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Contraction of perceived size and perceived depth in mirrors

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We investigated how size and depth are perceived in a plane or convex mirror. In Experiment 1, using a plane or convex mirror, 20 observers viewed a separation between two objects that were presented at a constant distance and reproduced it by a separation between other two objects in a natural viewing situation. The mean matches generally approximated the real size of the standard and did not equal either virtual size or visual angle of the standard. In addition, the mean matches obtained with convex mirrors were reduced by about 7% in comparison with those obtained with the plane mirror. In Experiment 2, we examined whether the perceived depth in a convex mirror is comparable to that in a plane mirror. We presented isosceles triangles on a table and required 12 observers to observe them with a plane or convex mirror. With the method of limits, we determined the triangle that was perceived as an equilateral triangle. When the apexes of isosceles triangles were directed to the observer or to depth, the ratio of height to base was larger in convex mirrors than in the plane mirror, whereas when the apexes were directed to left or to right, the ratio of height to base was smaller in the convex mirrors than in the plane mirror. The contraction of perceived depth amounted to about 6% in convex mirrors. The results of both experiments suggest that although separation and depth in convex mirrors appear to reduce, there is a strong tendency that visual system recovers the optical distortions by convex mirrors.

This study investigated how size (or separation) and depth are perceived in a plane or convex mirror. In this paper, size means the extent of an object in the frontoparallel plane; in particular, when a vacant space spreads between two frontoparallel objects, we refer to the space as separation. Distance means the extent from the observer to an object and depth means the difference between two distances. We believe that size, distance, and depth are accurately perceived in natural viewing situations in which a number of spatial cues are provided in usual combination. In contrast, many problems remain to be

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solved regarding spatial extents in the virtual world that is produced by mirrors.

Mirrors generally transform layout of the real world. A plane mirror produces an exact optical transformation of the real world: Size of real objects and their depth are maintained in the virtual world produced by the plane mirror. A convex mirror also transforms the real world into the virtual world, but the size and depth in the virtual world shrink much more than their counterparts in the real world (Higashiyama, Yokoyama, & Shimono, 2001). However, we, probably except for opticians, do not correctly recognize optical nature of the virtual world. If we look at the virtual world through a convex mirror, we may perceive the virtual world to shrink, but we do not believe, for example, that the virtual distance up to any object is not over the focal distance of the convex mirror. It thus seems that what is seen in a convex mirror differs from the optical transformations.

Higashiyama and Shimono (2004) indeed demonstrated that the virtual world transformed by a convex mirror is likely to be perceived veridically. They required the observers to judge size and distance of five targets that were presented at different distances. The observers saw the targets through a plane, moderately curved, or largely curved mirror. Despite the differences in optical nature among mirrors, size judgments were the same for both plane and convex mirrors: Perceived size of an object was constant independently of distance from the mirror to the target (i.e., size constancy). Yet, distance judgments differed between the mirrors. First, perceived distance was larger in convex mirrors than in the plane mirror. Second, perceived distance grew less rapidly in a convex mirror than in a plane mirror. According to conventional treatment of data (e.g., Da Silva, 1985), when the perceived distance was represented as a power function of real distance, the exponent of the power function was smaller in the convex mirrors than in the plane mirror.

In this study, we further explored spatial properties of mirror vision in two experiments. In particular, we examined whether perceived size in a convex mirror is as accurate as that in a plane mirror (Experiment 1) and whether perceived depth in a convex mirror is comparable to that in a plane mirror (Experiment 2). In contrast with the previous study (Higashiyama & Shimono, 2004), in Experiment 1, we varied a separation between two objects that were presented at a constant viewing distance. The observers viewed the separation by reflecting the objects in a plane or convex mirror, and they reproduced it by a separation between other two objects in a natural viewing situation. Our concern in this experiment is to specify what information the observers relied on in this situation. There are, at least, two sources of size information that are available to observers: One is the angular size of virtual separation that is subtended at an observer's eye, and another is the angular size of real separation that is achieved by taking visual contextual surroundings into account. We attempted to search how effective the sources of information are in mirror vision.

In Experiment 2, we examined how a depth between two points is perceived in a plane or convex mirror. In particular, we examined whether perceived depth shrinks in a convex mirror in comparison with a plane mirror. By contraction of perceived depth, we mean that if an object as a stick is presented in the frontoparallel plane and in the median plane, the object in the median plane is perceived to be smaller than that in the frontoparallel plane. Under natural binocular observations, depth is accurately perceived at a distance of 1m or less, but at a far distance, it is perceived to shrink (e.g., Johnston, 1991; Ono & Comerford, 1977) or is still perceived accurately (Durgin, Proffitt, Olson, & Reinke, 1995; Nakamizo & Shimono, 2001). Since a real depth is exactly conserved as the virtual depth in a plane mirror but it is reduced in the convex mirror, it is possible that the contraction of perceived depth would be facilitated in a convex mirror, even if the objects are close to the observer.

