 66389-395 (1989).

[5] Peli, E., "Vision multiplexing - an engineering approach to vision rehabilitation device development." Optometry and Vision Science, 78304-315 (2001).

[6] Vargas-Martin, F. & Peli, E. (2002). Augmented-View for Restricted Visual Field: Multiple Device Implementations. Optometry and Vision Science, 79, 715-723.

[7] Peli E. Wide-band image enhancement. US patent 6,611,618. 2003

[8] Spitzer, M.B., et al., "Optical approaches to incorporation of displays within glasses." Journal of the SID, 6211-212 (1998).

[9] Barabas J, et al, "Wide field 3D gaze tracking System." Ophthalmol. Vis. Sci. (ARVO Suppl.), 44, s1965.