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Vision Research 45 (2005) 2895–2909
Vision Research
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Phenomenal regression to the frontal and natural picture

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Received 28 May 2004; received in revised form 27 May 2005

Abstract

The retinal image of a figure on a slanted picture is narrower than that of a figure on a frontal picture. In this study, the perceived width of various figures (horizontal line segments, ellipses, faces, symbolic faces, and artistic pictures) on a slanted picture plane was measured. The width of the figures was magnified or reduced in order to vary the naturalness of the original figures. The perceived width was found to be much closer to the width of the original figures than to the retinal images of the slanted figures. The width of the original figures was also found to affect the perceived width of the slanted figures; the perceived width was observed to be more biased toward a more natural width. On the other hand, the naturalness of the figures did not affect the perceived slant. These results suggest that the visual system corrected the width of the figures on a slanted plane, taking into the account naturalness or prägnanz as well as the slant.

Keywords: Shape perception; Slant perception; Shape constancy; Visual art

1. Introduction

When an object is seen from different views, the retinal images are different. However, when the 3-D shape of the object is perceived in everyday life, the difference usually goes unnoticed. This phenomenon is termed shape constancy. When a flat, circular cardboard is slanted, the retinal image is elliptic. If observers judge the shape only from the retinal image, the perceived shape should be the ellipse of the retinal image. However, Thouless (1931a, 1931b, 1932) found that the perceived shape is closer to the circle of the real object than to the retinal projection, even though it is not a circle and is biased toward the retinal projection. There also exists a tendency to keep the perceived shape constant despite the change of retinal images due to the slant of objects. Although none of the observers manifested the opposite bias toward the retinal image in studies conducted by Thouless (1931a, 1931b, 1932), it has been reported that the bias does occur under some conditions (e.g., Lichte & Borresen, 1967; Landauer, 1969). In other words, the distortion of the retinal image due to slant is overcompensated. This phenomenon is termed overconstancy.

When an object is lying on a slanted plane and perspective information regarding the figure itself is unavailable but information regarding its background is available, the shape of the physical object is perceived fairly accurately (Lappin & Preble, 1975; Olson, Pearl, Mayfield, & Millar, 1976; Wallach & Moore, 1962). This suggests that even when a figure drawn on a plane is viewed without binocular cues, the figure is accurately judged according to the slant of the plane. Furthermore, when the figure is binocularly viewed, shape constancy may also be achieved through binocular disparities of the figure itself by means of the mechanism of ordinary shape constancy. Thus, it follows that shape constancy plays a role in the perception of a figure drawn on a slanted picture.

Shape perception of a picture is more complicated than that of a figure on a plane. Figures on a picture

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doi:10.1016/j.visres.2005.07.001

are often the projection of a real-world object. The retinal image is also a projection of the picture. Thus, the retinal image becomes the projective image of a projective image, (i.e., a double projection). When the picture is seen from the same view as that of the drawer's viewpoint, the retinal image of the picture is the same as the projection of the real object. On the other hand (for example, if the picture is viewed obliquely), the retinal image is not the same as the projective image of the real object (see Cutting, 1988; Sedgwick, 1991 for a geometrical analysis of the distortion). In order to accurately perceive original objects in a slated picture, it is necessary to trace back the double projection; first the pictorial projection is recovered from the retinal projection using the slant of the picture, following which the real scene is recovered from the recovered pictorial projection. This is a double inverse problem.

In a crowded gallery, it is not always possible for individuals to obtain the frontal view of a picture; they are often compelled to view the picture from the side. Further, individuals often watch movies from the side seats of a theatre. The slant of the picture results in a distortion of the retinal image. For example, the retinal image of a slanted picture is narrower than that of the frontal picture. In most cases, however, individuals are insensitive to the distortion of a slanted picture. Two hypotheses have been presented to explain it. The first is the compensation hypothesis, and the second is the subthreshold distortion hypothesis (Busey, Brady, & Cutting, 1990). According to the compensation hypothesis, the visual system compensates for distortion in a slanted picture using the perceived slant of the picture, and individuals remain largely unconscious of this distortion. According to the subthreshold distortion hypothesis, the distortion of a moderately slanted picture is fairly small and occurs at a subthreshold level. Thus, this results in the distortion going unnoticed by individuals. The horizontal shrink caused by side viewing varies approximately as the cosine of the angle between the perpendicular of a picture and the line of sight. The horizontal dimension of the retinal image shrinks only approximately 14% from a 30° side view.