EXPERIMENT 1

METHOD

Observers. Twenty university students (9 males and 11 females) volunteered as observers.

Stimuli and Mirrors. The stimuli for the standard separation were four red rectangle boards. Each board was 151 cm high x 8 cm wide x 0.3 cm thick. A 36 cm x 15 cm wooden base supported each board to make it stand erect on the ground. All the boards were presented 10 m behind the observer. Accordingly, the observer could not see the standard boards directly. There were two layouts of the boards --- the left and the right layout. In the left layout, the four boards were placed side by side to the left backward of the observer. The lateral separations from the leftmost board to the other boards were 2.11, 3.07, and 4.12 m; the rightmost board was almost placed at the back of the observer. In the right layout, the four boards were placed side by side to the right backward of the observer. The lateral separations from the rightmost board to the other boards were 1.20, 2.77, and 4.38 m; the leftmost board was almost placed at the back of the observer. Note that the separations for the left layout differed from the separation for the right layout. By using different separations, we examined how reliable the results are regardless the difference of layout.

There were two convex mirrors and one plane mirror to see the boards for the standard separation. The radii of curvature, $2f$, for the convex mirrors were 0.2 m (curvature, K = 5.0) and 0.4 m (K = 2.5), and the radius of curvature for the plane mirror was infinitely large (K = 0). The diameter of each mirror was 52 mm. The observer grasped each mirror with his or her hand and saw the standard boards with the mirror. The distance from the observer's eye to the mirror, d, was 30 cm on average.

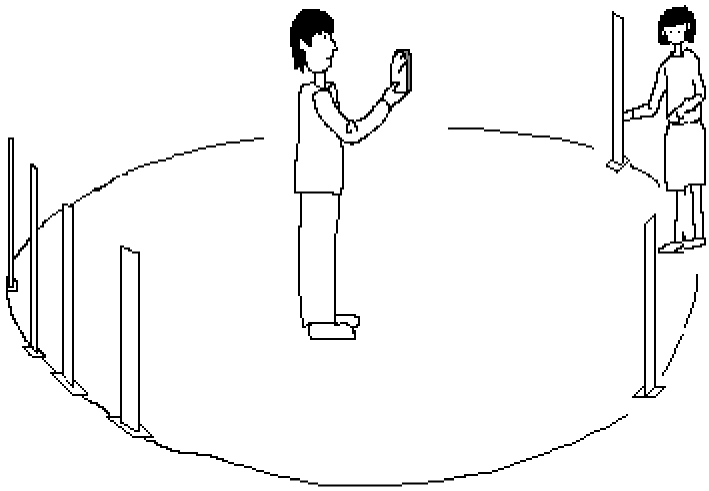

Figure 1. The setting of Experiment 1 (right layout). The four boards behind the observer were used for the standard separation and the two boards in front of him were used for the comparison separation.

Virtual size, $2h$, virtual distance, z, and visual angle, 2θ, for the standard separations, $2a$, were obtained by:

$$h = \frac{af}{f + y} \quad (1)$$

$$z = \frac{yf}{f + y} \quad (2)$$

$$\theta = \arctan \frac{h}{z + d} \quad (3)$$

where y is the real distance from the mirror to the object (Higashiyama et al., 2001; Higashiyama & Shimono, 2004). We assumed that $y = 10$ m in this experiment. Table 1 shows the values of $2h$, z, and 2θ for each mirror.

The stimuli for the comparison separation were two red rectangle boards that were the same size as the boards for the standard separation. These boards were presented 10 m in front of the observer. The right board was fixed at 40 cm to right of the median plane and the left board was gradually moved to left or to right by the experimenter.

Table 1. The standard separation (in m), 2*a*, and its virtual size (in m), 2*h*, virtual distance (in m), *z*, and visual angle (in rad), 2□, in mirrors.

