Collision judgment when viewing minified images through a HMD visual field expander

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ABSTRACT

Purpose: Patients with tunnel vision have great difficulties in mobility. We have developed an augmented vision head mounted device, which can provide patients 5× expanded field by superimposing minified edge images of a wider field captured by a miniature video camera over the natural view seen through the display. In the minified display, objects appear closer to the heading direction than they really are. This might cause users to overestimate collision risks, and therefore to perform unnecessary obstacle-avoidance maneuvers. A study was conducted in a virtual environment to test the impact of minified view on collision judgment.

Methods: Simulated scenes were presented to subjects as if they were walking in a shopping mall corridor. Subjects reported whether they would make any contact with stationary obstacles that appeared at variable distances from their walking path. Perceived safe passing distance (PSPD) was calculated by finding the transition point from reports of yes to no. Decision uncertainty was quantified by the sharpness of the transition. Collision envelope (CE) size was calculated by summing up PSPD for left and right sides. Ten normally sighted subjects were tested (1) when not using the device and with one eye patched, and (2) when the see-through view of device was blocked and only minified images were visible.

Results: The use of the 5× minification device caused only an 18% increase of CE (13cm, $p=0.048$). Significant impact of the device on judgment uncertainty was not found ($p=0.089$).

Conclusion: Minification had only a small impact on collision judgment. This supports the use of such a minifying device as an effective field expander for patients with tunnel vision.

Keywords: tunnel vision, visual field expander, head mounted display, collision judgment, virtual reality.

1. INTRODUCTION

Various eye diseases, such as glaucoma, retinitis pigmentosa, and chroideremia, often cause severe loss of peripheral visual field (tunnel vision). Patients with tunnel vision have great difficulties in mobility. They frequently fail to detect obstacles outside their small visual fields and bump into them. Many types of field expanders based on the principle of minification have been proposed, such as reversed telescope [1, 2], amorphic lens [3, 4], and video remapper [5]. However, partial rejection and failure of these devices has been reported [2, 3], due to resolution loss resulting from minification.

To deal with the problems of resolution loss, Peli et al proposed an augmented-vision Head Mounted Display (HMD) system based on a principle of spatial multiplexing [6, 7], i.e. superimposing minified edge images of the ambient scene over wearers' see-through natural vision. Because edge pixels in the display only occupy a very small portion of field of view, the edge images would not occlude wearers' see-through view. Thus, the resolution of see-through view is as good as that without using the system and the device provides users information about peripheral field. Although the information is coarse, it may greatly help patients detect obstacles that they would otherwise miss [8].

Figure 1 illustrates the augmented view provided by the HMD device. The upper image shows a full view of a street scene captured by the camera of the system. The white rectangle inset represents the size of the field of the display. The lower image shows a minified edge image of the scene (enlarged here for clarity) superimposed on the natural see-through view (shown here as the woman).

Figure 1. Illustration of the augmented view provided by the HMD system. The upper image shows a full view of a street scene captured by the camera of the system. The white rectangle inset represents the size of the field of the display. The lower image shows a minified edge of the scene (enlarged here for clarity) superimposed on the natural see-through view.

Figure 2 shows such a HMD device developed for us by MicroOptical Cooperation (Westwood, Massachusetts). Video images of a wide ambient scene are captured by a miniature camera mounted on one temple. The video signals are processed by a portable controller to derive edge images that are presented in the display (FOV=16°) on another side.

Mobility difficulties of patients with tunnel vision are usually due to their impaired abilities to detect potential obstacles. Once they detect the obstacles, they are able to predict potential collisions like normally sighted people, so they can make timely maneuvers to avoid collision. When a patient is wearing the HMD device showing minified images, the presented visual direction is much closer to the heading direction than it really is. A concern about using the device might be that the change in presented visual direction could greatly affect users' collision judgment. If patients feel that they are going to collide with everything they see in the display, it would cause too many unnecessary collision-avoidance maneuvers, and may even discourage them from walking with the device. The minification factor of the device tested in the experiment was 5×.

Another concern is that the parallax caused by the 11cm off-axis mounting of the camera with respect to the display may affect collision judgments. The current camera mounting is a result of considerations of cosmetics and weight balance. If an unacceptable impact of such a parallax on collision judgments were found, a new structure design may be needed.

