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# Motion parallax: effects of blur, contrast, and field size in normal and low vision

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**Abstract.** Can people with different forms of low vision use motion parallax to improve depth judgments? We used a staircase method to compare depth thresholds using motion parallax and static viewing. We tested eighteen normal-vision subjects with a range of simulated deficits in acuity, contrast sensitivity, and simulated peripheral-field loss, and ten low-vision subjects with a wide range of acuity, contrast sensitivity, and field loss. Subjects viewed three vertical cylinders monocularly and indicated which one was at a different depth from the other two. For motion-parallax trials, observers moved their heads (in a viewing assembly on rollers) from side to side over a range of 6–12 cm. For static trials, the viewing assembly was fixed in place. Normal-vision subjects' depth thresholds with motion parallax were significantly smaller than those with static viewing by an average factor of 1.95 ($p < 0.05$) across all levels of acuity and contrast. For low-vision observers, the depth thresholds exhibited large individual differences; however, the motion-parallax thresholds were smaller than the static thresholds by an average factor of 2.05 ($p < 0.01$). These findings indicate that motion parallax can provide useful depth information for people with low vision.

## 1 Introduction

We have examined the potential role of motion parallax as a cue to depth perception in low vision. Low vision refers to any chronic visual condition, not correctable by spectacles or contact lenses, that impairs everyday function. Recent estimates (Tielsch et al 1990) indicate that there are more than three million people in the United States with low vision. The visual deficits in low vision can usually be classified in terms of acuity loss, contrast-sensitivity loss, and visual-field loss. Many studies have examined how these deficits impair everyday tasks such as reading, mobility, and driving. However, few studies have explicitly investigated depth perception with low vision.

With normal vision there are many cues that can contribute to depth perception. Of these, stereopsis may provide the most vivid and salient sense of three-dimensional structure. Stereopsis depends on good vision in both eyes. Studies with normal-vision observers show that interocular differences in contrast impair the perception of stereo depth (eg Legge and Gu 1989) and binocular visual direction (Mansfield and Legge 1996). Also, stereo-depth thresholds deteriorate with increased blur (eg Westheimer and McKee 1980) and with reduced contrast (eg Legge and Gu 1989). Increased blur and reduced contrast are common in low-vision perception and the deficit is often more severe in one eye than the other. For these reasons, many people with low vision make little or no use of stereopsis.

There are many pictorial cues to depth which can be perceived with monocular vision (eg occlusion, texture gradients, shape from shading). It is likely that the effectiveness of many pictorial depth cues will be reduced by specific types of visual loss. For example, the subtle shading differences in shape from shading may be below contrast threshold for observers with a contrast-sensitivity deficit, and the perception of depth from texture gradients may require the combination of relatively good acuity and a large visual field.

Motion parallax is a monocular depth cue that can produce vivid impressions of depth and spatial layout similar to those obtained with stereopsis (von Helmholtz 1925;

Rogers 1993). Motion parallax occurs when an observer is moving relative to the environment. As the observer moves, the retinal images corresponding to items at different depths move across the retina with different velocities. The velocity of the retinal image is inversely related to the distance of the item. Measurements from observers with normal vision have shown that motion parallax can support the discrimination of depth differences equivalent to a stereoscopic disparity of 3.73 min arc for two point sources of light (Tschermak-Seysenegg 1939), and 0.3 – 0.6 min arc for detecting depth corrugations in random-dot stimuli (Rogers and Graham 1982; Steinbach et al 1991).

Could motion parallax provide a depth cue for people with low vision? Research has not specifically examined the utility of motion parallax under reduced or degraded viewing conditions or with low-vision subjects. Motion parallax is, however, often cited as a likely cue in studies of mobility with reduced viewing conditions (Eyeson-Annan and Brown 1992; Pelli 1987). Pelli found that, for normally sighted subjects with simulated visual deficits, the accuracy and time taken to walk through a maze were only impaired with very severe visual degradation (ie acuity poorer than 2.0 logMAR, contrast reduced by 96%, or visual fields near 10 deg). He suggested that the subjects in his study could have been using motion parallax. This is plausible in light of research showing that motion perception is only slightly affected by large changes in contrast (McKee et al 1986) and blur (Straube et al 1990).