Layout	Standard Separation	Plane Mirror ($2f = \infty$)			Convex Mirror ($2f = .4$)			Convex Mirror ($2f = .2$)		
	$2a$	$2h$	z	2□	$2h$	z	2□	$2h$	z	2□
	1.20	1.20	9.98	6.68	.0236	.196	2.72	.0120	.099	1.72
Left	2.77	2.77	9.90	15.46	.0548	.196	6.32	.0278	.099	4.00
	4.38	4.34	9.76	24.56	.0880	.196	10.14	.0444	.099	6.36
	2.11	2.11	9.94	11.76	.0416	.196	4.80	.0210	.099	3.02
Right	3.07	3.07	9.88	17.14	.0610	.196	7.04	.0308	.099	4.42
	4.12	4.12	9.79	23.08	.0824	.196	9.50	.0416	.099	5.96

Note – $2f$ = radius of curvature in m.

Procedure. The experiment was done on the open flat roof of a building on campus. On looking into a mirror, the observer saw the standard boards against trees and halls. Half the observers participated in the left layout and the remaining observers participated in the right layout. For the left layout, each observer grasped the mirror with the left hand and saw the boards behind his or her left shoulder. For the right layout, each observer grasped the mirror with the right hand and saw the boards behind his or her right shoulder.

In either layout, as is shown in Figure 1, the observer stood on the roof, directing his or her face to the boards for the comparison separation. Whenever the observer wanted to see the boards for the standard separation, he or she saw their virtual images in mirrors. Whenever the observer wanted to see the boards for the comparison separation, he or she saw them directly. Observation was always made binocularly. The observer was permitted to move the head freely and also to move the hand that was used to grasp the mirror.

Each observer adjusted the comparison separation. He or she directed the experimenter to move the left comparison board to and fro while keeping the right comparison board stationary at a preset position. When the angular size of the comparison separation equals the angular size of the standard separation, the observer told the experimenter to stop moving the left comparison board. In the instructions to the observers, the experimenter emphasized the observers to judge angular size of the separation and explained angular size by drawing a person and two boards on paper and by indicating the angle subtended at the observer's eye by the inner edges of the boards. However, the experimenter did not explain how different the real and virtual images are. For each standard separation, there were two trials: The approaching trial in which the movable comparison board approached the stationary comparison board, and the leaving trial in which the movable comparison board went away from the stationary comparison board.

The order of mirrors was randomly determined for each observer. For a given mirror, the observer made consecutive judgments for six combinations of three separations and two directions. The order of the combinations was randomly determined for each observer.

RESULTS AND DISCUSSION

Figure 2 presents the results: The upper panel represents the results of the left layout, and the lower panel represents the results of the right layout. In each panel, the mean matches (i.e., symbols connected with real lines) are shown as a function of the standard, with the mirror as the parameter. Each mean match was based on 20 judgments (10 observers x 2 series).

Figure 2 also shows the curves that would be obtained if the matches of the comparison were based on visual angle of the virtual separation (i.e., symbols connected with dotted lines). In this experiment, the visual-angle matches were obtained by 20 tan□ (in meters) for any mirror used. For a plane mirror, the visual-angle matches are the same as the real-separation matches, which are represented in Figure 2 by a line with the slope of unity. But, for a convex mirror, the visual-angle matches are fairly smaller than the real-separation matches.

Clearly, for any mirror used in this experiment, the mean matches approximated the real-separation matches, rather than their visual-angle matches. In addition, the mean matches definitely differed from the virtual sizes of the standard that were produced by the convex mirrors. As is shown in Table 1, the virtual sizes of the standard in the convex mirrors, $2h$, are very small --- 0.088 m or less. This implies that when the observer looked at the virtual images in convex mirrors, he or she had judged spatial properties of the real, not virtual, layout of the environment.

To examine whether there was a difference in matches among mirrors, for each layout, we performed a two-way (separation x mirror) ANOVA with repeated measures. In each analysis, series (i.e., approaching and leaving) was not included as factor. For the left layout, the main effect of separation was significant, $F(2, 18) = 96.0$, $p < .001$, and the interaction of separation and mirror was significant, $F(4, 36) = 3.2$, $p < .05$. This suggests that for the larger standard separation, the mean matches for the plane mirror were larger than those for the convex mirrors. For the right layout, the main effect of separation was significant, $F(2, 18) = 439.2$, $p < .001$, and the main effect of mirror was significant, $F(2, 18) = 4.2$, $p < .05$. This means that the mean matches for the plane mirror were larger than those for the convex mirrors. Thus, for both layouts, the mean matches obtained with the convex mirrors were generally smaller than those obtained with the plane mirrors.

