George C. Woo Editor

Low Vision

Principles and Applications

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The Visual Requirements of Mobility

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1. Introduction

Most of us use our eyes to great advantage in getting about the world. Visual guidance of walking is a very useful skill. While the totally blind can and do learn to travel without sight, they do so using different cues, and travel more slowly and less safely than the sighted. However, relatively few people - only half a million in the U.S. - are totally blind, whereas several million have low vision. Low vision is handicapped vision, i.e. visual function is sufficiently restricted to seriously impair the peron's ability to do important tasks [l]. The two most important of those tasks, judging by the complaints of people with low vision, are reading and mobility. The visual requirements of reading have been described elsewhere [2-4]. Here we consider the visual requirements of mobility.

The low vision population is mostly and increasingly elderly. It is very common for those with low vision to cease travelling independently because they feel they can no longer do so safely. This makes them dependent on others for shopping and for visiting anyone outside the home. One motivation of our research is the hope that a better understanding of the visual requirements of mobility might lead to help for these people.

Our method is empirical. We artificially restrict the vision of normally sighted subjects, and measure their performance at specific mobility tasks. There are several advantages in using artificial restriction of normal vision, rather than real low vision. The artificial restrictions are well understood, stable, and repeatable from observer to observer. They can be varied over the full range of 0 to 100% of normal. They allow parametric investigation of the effect of one variable without confounding variation of the other parameters. We can retest the same subject at many degrees of restriction so the subjects act as their own controls. This allows us to discount the effects of subject variables such as motivation and athletic skill.

We are also testing low vision subjects on the same mobility tasks. We do this because we are interested in the mobility of people with low vision. It is possible that a long-term visual restriction is either less disabling (as a result of long-term learning) or more disabling (as a result of long-term deprivation from important environmental cues, or, more likely, as a result of loss of confidence and motivation).

MARRON and BAILEY [5] measured the mobility and vision of nineteen low vision subjects. They found that area of visual field and peak contrast sensitivity were the best predictors of mobility performance and that acuity was not a good predictor.

We controlled and measured three parameters of vision: field, resolution (i.e. acuity), and contrast. These three parameters provide a first-order description of any optical imaging system, such as the human eye.

Recently there has been considerable interest in measuring contrast sensitivity function. Figure 1 illustrates the reader's contrast sensitivity function. Any patch of the figure is a sinusoidal grating. As you direct your gaze gradually upward the contrast falls until the grating eventually disappears. As you go from left to right the grating gets finer until the grating is too fine to resolve. The outline of visibility, an inverted U, is the reader's contrast sensitivity function. This function is characterized by its vertical position on the contrast axis and by its horizontal position along the spatial frequency or resolution axis. In our experiments we restricted contrast, corresponding to the vertical axis of Fig. 1, and resolution, corresponding to the horizontal axis of Fig. 1.

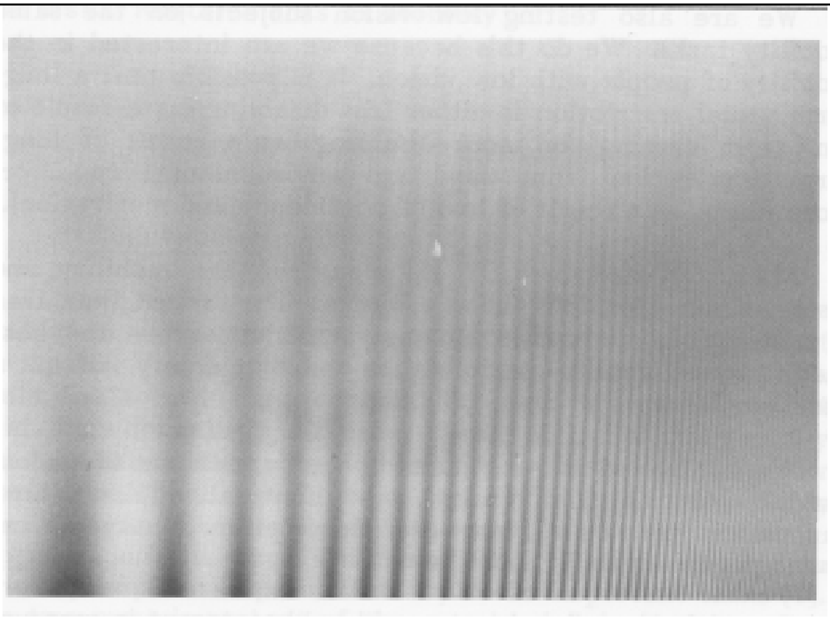

Figure 1. A sinusoidal grating. The spatial frequency increases from left to right. The contrast decreases from bottom to top. The outline of visibility of the grating is the viewer's contrast sensitivity function. The diagram is based on a similar figure by Campbell and Robson.