In this study we compared depth-discrimination thresholds for motion parallax with those obtained with static viewing. We addressed the following questions. (1) How does motion parallax improve upon static-monocular depth discrimination for normal observers with simulated reduction in resolution, contrast sensitivity, and field size, and for low-vision observers? (2) How does performance vary with the level of degradation; does motion parallax provide useful depth information in extremely degraded visual conditions? (3) What are the implications of these findings for people with low vision?

## 2 Experiment 1

In this experiment we measured depth thresholds from normal-vision observers. We systematically limited spatial resolution, contrast, and field size. These three factors represent a convenient way of describing image quality in the human eye (or any other optical imaging system), and can be used to broadly classify the visual deficits found with low vision (eg Legge 1991). The visual consequences of many eye diseases are simulated as these three factors are reduced. For instance, low resolution (blur) is found with many eye problems including cataract, keratoconus, and corneal scarring; reduced contrast simulates intraocular scatter from cataract; and restricted field represents peripheral scotoma which may be found with glaucoma or retinitis pigmentosa. *Central*-field loss is a very common form of low vision, with age-related macular degeneration being the leading cause. We did not simulate central-field loss for the following reasons: in our motion-parallax task we allowed the head and eyes to move freely making it difficult to simulate a central scotoma that is stabilized in retinal coordinates. Also, people with central-field loss may be less disabled on mobility tasks than people with peripheral-field loss (Faye 1984; Marron and Bailey 1982; Wilson 1976). Therefore, limiting our investigation to peripheral-field loss is not only more practical, but also more relevant to mobility problems.(1)

### 2.1 *Methods*

2.1.1 *Subjects.* There were eighteen normally sighted observers (six participants for each of the three parts of the experiment) ranging in age from 17 to 49 years. The observers had a mean acuity of −0.08 (SD 0.13) logMAR (Snellen 20/17) and Pelli – Robson

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(1) People with central-field loss may benefit from motion parallax in some near tasks not involving mobility, such as reaching and grasping.

contrast sensitivity score of 1.74 (SD 0.08). Each observer gave written consent and received payment or course credit for participating in the study.

2.1.2 *Stimuli and apparatus.* Subjects viewed three cylinders against a white background through a viewing slit and a viewing assembly. The cylinders were 47 cm tall, made from polyvinyl chloride plumbing pipe and machined in a lathe to have diameters of 4.2, 4.4, and 4.6 cm. They were sanded to make them smooth and visually textureless. The cylinders were placed in plastic mounts which could be moved easily in depth (see figure 1). The tracks were calibrated with marks at 1 mm intervals, allowing the cylinders to be placed with 1 mm accuracy. The three tracks were horizontally positioned 10 cm apart. Room lights were diffused in order to give relatively uniform illumination across the visual field. The mean luminance of the cylinders was 7.46 cd $m^{-2}$ and mean luminance of the background was 21.17 cd $m^{-2}$, giving a contrast of 0.65 [the Weber definition of contrast is used throughout this paper. Contrast was calculated from the cylinder luminance $L_c$ and background luminance $L_b$ by using the following expression: $(L_b - L_c)/L_b$].