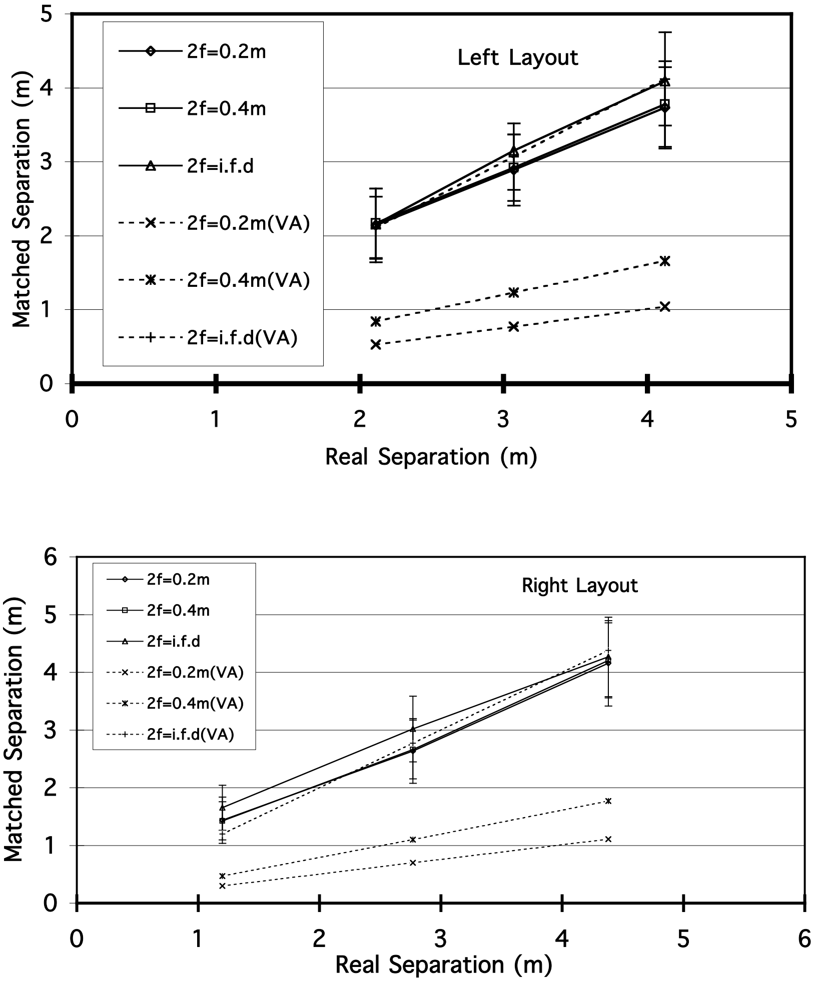

Figure 2. Mean matched separation (symbols connected with real lines) as a function of real separation for the left (upper panel) and the right layout (lower panel). The parameter is the radius of curvature [2*f* = .2 m (diamond), .4 m (square), and infinitely large distance (triangle)]. The bar attached to either side of each data point represents the standard deviation. The symbols connected with dotted lines are the predictions of setting on the basis of visual angle.

Table 2. Proportion of size contraction as a function of separation and curvature.

	Left layout			Right Layout		
Curvature	2.11m	3.07m	4.12m	1.20m	2.77m	4.38m
0.0($2f = \infty$)	1.00	1.00	1.00	1.00	1.00	1.00
2.5($2f = 0.4$)	1.01	0.93	0.92	0.86	0.88	0.99
5.0($2f = 0.2$)	0.99	0.92	0.91	0.87	0.87	0.97

Note – $2f$ = radius of curvature in m.

Table 2 indicates to what extent the convex mirrors reduced perceived separation. Each entry is the ratio of the mean matches for each mirror to the mean matches for the plane mirror. The average ratio was 0.93 (*SD*=0.05), which implies that a 7% reduction of perceived separation was obtained in the convex mirrors.

The important result of Experiment 1 was that the mean matches generally equaled the real size of the standard and did not equal either virtual size or visual angle of the standard. Although we did not intentionally instruct the observers to judge real size of the standard, there was a strong tendency for the observers to judge it. It is also important to note that this tendency of judging real size of the separation was not perfect. The matches for each convex mirror were generally smaller than those for the plane mirror, reflecting the differences in virtual size between the convex mirror and the plane mirror.

EXPERIMENT 2

In Experiment 2, we examined whether perceived depth in a convex mirror shrinks in comparison with that in a plane mirror. As was mentioned above, when perceived distance was represented as a power function of real distance, the exponent of the power function was smaller in the convex mirrors than in the plane mirror. This suggests that perceived depth shrinks in convex mirrors. Yet, there are no or few studies that compared perceived depth among mirrors of different curvatures.