Before the device is evaluated in patients' daily lives, we conducted a collision judgment study to address these concerns. We did the experiment in a virtual environment, in which subjects were safe, and we had complete control of conditions.

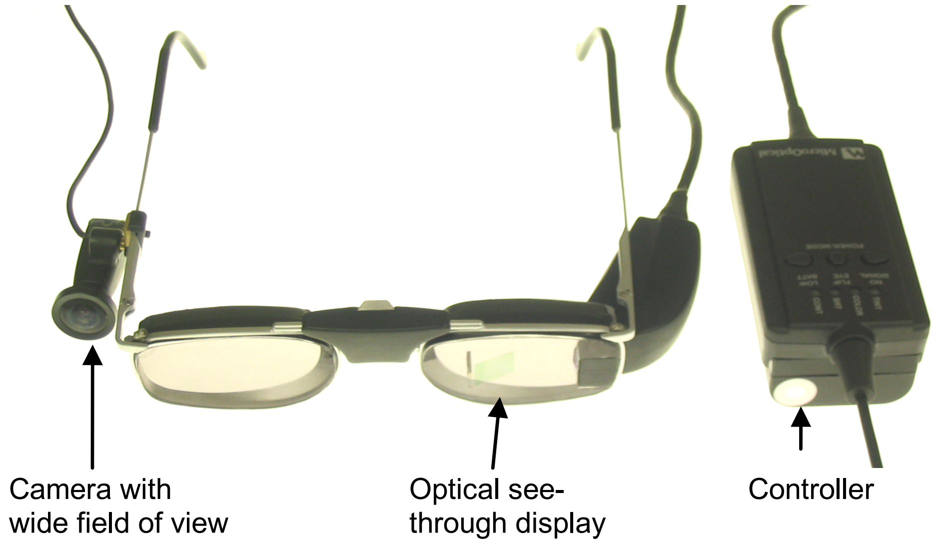

Figure 2. An augmented-vision HMD device developed for us by MicroOptical for patients with tunnel vision.

2. METHODS

2.1 Virtual obstacle course

Ten normally sighted subjects (visual acuities were 20/20 or better) were tested. They stood 77cm from a 172cm wide rear projection screen that displayed a photo-realistic representation of a shopping mall corridor. At that distance, the screen subtended 96º wide. The virtual reality was created using the World Toolkit API [9, 10]. The corridor floor was textured with tiling, and the sidewalls were textured with storefront pictures taken from an actual shopping mall in the Boston area.

The movie scene was updated as if a subject was moving at 1.5m/s down a preset zigzag path. Each trial consisted of moving down one straight segment of the path (Figure 3). During each trial, a stationary human-sized obstacle (0.7m wide×0.7m deep×2m tall) appeared at 5m and lasted for one second. The obstacles were placed at different distances from the trajectory of the path segment (path offset). For each subject, 44 tested path offsets were evenly distributed from -20cm to 120cm on each side of left and right (total 88 trials). Subjects reported verbally whether they would have any contact with the obstacle if they continued on the same trajectory. The subjects were instructed to make a choice even if uncertain about their decisions. At the beginning of the next trial, the virtual viewpoint was rotated to face the next path segment before movement resumed.

Each subject performed the task with and without the HMD device. A subject always used the same single eye in both conditions. When wearing the HMD, see-through views of both eyes were blocked and subjects could only see the images in the display with one eye (Figure 4). In the without-device condition, the eye that would not be fit with display in the with-device condition was patched. 5 subjects were assigned a right eye display and the others the left eye display. The condition order was randomized.

If a subject used left-eye display, we used "display side" to refer to those obstacles appeared at a path offset to the left of the subject's heading direction, and vice versa. "Camera side" refers to the opposite side of "display side". For the purpose of comparison, we treated the un-patched eye side as the display side in the without-device condition, as the un-patched eye was fit with display when HMD was used.