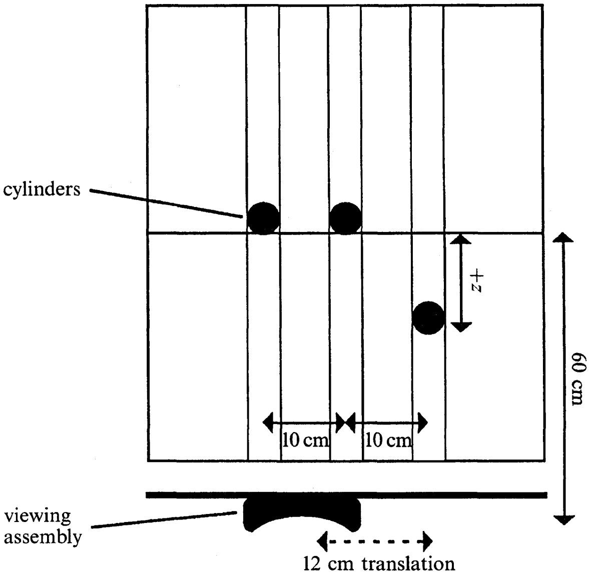


**Figure 1.** Apparatus: the viewing assembly, which could move from side to side, consisted of a head-and-chin rest and a set of welder's goggles which were modified to carry the blurscope, contrast-attenuating disks, and field-restricting tubes (see text for details).

Subjects viewed the cylinders monocularly with their right eye through a rectangular aperture 3 cm high by 18 cm wide in a black aluminum panel. (Their left eye was covered with an eye patch.) Neither the tops nor the bottoms of the cylinders could be seen through this viewing slit. A shutter, controlled by the experimenter, was used to occlude the slit between trials.

Our apparatus was designed to minimize the number of static-monocular depth cues, and thus to increase the difference between static and motion-parallax depth thresholds. For example, by using cylinders with different diameters and rearranging the cylinders on each trial we reduced the efficacy of a 'size cue' (ie the visual subtense of the cylinders covaried with their distance from the observer).

A viewing assembly on rollers was set in front of the viewing slit. Using this assembly, subjects could translate their heads laterally over a 12 cm range. The assembly was fitted with an adjustable chin-and-head rest. A pair of welder's goggles affixed to the assembly was modified for each part of the experiment as described below.

*Blur modification.* Resolution was degraded with a blurscope (Pelli 1984). The blurscope is a modified unit-power, wide-field (60 deg) telescope incorporating a diffusion screen.

It has the advantage over a positive lens in that the amount of blur does not depend on pupil size; rather, it depends only on the distance between the two fiber-optic bundles in the blurscope. The blurscope was held in a short tube (5 cm long) attached to the welder's goggles which allowed it to move as the viewing assembly moved. The level of blur was calibrated by measuring the letter acuity of all subjects without the blurscope and with two levels of blur. The resulting mean acuities were −0.03 logMAR (SD 0.19), 1.25 logMAR (SD 0.10), and 1.66 logMAR (SD 0.08) (Snellen equivalents: 20/19, 20/356, and 20/914).

*Contrast-reduction modification.* Contrast was reduced by using 'contrast-reduction disks' (Pelli 1984) placed in trial frames that were set into the welder's goggles. The disks contained diamond powder suspended in clear plastic. They reduced the contrast of the retinal image uniformly over all spatial frequencies from 0.5 to 30 cycles $\text{deg}^{-1}$, and were calibrated by measuring the contrast of the cylinders and background with and without the disks in place. Three levels of contrast attenuation were used which resulted in contrasts (between the cylinders and background) of 0.65, 0.062, and 0.043.

*Restricted-field modification.* Field size was restricted by using disks with central apertures of varying sizes at the end of an opaque tube 2.5 cm long that fit into the viewing goggles. The subject looked through the short tube with the disks at the other end. Three levels of restricted field were used, producing field widths of 62, 12, and 4.4 deg. The 62 deg field allowed simultaneous viewing of all three cylinders, the 12 deg field allowed simultaneous viewing of two cylinders, and the 4.4 deg field allowed viewing of only one cylinder at a time. Although this condition was intended to simulate peripheral-field loss, it should be noted that our field restriction did not move with the observer's eye movements. Instead, the subjects moved their heads to change the field of view.

2.1.3 *Procedure.* We measured depth thresholds for motion parallax and static viewing. On each trial, two of the three cylinders were placed 60 cm away, while a third cylinder was either placed closer ($+z$) or farther ($-z$) than the other two (see figure 1). The subject's task was to decide which cylinder was 'out of plane' and to tell whether that cylinder was further or closer than the other two (ie this task was a six-alternative forced choice, where the subjects responded "left front", "middle back", etc). Subjects were allowed 10 s to view the cylinders, and were notified when only 2 s remained. Time was kept with a stopwatch. After 10 s, the experimenter closed the viewing slit, preventing the subject from viewing the cylinders.