To examine perceived depth in mirrors, we presented triangles on a table and required the participants to see the triangles by reflecting them in a plane or convex mirror. We asked the observers to judge whether the triangles are equilateral. The triangles to be judged were constant in base but were different in height (i.e., isosceles triangles). If apexes of triangles are directed to the observer (or to depth) and if perceived depth shrinks in a convex mirror, the triangle that appears to be equilateral has a larger ratio of height to base for the convex mirror than for the plane mirror. Similarly, if apexes of triangles are directed to the left (or to right) and if perceived depth shrinks in a convex mirror, the triangle that appears to be equilateral has a smaller ratio of height to base for the convex mirror than for the plane mirror. In short, it is predicted that the ratio of height to base depends on orientation of triangle in a convex mirror.

METHOD

Observers. Twelve university students (7 males and 5 females) were served as observers. They were paid for their participation.

Stimuli and Mirrors. The stimuli were 25 isosceles rectangles that were cut out from white paper. The bases of triangles were 200 mm and their heights were varied from 133 mm to 253 mm in a 5-mm step. The isosceles triangle of 173 mm high was equivalent to an equilateral triangle of 200mm side each. The triangles were presented on a table that was covered with a black cloth. The distance from the mirror to the base of each triangle was about 75 cm, and the height from the tabletop to the observer's eye was about 47 cm. When the triangle was reflected at the center of a convex mirror, the mirror axis intersected the table at an angle of about 39 deg.

Two convex mirrors and one plane mirror were used to see the triangles. The radii of curvature, 2*f*, for the convex mirrors were 0.22 m (K = 4.55) and 0.60 m (K = 1.67), and the radius of curvature for the plane mirror was infinitely large (K = 0). The diameter of each mirror was 20 cm. The distance from the observer's eye to the mirror was about 30 cm.

The virtual size of an object that is placed obliquely to the mirror axis, $2l$, is approximately obtained by

$$l = \sqrt{h'^2 + z'^2} \qquad (4)$$

where

$$h' = \frac{(a\sin\theta)f}{f + (y_N + a\cos\theta)}$$

and

$$z' = \frac{(y_N + a\cos\theta)f}{f + (y_N + a\cos\theta)} - \frac{y_N f}{f + y_N}$$

where $2a$ is the real size of the object; y_N is the real distance from the mirror to the near end of the object; θ is the angle at which the mirror axis intersects the object (0 deg < θ < 90 deg). Note that $l = h$ (Equation 1) when θ = 90 deg

By Equation 4, we can determine virtual sizes of the triangles as observed in Experiment 2. For simplicity, consider a condition where the base of a triangle (0.2 m long) is normal to the mirror axis (θ = 90 deg) or it is directed to depth on the table (θ = 39 deg). Table 3 shows the results that are obtained when we assume that a = 0.2 m and y_N = 0.75 m: For the plane mirror, the size of the virtual image keeps constant (i.e., 20 cm) for either orientation of the base; but for the convex mirror, when the orientation of the base changes from 90 deg to 39 deg, the size of the virtual image is reduced by 42% (in the case of 2*f* = .60 m) or by 46% (in the case of 2*f* = .22 m).

Table 3. Virtual size (in m) of a base of 0.2 m long that is observed with three mirrors.

Slant of triangle	Plane Mirror ($2f = \infty$)	Convex Mirror ($2f = 0.60$)	Convex Mirror ($2f = 0.22$)
39° (on the table)	0.2	0.033	0.014
90° (normal to mirror axis)	0.2	0.057	0.026

Note – 2f = radius of curvature in m.

Procedure. The experiment was done in a laboratory under usual indoor illumination. The observer sat on a chair with a plane or convex mirror in his or her hands and saw triangles on the table that was placed behind the observer. To see the triangles, the observer raised the mirror above the shoulder and reflected them in the mirror. Observation was always made binocularly. The observer was permitted to move the head and hands freely. Five observers saw the triangles behind their left shoulders and seven observers saw them behind their right shoulders. Figure 3 illustrates the relation among the observer, the mirror, and the triangle.