2. Methods

The subject's other eye was occluded so all viewing was monocular. Thus all subjects *were* denied the benefit of binocular parallax, a cue to depth and three dimensional structure. This was done for two reasons. Firstly, it is technically difficult to maintain alignment of devices worn on two eyes as the subject walks about. Secondly, clinically, diseases producing low vision rarely affect both eyes equally, and a person is classified as having low vision on the basis of the vision in the better eye, so it is not clear how much benefit the worse eye provides. For these reasons the possible role of binocular parallax in mobility is beyond the scope of this study. It is worth pointing out, however, that the subjects move through the test environments and thus do benefit from motion parallax, which offers very similar information to binocular parallax, yielding a strong impression of three dimensional depth, as every movie goer knows.

We use three kinds of artificial visual restriction: field, contrast, and resolution. All the restrictions are designed to fit in standard trial frames.

We restrict field by a truncated paper cone, base in (Fig. 2). This produces a peripheral field loss. Note that the field restriction is fixed to the head, unlike a scotoma, which is fixed to the eye. To scan the world our subjects must move their heads, whereas people with scotomas scan the world by moving their eyes. We used six field diameters from 1 degree up to 60 degrees.

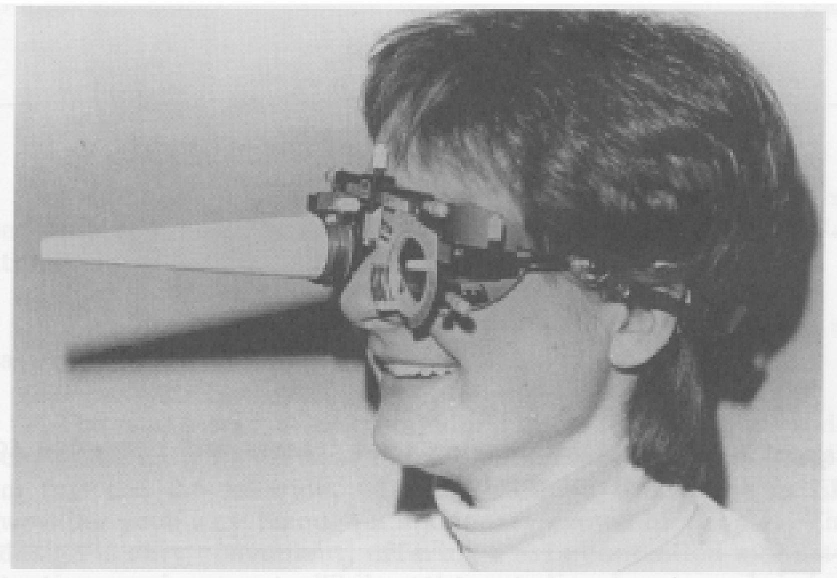

Figure 2. Subject wearing trial frames and paper cone to restrict visual field.

We restrict contrast by ***contrast reduction disks*** (Fig. 3). They consist of 0.5 μm diamonds suspended in a clear plastic disk the size of a trial lens. Looking through a contrast reduction disk is like looking through a fog. The contrast reduction factor was controlled by making disks with various concentrations of diamonds. Contrast sensitivity measurements have shown that these disks reduce the contrast of the retinal image by the same factor at all spatial frequencies from 0.5 to 30 c/deg. Many diseases can cause loss of contrast sensitivity. In particular, intraocular scatter (e.g. due to cataract) will reduce the contrast of the retinal image. We use six contrast factors from 0.3% up to 100% of normal contrast.

Figure 3. Subject wearing trial frames and blurscope to restrict resolution.

We restrict resolution (i.e. acuity) by a blurscope (Fig. 4). This is a modified unit-power telescope incorporating a diffusion screen. (A complete description will be published elsewhere.) We tested mobility at eight resolutions corresponding to acuities of 6/2400 (20/8000) to 6/6 (20/20).