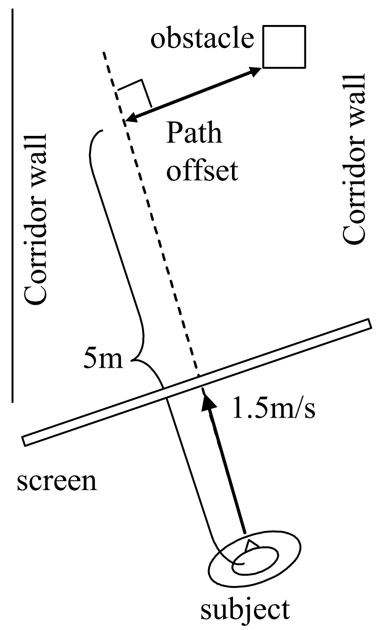

Figure 3. Illustration of the experimental layout (not to scale). Subjects "walked" zig-zag paths in a virtual shopping mall corridor. Obstacles appeared in front at different path offsets from the walking trajectory. Subjects reported whether there would be physical contact with the obstacles if they continued walking in the same direction.

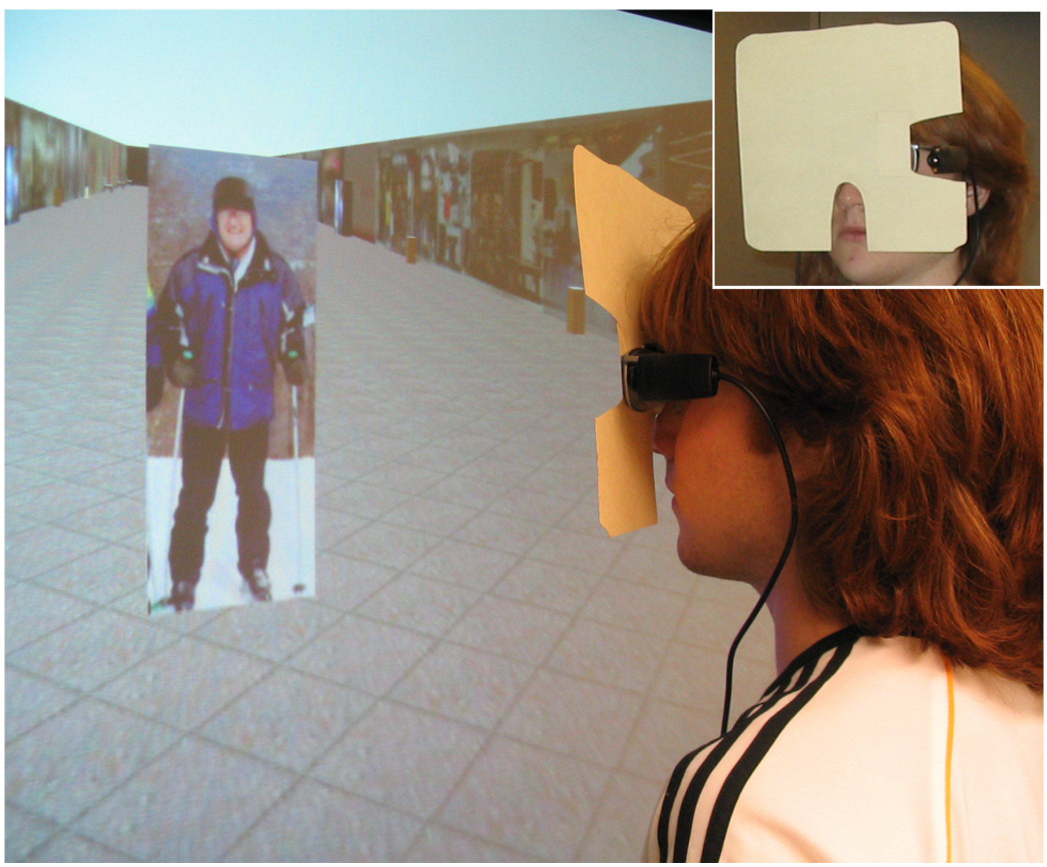

Figure 4. A subject wearing HMD in collision judgment study. Inset picture shows that the see-through view of both eyes was blocked when using the HMD.

2.2 Data analysis

For each subject, the yes/no responses were given a value (yes=1, no=0). Response values at different path offsets were fit to a Gaussian cumulative density function (a common psychometric function). The mean of the Gaussian represents the perceived safe passing distance (PSPD), which was calculated for left and right sides separately, and the standard deviation of the Gaussian represents the decision certainty [10]. Collision envelope (CE) size was calculated by summing up PSPD on both sides, which reflects the size of a space within which the possibility that obstacles are judged to cause collisions is more than 50%.

Paired t-test was primarily used to test the effects of minified display and the off-axis mounting of camera. Effects with $p < 0.05$ were considered to be statistically significant.