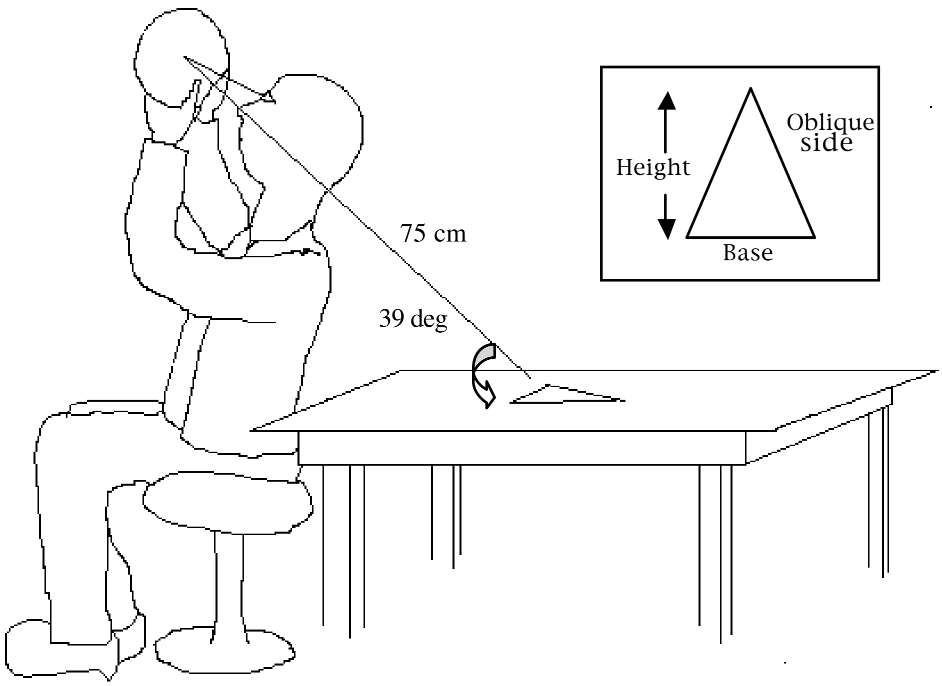

Figure 3. The setting of Experiment 2. The observer looks at the triangle on the table. The line connecting the mirror with the triangle (i.e., mirror axis) intersected the table at an angle of 39 deg. The right top shows the view that was seen when a triangle is directed to depth.

There were two within-subject factors. One was the mirror that was used to see the triangles. Another was the orientation of the triangle: The apexes of isosceles triangles were directed to the observer, to depth, to left, or to right. For each of 12 combinations of mirror and orientation, we determined a PSE (i.e., subjective point of equality) for an equilateral triangle in accordance with the method of limits. One triangle was presented at a time. For a given trial, each observer judged whether the oblique side of the triangle was larger or smaller than its base. The observers were instructed to judge "objective" size, not "apparent" size, of the triangles. By "objective" size, we mean size that is measured with a physical ruler (Da Silva & Dos Santos, 1984; Higashiyama, Ishikawa, Tanaka, 1990). There were two ascending series and two descending series. We stopped the ascending or descending series when the observer changed his or her response from the repeated "small" responses to the first "large" response or from the repeated "large" responses to the first "small" response. The order of combinations of mirror and orientation was randomly determined for each observer.

RESULTS AND DISCUSSION

For each combination of mirror and orientation, the mean PSE was obtained from each observer by averaging four PSEs where the responses changed from "small" to "large" or from "large" to "small." Figure 4 shows the results: The mean PSEs that were taken across the 12 observers are represented as a function of curvature, with the orientation as the parameter.

The main effect of orientation was significant, $F(3, 33) = 8.07$, $p < .001$. The interaction of mirror and orientation was significant, $F(6, 66) = 4.27$, $p < .01$. This interaction is interpreted: When the apexes of isosceles triangles were placed to the observer or to depth, the mean PSE was smallest for the plane mirror but it increased for the moderately curved mirror and again decreased for the largely curved mirror, whereas when the apexes of triangles were directed to left or to right, the mean PSE for the convex mirrors were smaller than that for the plane mirror. Clearly, perceived depth of the triangles was more compressed in the convex mirrors than in the plane mirror.

The proportion of depth contraction was obtained by evaluating the mean PSE for each mirror relative to the mean PSE for the plane mirror. For the triangles directed to the observer or to depth, the mean PSE for each mirror was divided by the mean PSE for the plane mirror. For the triangles directed to left or to right, the mean PSE for the plane mirror was divided by the mean PSE for each mirror. If the proportion of depth contraction equals unity, the depth for the convex mirror changes at the same rate as that for the plane mirror; if the proportion of contraction is larger than unity, the depth for the convex mirror is more reduced than that for the plane mirror; if the proportion of contraction is smaller than unity, the depth for the convex mirror is less reduced than that for the plane mirror. Table 4 shows the results. For the moderately curved mirror, the proportion ranged from 1.05 to 1.10, whereas for the largely curved mirror, it ranged from 0.97 to 1.08. The ground mean was 1.06 (SD = 0.04). This implies that 1) a 6% depth contraction was obtained in the convex mirrors and 2) the depth contraction is more remarkable in the moderately curved mirror than in the largely curved mirror.