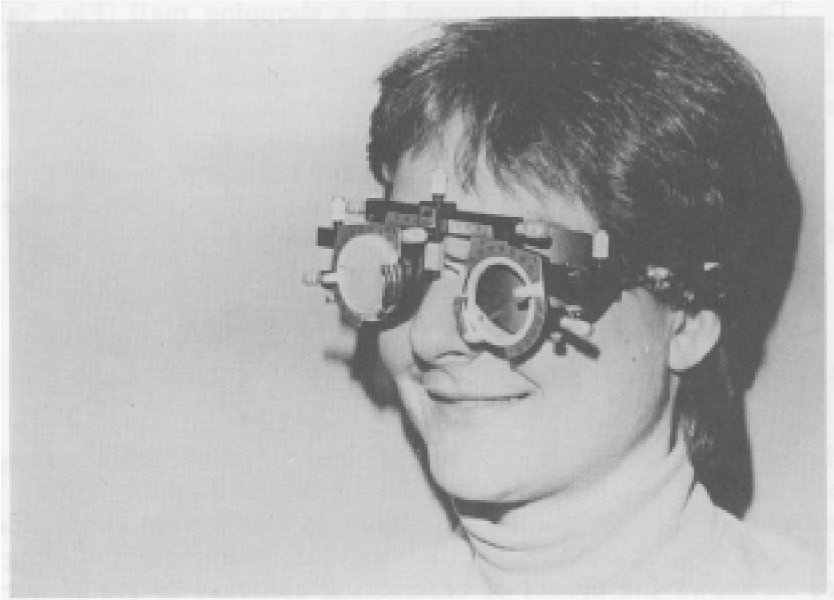

Figure 4. Subject wearing trial frames and contrast reduction disk to restrict contrast.

In addition to the above restrictions, each normally sighted subject's performance was also measured while blindfolded to establish the level of nonvisual performance.

We measured mobility performance in two environments: a laboratory maze and a shopping mall.

The maze was a long corridor (15 m long by 2 m wide) cluttered with 19 vertical foam rubber columns, each about 2 m tall and 0.5 m wide. Walking through this maze is like working your way through a stationary crowd of people. This design is very convenient, offering a safe controlled mobility-testing environment. While other studies have used indoor mazes or obstacle courses to test mobility [5] they have all been of a fixed design, and it is difficult to make the maze long enough to get a significant number of errors in a single passage by the subject. A particular advantage of the foam rubber columns is that they are easily moved. We randomize the positions of all the columns before every test. This allows us to retest each subject many times, each time in a brand new maze.

The other test environment is a shopping mall (Fig. 5a). The subjects begin at one end of the L-shaped mall and are asked to walk to the other end, a total distance of about 250 m.

For each environment we measure time and bumps. *Time* is how long it takes them to do the task; *bumps* is the number of contacts with obstacles plus any full stops.

3. Results

Figure 5a shows the shopping mall which we used for testing mobility. Figure 5b shows the effect of restricting field to 7 degrees. Figure 5c shows the effect of restricting resolution to 1.6 c/deg, equivalent to an acuity of 6/150 (20/500). Figure 5d shows the effect of restricting contrast to 1% of normal contrast.

Figure 5a: ‘The shopping mall used for testing mobility.

Figure 5b: Field restricted to 7 degrees.

Performance was measured for the entire range of each type of restriction. Blindfolded travel in the maze was much slower (average of 80 s vs. 20 s travel time) and less accurate (17 bumps vs 0.5 bumps). In both environments the level of performance was nearly unimpaired for degrees of vision from normal down to very restricted vision. Beyond this point, performance worsened quickly to the level of blindfolded travel. We summarize our results by this *critical point*, the severest restriction at which performance is only slightly impaired. Performance in the maze is only slightly impaired by the following restrictions (critical points): 10 degree field, resolution of 6/600 (20/2000), and 4% of normal contrast. The corresponding critical points in the mall are 4 degree field, resolution of 6/600 (20/2000) and 2% of normal contrast.

We wondered whether our subjects were making use of auditory cues. It is well known that blind travellers can learn to use echo location to sense nearby objects. Several of our subjects volunteered that in the shopping mall they could orient themselves by the sounds of rustling bags of the people

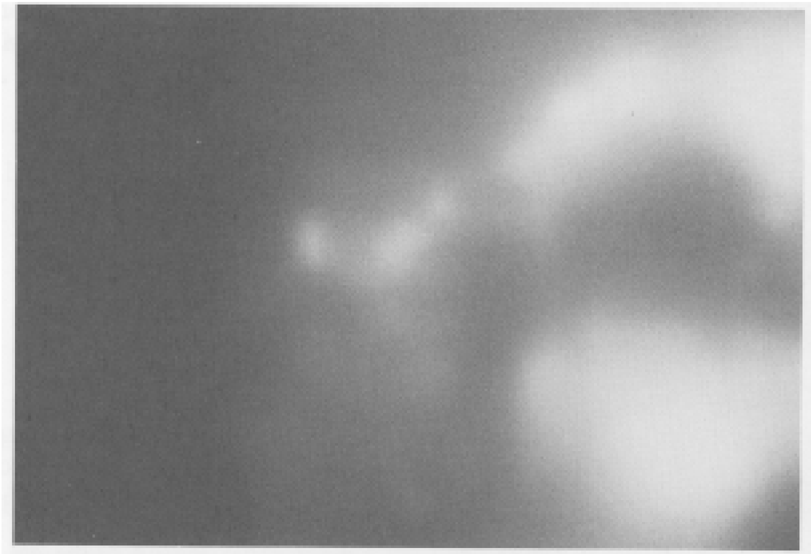

Figure 5c: Resolution restricted to 1.6 c/deg, equivalent to an acuity of 6/150 (20/500).