At the beginning of the trials for each condition of visual restriction, subjects were allowed seven or eight trials as practice to familiarize them with the task and viewing conditions. The subjects were given feedback on their depth judgments and were allowed to view the configurations again after the feedback. Subjects received no feedback for experimental trials.

For static trials, the viewing assembly was fixed so that the observer's eye was aligned with the central cylinder. For motion-parallax trials the viewing assembly was free to move. The observers were encouraged to move their heads from side to side as much as they liked, but were asked to refrain from rotational head movement. We measured the magnitude and speed of lateral head movements from video recordings of two observers performing the motion-parallax task. One observer used a mean head translation of 7.8 cm (SD 2.0), with a mean velocity of $\pm 9.8 \text{ cm s}^{-1}$ (SD 2.3), and the second observer used a mean translation of 9.4 cm (SD 2.4) with a mean velocity of $\pm 11.4 \text{ cm s}^{-1}$ (SD 3.5). The head movements of these observers were typical of those made by the other observers in this experiment.

Depth thresholds were estimated by using a staircase procedure. Each correct answer led to a down step in the staircase (ie the depth difference was decreased by one step on the next trial), and each incorrect answer led to an up step. Step sizes (which ranged from 0.5 to 2 cm according to conditions) and starting points for the staircases were determined in pilot experiments. A staircase was run until six turning points occurred. The threshold was computed as the mean of the depth differences at the six turning points. The threshold estimate corresponded to the depth at which the subject performed at 50% correct. For each condition, depth thresholds were determined for static viewing and motion parallax, for both $-z$ and $+z$ depth differences. Where possible, the static and motion-parallax trials were interleaved.

Six subjects participated in each of the three experimental conditions. The three conditions each contained three levels of blur, contrast, and field loss. The order in which these were run was counterbalanced across subjects.

2.1.4 *Data analysis.* Depth thresholds were converted to equivalent disparity (in min arc) by the formula:

$$\text{disparity} = 60 \times 57.3 \times id[D(D+d)]^{-1}, \tag{1}$$

where $D$ is the viewing distance (60 cm), $d$ is the depth threshold (in cm), and $i$ is the range of translational eye movement which was set to 8.6 cm (the mean head translation used by the subjects for whom we made detailed head-movement measurements). To allow comparison between the thresholds obtained with motion parallax and static viewing, the static-viewing thresholds were also converted into equivalent disparity by means of the same formula (with $i$ set to 8.6 cm). This made our adoption of equivalent disparity analogous to other studies (ie Rogers 1993; Rogers and Graham 1982). When equivalent disparity was used, the differences between the depth thresholds obtained in the $+z$ and $-z$ conditions were not significant, so we pooled these data. On 15 of the 192 threshold estimates, the staircase reached the minimum depth difference (ie 0 cm). In these cases, the subject's responses were accumulated over the length of the staircase and 50% thresholds were determined from the best fitting Weibull function to the data on percentage correct versus depth difference. In four cases the Weibull fit was unsatisfactory, and the staircase was repeated.

### 2.2 *Results*

2.2.1 *Blur.* Figure 2a shows depth thresholds as a function of blur. Across all three levels of blur, thresholds obtained with static viewing were larger than those obtained with motion parallax by an average factor of 1.91 ($F_{1,5} = 52.54$, $p < 0.001$). Depth thresholds for both motion parallax and static viewing increased with increasing blur ($F_{2,10} = 60.10$, $p < 0.001$). A Tukey HSD test showed that this main effect was due to the difference between the $-0.03$ and 1.6 logMAR levels. There was no interaction between blur and viewing mode (motion parallax or static viewing).