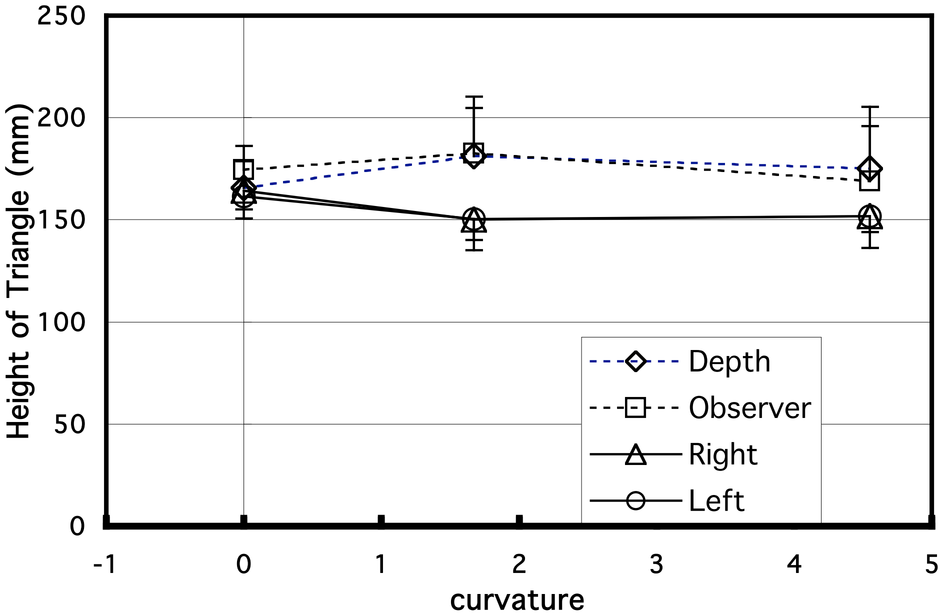

Figure 4. Mean height of triangle (mm) as a function of mirror curvature. The parameter is the orientation of the triangle presented on the table. The bar attached to one side of each data point represents the standard deviation.

Table 4. Proportion of depth contraction as a function of orientation of triangle and curvature. The triangle was placed on the table (□ = 39°).

Curvature	Orientation of triangle			
	Depth	Observer	Right	Left
0 ($2f = \infty$)	1.00	1.00	1.00	1.00
1.67 ($2f$ = 0.60)	1.09	1.05	1.10	1.07
4.55 (2f = 0.22)	1.06	0.97	1.08	1.06

Note – $2f$ = radius of curvature in m.

GENERAL DISCUSSION

The results of this study showed that perceived separation for convex mirrors was reduced by 7% in comparison with a plane mirror. This is in contrast with the results of the Higashiyama and Shimono study (2004), which indicated that under "objective" instructions, there is no substantial difference in size estimation between a plane and a convex mirror. The variable resulting in such a difference in size judgments may be the instructions to the observers. In Experiment 1, we instructed the observers to judge angular size of separations, but we did not specify whether the separation to be attended to is real or virtual. In this situation, the matched separation may be affected by both real and virtual sizes of the separation and, consequently, the matched separation was somewhat reduced in convex mirrors.

The results of this study also showed that perceived depth for convex mirrors was reduced by 6% in comparison with a plane mirror. This result agrees with the results of our previous studies (Higashiyama et al., 2001; Higashiyama & Shimono, 2004), in which scales for distance were obtained by three psychophysical methods. For each method used, the exponent of power function was smaller in convex mirrors than in a plane mirror (0.89 against 0.95 for the partition method; 1.36 against 1.43 for the method of magnitude production; 0.88 against 1.03 for the method of magnitude estimation). Thus, the power function for convex mirrors grows less rapidly than that for the plane mirror; this outcome predicts the compression of perceived depth in convex mirrors.

Despite contraction of both perceived separation and perceived depth, however, the present results gave us an impression that veridical perception, which is comparable to a plane mirror, occurred in convex mirrors. The mean matches of separation obtained with a plane or convex mirror approximated the predictions from real separation and did not agree with the predictions from virtual separation (See Figure 2). In other words, in spite of the two possible sources of size information, the observers based their judgments overwhelmingly on *real* size of separation. Likewise, although the convex mirror reduced virtual depth by 42% or 46% in this study, the contraction of perceived depth (6%) did not agree with this optical compression (See Figure 4). There seems to be a strong tendency for the observers to judge real depth, rather than virtual depth.