walking along the length of the mall. They said these auditory cues were very helpful. To determine how much benefit the subjects were obtaining from auditory cues we made a pair of headphones which produce loud uncorrelated white noise in the two ears, making the wearer effectively deaf. We retested performance at each of the critical points in the maze and mall with and without the headphones and found no significant difference in time or bumps.

In order to help relate our results to actual low vision travel we did several supplementary experiments. Even if one can walk up and down a mall there is little point in doing so unless one can find specific stores in the mall and find specific products in the store. We have measured the visual requirements (critical points) for finding stores at the mall. They are similar to those for just walking up and down the mall. The visual requirements for shopping in a supermarket are higher, but still well below the criteria for legal blindness.

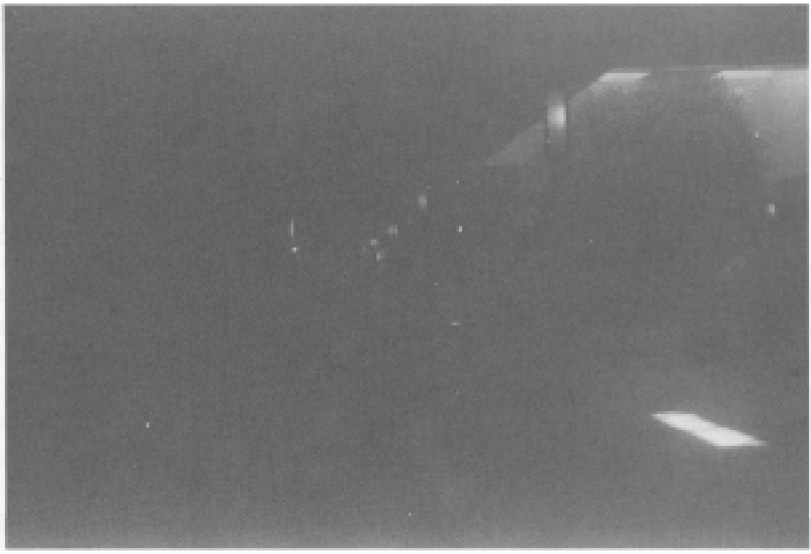

Figure 5d: Contrast to 1% of normal contrast.

4. Conclusions

Our results show that very little vision is required to walk through indoor environments with reasonable accuracy and speed.

Since the critical points are so low, far below the criteria of legal blindness, a remaining puzzle is why people who presumably have enough vision to travel with reasonable accuracy and speed in our tests still complain of mobility problems. These people may be reluctant to travel partly because they consider the risk of injury to be excessive. Our experiments do not allow us to estimate the risk of injury, as no potentially dangerous events occurred. This is partly because we intentionally excluded the greatest dangers: drop offs (i.e. stairs and curbs) and moving vehicles. We speculate that many people with low vision could travel, but choose not to simply because they feel it is too dangerous. If this is true, it would be very important to determine whether this risk assessment is accurate. People are notoriously bad at estimating the probability of rare events. For example, many people avoid flying, yet fail to wear their seatbelt while driving, which is much more dangerous. There may be an important role here for low vision mobility instruction in teaching how to assess the safety of travel by the client in various environments.

Although it is difficult to assess the probability of injury faced by the low vision traveller, the danger is certainly real. Walking off an unseen drop off or being hit by an unseen car can be serious or fatal, especially for an elderly person, as are most people with low vision. There are three approaches to minimizing this danger: training, aids and environmental modification. Our research suggests that training may be important in helping the person assess risk. Of existing aids, the most important are the telescope (used only while standing still because it is disorienting to walk with) and the long cane (detects drop offs).

Are there any simple changes to the environment that would make it safer for the low vision traveller? A striking and unexpected result of the simulations is that self luminous objects, such as neon signs and street lights, are exceedingly resistant to loss of contrast and loss of resolution (Figs. 5c and 5d). It seems likely that the danger of drop offs could be greatly reduced or eliminated by marking the upper edge with light bulbs! It is hard to imagine installing lights outdoors along every curb of every city block, but in indoor public spaces, such as shopping malls, it may be worthwhile to install a strip of lights along the top edge (of just the top step) of every stairway. Once the traveller is aware that a drop off is nearby he or she can slow down and negotiate safely.

5. Acknowledgements

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