2.2.2 *Reduced contrast.* Figure 2b shows depth thresholds as a function of contrast. Across all three contrast levels the thresholds obtained with static viewing were larger than those obtained with motion parallax by an average factor of 2.00 ($F_{1,5} = 10.69$, $p < 0.05$). Depth thresholds for both motion parallax and static viewing increased with decreasing contrast ($F_{2,10} = 40.70$, $p < 0.001$). A Tukey HSD test showed that this main effect was driven by the performance at the 0.022 contrast level. There was no interaction between contrast and viewing mode.

2.2.3 *Restricted field.* Figure 2c shows depth thresholds as a function of field size (static-viewing data were not collected for the 12 deg and 4.4 deg fields, because the observers could not see all three cylinders in these conditions). For the 62 deg field, thresholds obtained with static viewing were larger than those obtained with motion parallax by an average factor of 2.90 ($t_5 = 7.51$, $p < 0.001$). Motion-parallax depth thresholds increased as field size was decreased ($F_{2,10} = 11.84$, $p < 0.01$).

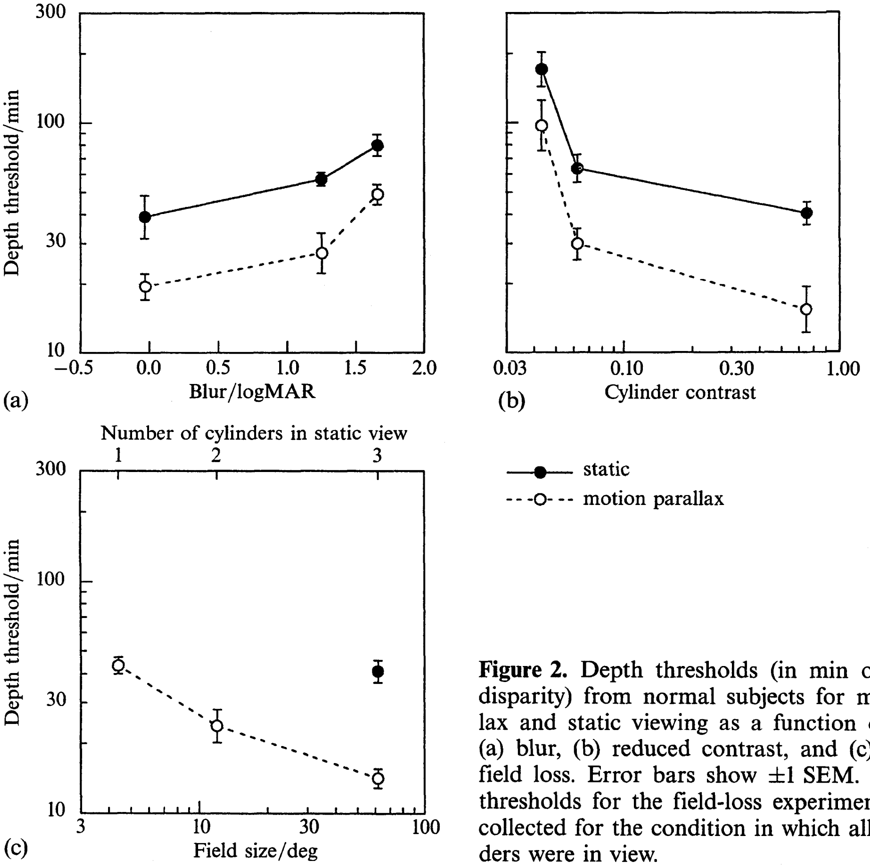


**Figure 2.** Depth thresholds (in min of equivalent disparity) from normal subjects for motion-parallax and static viewing as a function of simulated (a) blur, (b) reduced contrast, and (c) peripheral-field loss. Error bars show ±1 SEM. Static depth thresholds for the field-loss experiment were only collected for the condition in which all three cylinders were in view.

## 3 Experiment 2

While the data from experiment 1 indicate the individual effects of specific forms of simulated visual deficits on depth discrimination, these data may not generalize directly to low-vision subjects. Quite often, low vision involves more than one type of deficit (for example, macular degeneration involves field loss and a loss of acuity). It is unclear whether motion parallax is a useful depth cue in low vision, especially when vision loss is severe. To address this issue we collected depth-threshold data from low-vision observers.