The tendency that the perception of separation and depth is veridical to a considerable degree in convex mirrors should not be surprised when we consider the perception of photographic pictures. The layout of virtual images in convex mirrors is similar to the layout of depicted images in photographs, in that in either visual medium, the images to be observed are generally smaller than the real objects and only pictorial cues to depth (e.g., texture gradient, relative size, familiar size, interposition, and light and shade) are available in a two-dimensional depthless plane or in a very limited depth between the mirror surface and the focal distance. Evidence regarding depth perception in photographic pictures (e.g., Smith & Gruber, 1958; Bengston, Stergios, Ward,

& Jester, 1981) has suggested that when the optical array entering the eyes from a photograph approximated the optical array entering the lens of camera, the perceived depth in the photograph approximates that in the real scene. Similarly, it is well known that size constancy is also maintained to a high degree in photographs that include only pictorial cues to depth (Smith, 1958; Shimada, 1975). These results suggest that if pictorial cues to depth are available to observers, size and depth are very accurately judged even in photographs. Accordingly, we may argue that if there are ample pictorial cues to depth in the virtual world, perceived separation and perceived depth is accurate in mirrors as well.

Moreover, there are other cues to depth in mirror vision. The images in a mirror moved concomitantly with the motion of hands that grasp the mirror. The observer can search the visual world by moving his or her head and keeping the hand stationary. This mobility of virtual images generated by self-motion provides the images in mirrors with other depth cues that are not found in static photographs. They are possibly motion parallax (e.g., Helmholtz, 1866/1911; Hershenson, 1999) and deletion and accretion (e.g., Kaplan, 1969) that exert as a powerful cue to depth. Addition of these dynamic cues to the static cues makes images in mirrors much more realistic than static photographs and, as a result, may contribute to veridical perception of separation and depth in mirrors.

REFERENCES

Bengston, J. K., Stergios, J. C., Ward, J. L., & Jester, R. E. (1981). Optic array determinants of apparent distance and size in pictures. *Journal of Experimental Psychology: Human Perception and Performance*, 6, 751-759.

Da Silva, J. A. (1985). Scales for perceived egocentric distance in a large open field: Comparison of three psychophysical methods. *American Journal of Psychology*, 98, 119-144.

Da Silva, J. A., & Dos Santos, R. A. (1984). The effects of instructions on scales for perceived egocentric distance in a large open field. *Bulletin of the Psychonomic Society*, 22, 189-192.

Durgin, F. H., Proffitt, D. R., Olson, T. J., & Reinke, K. S. (1995). Comparing depth from motion with depth from binocular disparity. *Journal of Experimental Psychology: Human Perception and Performance*, 21, 679-699.

Helmholtz, H. L. F. von. (1866/1911). *Handbuch der physiologischen Optik*. Leipzig: Voss. (J. P. C., Southhall, Ed. and Trans., *Helmholtz's Treatise on physiological optics* (Vol. 3). Rochester, NY: Optical Society of America).

Hershenson, M. (1999). *Visual space perception*. Cambridge, MA: The MIT Press.

Higashiyama, A, Ishikawa, T, Tanaka, K. (1990). Visual alleys as a function of instructions under informative and reduced conditions of viewing. *Perception & Psychophysics*, 47, 468-476.

Higashiyama, A., & Shimono, K. (2004). Mirror vision: Perceived size and perceived distance of virtual images. *Perception & Psychophysics*, 66, 679-691.

Higashiyama, A., Yokoyama, Y., & Shimono, K. (2001). Perceived distance of targets in convex mirrors. *Japanese Psychological Research*, 43, 13-24.

Johnstone, E. B. (1991). Systematic distortions of shape from stereopsis. *Vision Research.* 31, 1351-1360.

Kaplan, G. (1969). Kinetic disruption of optical texture: The perception of depth at an edge. *Perception & Psychophysics*, 6, 193-198.

Nakamizo, S., & Shimono, K. (2001). Depth scaling by the visual system with absolute distance information: A review. *Vision*, 13, 163-180. (Japanese with English abstract).

Ono, H., & Comerford, J. (1977). Stereoscopic depth constancy. In W. Epstein (Ed.), *Stability and constancy in visual perception: Mechanisms and processes*. (pp. 91-128). NY: John Wiley & Sons.

Shimada, T. (1975). Developmental studies on size constancy (I): Experiments on size constancy in the photographs with single comparison method. *Japanese Psychological Research*, 17, 203-212.

Smith, O. W. (1958). Judgments of size and distance in photographs. *American Journal of Psychology*, 71, 529-538.

Smith, O. W., & Gruber, H. (1958). Perception of depth in photographs. *Perceptual and Motor Skills*, 8, 307-311.

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