3. RESULTS

Figure 5 shows the PSPD for both display side and camera side. When the device was used, PSPDs on camera side were 20cm larger than that on display side (p=0.005). This was probably associated with the parallax between the camera and the display (11cm). Interestingly, an 8cm PSPD asymmetry of the same nature and direction was also found in the without-device condition, and it approached statistical significance (p=0.056). This finding was consistent with results from our other collision judgment studies [10]. It seemed that the asymmetry in the without-device condition was related to monocular viewing, but the mechanism causing the asymmetry is not clear.

For camera side, the HMD device significantly increased PSPD by 13cm (p=0.004), but the effect was not found for display side (p=0.890). As shown in Figure 5, the PSPDs for obstacles on the display side were almost the same in both conditions.

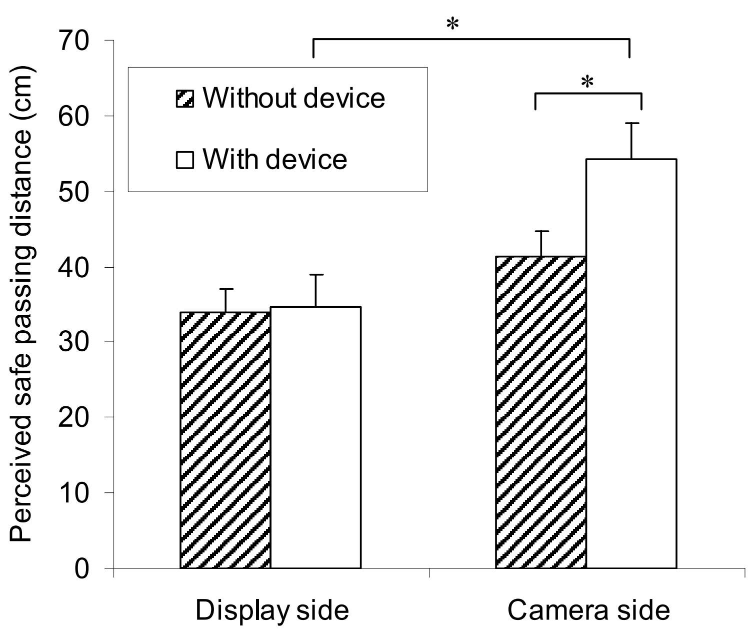

Figure 5. The HMD device increased PSPD only on the camera side. A PSPD asymmetry appeared in both with- and without-device conditions. Error bars are standard error of mean.

Figure 6 shows the CE size with and without the HMD device. As can be seen, the HMD device increased CE size by 13cm (p=0.048), but the relative increase was only about 18%.

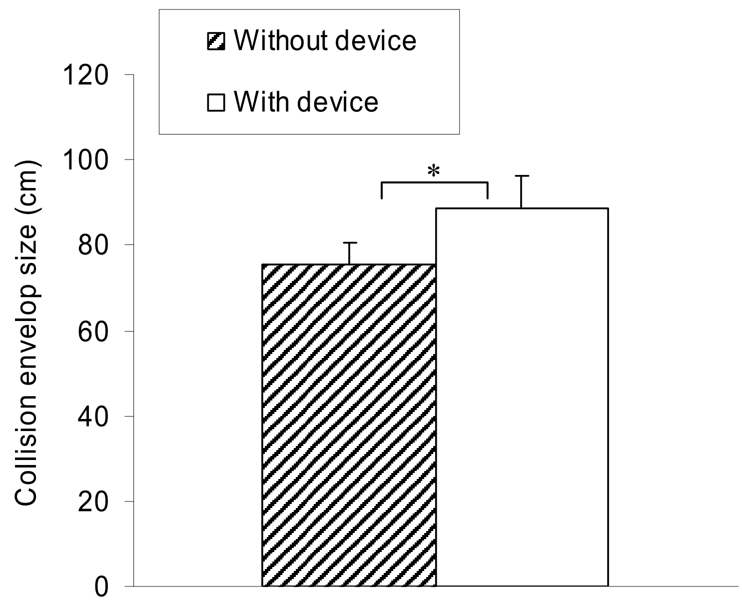

Figure 6. Collision envelope size with and without the HMD device. Error bars are standard error of mean.