### 3.1 *Methods*

3.1.1 *Subjects.* Measurements were obtained from ten observers with low vision with a range of acuities, contrast sensitivities, and field loss (see table 1). The low-vision observers' mean acuity was 1.04 logMAR (SD 0.50) (Snellen 20/220), and mean Pelli–Robson contrast-sensitivity score was 0.83 (SD 0.65). Field loss was categorized as either central (field loss within the central 5 deg), peripheral (field loss outside of the central 5 deg), or none, on the basis of the visual-field measurements in the ophthalmological records of each observer. The observers wore their usual corrective spectacles or contact lenses, and used their best eye to view the cylinders. Each observer gave written consent and received payment for participating in the study.

3.1.2 *Stimuli and apparatus.* The cylinders were the same as in experiment 1, but the viewing assembly was simplified: the blurscope, contrast-reduction lenses, and field-restriction disks were not used. Instead, we relied on the naturally occurring vision loss of the subjects. They viewed the cylinders through a circular aperture in the viewing goggles (the goggles were modified to permit viewing with the left or right eye).

**Table 1.** Low-vision observers.

| Subject | Age/years | Acuity/logMAR | Contrast sensitivity | Field loss | Diagnosis |
|---|---|---|---|---|---|
| A | 35 | 1.46 | 0.75 | central | macular degeneration |
| B | 44 | 1.08 | 1.35 | central | uveitis |
| C | 56 | 0.88 | 0.09 | central | retinitis pigmentosa |
| D | 32 | −0.02 | 1.80 | peripheral | retinitis pigmentosa |
| E | 24 | 1.40 | 0.45 | peripheral | glaucoma |
| F | 72 | 0.62 | 1.35 | peripheral | ischemic optic neuritis |
| G | 35 | 0.86 | 0.45 | none | Leber's disease |
| H | 47 | 1.68 | 0.00 | none | corneal opacification |
| I | 37 | 1.40 | 0.45 | none | nystagmus/staphyloma |
| J | 22 | 1.08 | 1.65 | none | uveitis |

Note: Central, field loss within the central 5 deg of field; peripheral, field loss outside the central 5 deg of field.

3.1.3 *Procedure.* Depth thresholds were measured with static viewing and motion parallax for both the $+z$ and $-z$ depth differences. The staircase procedure was modified from that used in experiment 1. The step sizes were a percentage (either 10% or 15%) of the current depth difference, thus preventing the staircase from reaching a 0 cm depth difference. The staircase was run for ten turning points; the last six of which were averaged to obtain the 50%-correct depth threshold. The motion-parallax and static trials were run in separate experimental blocks.

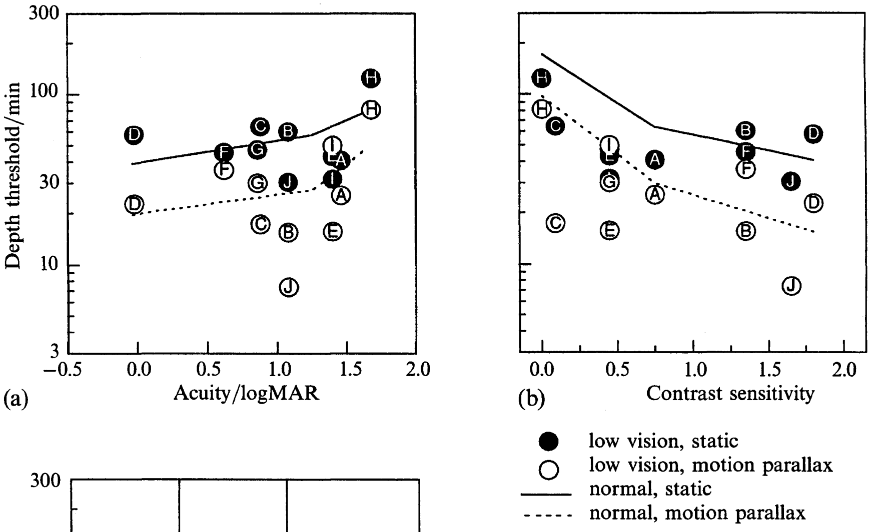
Before each block, the observers were allowed practice trials in which they viewed several different cylinder configurations and were given feedback. Performance in the practice trials was used to determine the starting depth differences for the experimental trials.