Figure 7 shows decision uncertainty. The larger the value, the more uncertain is the PSPD judgment. There seemed to be a trend that the HMD device increased judgment uncertainty, but the effect of the device was not found to be statistically significant (Repeated measures ANOVA, $F_{1,9}=3.6$; $p=0.089$).

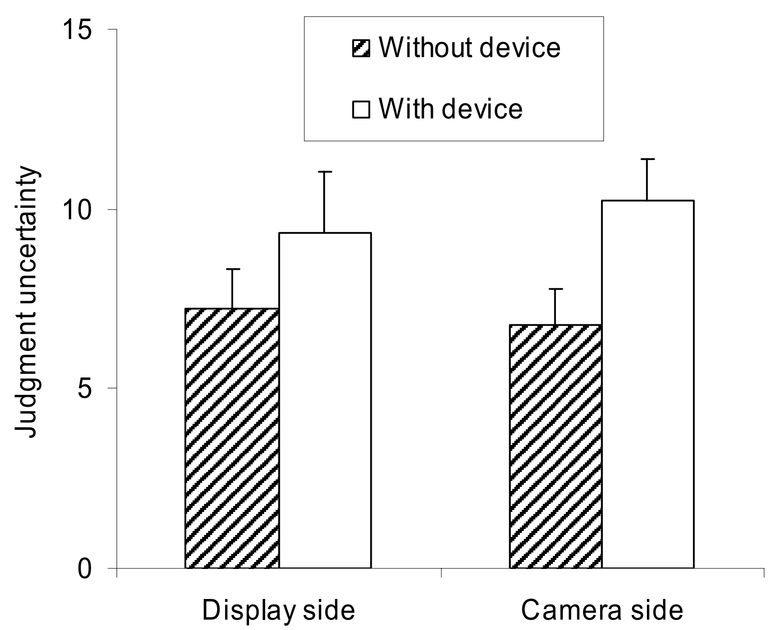

Figure 7. Decision uncertainty with and without the HMD device. The larger the value, the more uncertain is the PSPD judgment. The device seemed to increase uncertainty of judgment, but the effect was not statistically significant. Error bars are standard error of mean.

4. DISCUSSIONS

Despite the very small (1:5 scale) edge images seen in the HMD device, subjects' judgments of potential collision did not change much compared to natural viewing condition.

Firstly, this might suggest that the coarse form of edge images can provide users sufficient information for collision judgment. Detailed information about obstacles is not necessary for making judgment. Once obstacles are detected in the edge image display, patients will be able to tell that they may collide with obstacles outside their VF but within their collision envelope. The concept of augmented vision was shown promising in this study to be helpful from this perspective.

Secondly, the results might also indicate that image scale had very minor effect on collision judgment. Although the device did increase PSPD on the camera side (13cm) and CE size (13cm or 18%), the change was not comparable to an effect that one may suspect from a 5× minification. In other words, 5× minification of image presentation did not result in 5× magnification of CE. Regan's direction discrimination model [11] can explain why subjects' collision judgments did not change much. According to Regan, a perceived obstacle offset is determined by the ratio between the translational speed of the obstacle and it expansion speed. In minified images presented by the HMD, because the translational velocity and expansion speed of obstacles decrease by the same proportion, the ratio between them does not change. Therefore, subjects wearing the device could still discriminate obstacles offsets correctly, as they did without the device. The concern that the device may cause too many unnecessary collision-avoidance maneuvers can be eased.

Although there was a significant increase of PSPD and CE comparing to without-device condition, it means patients wearing the device would make a bit safer judgments. The negative effect of it may be just a small increase of unnecessary obstacle-avoidance maneuver, but there will be no risk posed to patients. As the off-axis mounting of the camera did not cause any reduction of PSPD on any side, which would increase collision risk on the side, we do not think it is necessary to minimize the parallax by mounting the camera on the display side.

Theoretically, minified image presentation should result in deteriorated precession of motion discrimination, which then would presumably cause increased decision uncertainty. However, we have not found a statistically significant increase in decision uncertainty ($p=0.089$) due to the device use, although there seemed to be such a trend. More subjects are needed to identify the effect.

5. CONCLUSIONS

Minified presentation of edge images and off-axis mounting of camera did not change collision judgment much. These results suggest that the device can effectively and safely serve as field expander for patients with tunnel vision.

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