### 3.2 *Results*

Figure 3 shows the depth thresholds from the low-vision observers plotted as a function of acuity, contrast sensitivity, and field loss (either central, peripheral, or none). The depth thresholds exhibited large individual differences. However, all but one observer (subject I) performed better on the depth task with motion parallax compared with static viewing. On average the motion-parallax thresholds are smaller than the static-viewing thresholds by a factor of 2.05 ($t_9 = 3.69$, $p < 0.01$).

Do the depth thresholds of the low-vision observers depend on acuity, contrast-sensitivity, and visual-field loss? While it is certainly the case that the observer with the highest depth thresholds also had the poorest acuity and contrast sensitivity, multiple-regression analysis showed that both threshold performance and the improvement attributable to motion parallax were only weakly correlated with acuity, contrast-sensitivity, and visual-field status. A failure to find a strong effect of these parameters on low-vision performance is likely due to the sizeable individual differences of the observers. Nevertheless, observers with poor acuity and poor contrast sensitivity showed improved depth thresholds when they used motion parallax as did observers with relatively good acuity and good contrast sensitivity. The fact that motion parallax improved the depth thresholds of all but one observer shows that motion parallax is an effective depth cue under various combinations of visual deficits.

How do the depth thresholds from low-vision observers compare with those from normally sighted observers with simulated low vision? The normal-vision data from experiment 1 for blur and contrast reduction are plotted in figures 3a and 3b. It can be seen that the majority of the low-vision depth thresholds are better than those from the normal observers (in figure 3b, the motion-parallax thresholds for subjects E and J fall below the normal-subject line nearly by a factor of 3). It is not known why the low-vision thresholds are better than those of the normal-vision subjects with simulated low vision.



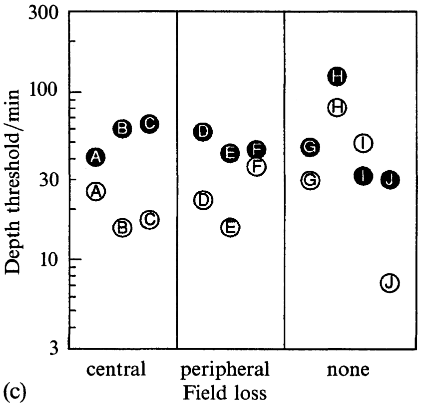


**Figure 3.** Depth thresholds (in min of equivalent disparity) from low-vision subjects for motion parallax and static viewing as a function of (a) acuity, (b) Pelli – Robson contrast-sensitivity score, and (c) field loss. Letters in the circles identify the subjects listed in table 1. In (a) and (b) the solid and dashed lines show the data from experiment 1 for static viewing and motion parallax, respectively. In (b) we expressed the contrast attenuation used in experiment 1 in terms of contrast sensitivity by measuring the contrast sensitivity (using the Pelli – Robson chart) of normal subjects through the attenuation disks.

## 4 Discussion

The data shown in figures 2 and 3 indicate that with motion parallax the smallest depth differences that could be detected were approximately a factor of 2 smaller than those with static viewing. The advantage of motion parallax was found at all the levels of resolution, contrast, and field size tested in experiment 1, and in all but one low-vision observer in experiment 2. Thus, motion parallax is a robust monocular depth cue over a wide range of resolutions, contrasts, and field sizes.

We can use the thresholds collected in our study to illustrate the possible benefit afforded by motion parallax in real-world situations. Typical depth thresholds in our study were 27 min arc for motion parallax and 54 min arc for static viewing. In order to detect a step 20 cm high, such as a roadside curb, an observer (using the same 8.6 cm head translation used in our experiment) would need to be no closer than 1.33 m when using motion parallax or 0.95 m when using static viewing. When pouring a glass of wine(2) the pourer is required to judge the relative distance of the rim of the glass and the mouth of the bottle. For a glass 5 cm in diameter the required accuracy is ±2.5 cm, which, if the glass is located 50 cm away, corresponds to ±28 min arc. Thus with motion parallax (depth threshold = 27 min arc with 8.6 cm head translation) the wine can be poured without spillage. However, with static viewing (threshold = 54 min arc) this is not the case. In such real-world situations, the precise magnitude of the motion-parallax advantage over static viewing will depend on the

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(2) We favor using red wine for this demonstration as it provides better contrast than the more transparent white or rosé wines.

actual range of head movements used and on the richness and availability of other depth cues. Therefore, our data should be taken only as a qualitative indicator of the potential value of motion parallax in low-vision depth perception.

What cues could account for the depth thresholds in the static-viewing conditions? Although we took measures to minimize static-monocular cues, some cues remained. For example, there was a 'size cue' such that the visual angle subtended by the cylinders covaried with their distance from the observer. We used cylinders with different diameters (see section 2.1) to reduce the usefulness of this cue at small depth differences. Another cue was the 'gap cue'; information about the cylinder configuration could be obtained by comparing the visual angles of the gaps between the cylinders (for example, the angle between the left and the middle cylinder increases when the left cylinder is moved towards the observer). Other possible depth cues include accommodation and 'ocular parallax' [optic flow from eye movements, due to the center of eye rotation being behind the entrance pupil by approximately 11 mm (see Bingham 1993)]. It is unclear how these depth cues would be impaired by low vision. Perhaps some of the variation in the depth thresholds of the low-vision observers is due to their differing use of the available depth cues.

What are the implications of our findings for low-vision rehabilitation? It is possible that the utility of motion parallax has already been recognized and incorporated into the adaptive behavior of some low-vision patients. Marrota et al (1995) measured head movements during a reaching task in adults who have had one eye enucleated. They found a significant correlation between the magnitude of head movements and the time since enucleation indicating that patients adapt to their monocular vision over time. However, during informal conversation after our experiments, many of the low-vision observers indicated that they had never consciously used motion parallax in their daily activities, and did not realize it could be a helpful cue. To explore this issue further, we collected additional data from two of our low-vision observers (E and G), to see if the advantage provided by motion parallax increased with repeat testing. After running the experiment three times, we found no change in the depth-discrimination advantage for motion parallax. This may indicate that these subjects have been using motion parallax throughout their lives and had already reached their best performance on motion-parallax tasks. Alternatively, our failure to find a learning effect could indicate that the ability to use motion parallax in low-vision can be acquired quickly. In either case, the motion-parallax advantage may suggest new strategies for low-vision rehabilitation. The benefit of motion parallax should be quick to teach to the individuals who are not aware of it, as had been found with normal-vision observers (Ferris 1972).

People with low vision, especially those with peripheral-field loss, often have difficulty in mobility and orientation. Can motion parallax help? Cutting et al (1992) found that performance of normal-vision subjects in a direction-of-heading task was governed by motion-parallax cues rather than optic flow. They argued that motion parallax is a salient and computationally simple cue for way finding. Our finding that motion parallax is a robust depth cue over a wide range of visual deficits leaves the possibility that motion parallax can be helpful for low-vision mobility.

One intriguing aspect of the data from experiment 1 is the effect of peripheral-field loss. As field size was decreased, there was a large deterioration in the motion-parallax depth thresholds. Indeed, with the smallest field size the motion-parallax threshold matched that with static viewing (with a full field of view). One reason for this finding may be that the number of cylinders that could be seen simultaneously decreased as field size was reduced. (The low-vision data did not show a consistent effect of field size on depth thresholds, conceivably because all observers had field widths greater than 20 deg and could always see all three cylinders.) These data suggest that for motion parallax to provide an advantage in depth perception the objects whose depths are being compared need to be simultaneously visible. Perhaps the cue in motion parallax is not simply a difference in absolute retinal-image velocity, but rather the expansion or compression of the retinal image that is caused by the different retinal velocities.

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