The controversy surrounding the two hypotheses still continues. There exists some evidence supporting the view that the slant of the slanted picture is not completely ignored during its perception (Perkins, 1973; Rosinski, Mulholland, Degelman, & Farber, 1980; Wallach & Marshall, 1986). Since the perception of a slanted picture is not solely dependent on the retinal image, this evidence does not conform to the subthreshold distortion hypothesis. However, some researchers have argued that these results can also be explained by ordinary shape constancy (e.g., Rogers, 1995) and that it is not necessary for the compensation mechanism to be used specifically for picture perception, i.e., the mechanism used to solve the double inverse problem. Therefore, it appears that shape constancy is involved in the perception of a slanted picture. The answer to this controversy could be found in a stance that lies in between the two hypotheses. A certain amount of compensation for distortion owing to slant does occur; however, the compensation mechanism does not completely solve the double inverse problem.

When a frontal object (for example, a frontal card) is drawn on a picture, the shape judgment of the object is essentially the same as that of the drawn image. For example, when a frontal round cardboard is drawn, the projective shape is almost the same shape as the original. Hence, in this case, the double inverse problem amounts to the single projection problem. (How to discern whether the depicted object is frontal with respect to the drawer is another difficulty.) Further, when the viewer judges the geometrical attributes of figures drawn on the picture, (for example, when the image shape drawn on a picture is judged), the task is essentially the same as shape judgment in studies pertaining to (implicit) shape constancy. In these cases, the shape constancy mechanism should work for the judgment of figures on a picture. Although some relation between shape constancy and perception of slanted pictures has been suggested (Wallach & Marshall, 1986), the exact role played by shape constancy in picture perception has not been sufficiently discussed. Individuals often view a picture or a screen in an oblique manner. For instance, students commonly view the blackboard obliquely from their side seats. Along similar lines, this study examines the shape constancy of an image drawn on a slanted picture.

Two types of hypotheses regarding shape constancy have been proposed; the first is the slant–shape invariance hypothesis (Koffka, 1935), and the other is the knowledge and prägnanz hypothesis. According to the former hypothesis, the retinal projection of a given form determines a unique relation between perceived slant and perceived shape.

A number of studies have shown that the conditions that reduce the effectiveness of slant cues diminish shape constancy. For example, a lower degree of constancy occurs under monocular viewing than under binocular viewing (Thouless, 1931b). When slant cues are eliminated (for example, by darkening the experimental room), little shape constancy is observed (Langdon, 1951, 1955a, 1955b; Beck & Gibson, 1955). These facts appear to support the slant–shape invariance hypothesis because the perceived slant should be reduced by monocular viewing or eliminating slant cues. A number of researchers have examined the validity of the slant–shape invariant hypothesis by comparing the perceived slant with the perceived shape; however, a rather loose link was found to exist between the two. Kaiser (1967) reported a correlation between error in shape judgment and error in slant judgment under monocular conditions, but not under binocular conditions. Oyama (1977) calculated the correlations between judged slant and slant corresponding to judged shape using Kaiser's data (not errors in slant and shape judgment) and found that they were moderate (between 0.6 and 0.75) under both monocular and binocular conditions. These relationships are not as strong as the slant–shape invariance hypothesis would have predicted. A number of studies have shown that perceived shape is not linked with perceived slant (e.g., Nelson & Bartley, 1956; Clark, Smith, & Rabe, 1956a, 1956b) or under limited conditions such as monocular viewing (e.g., Kaiser, 1967). Sedgwick (1986) examined studies on the slant–shape invariance hypothesis and concluded that a perceptual coupling between shape and slant is most likely to be observed under the conditions where most of the normal visual information for shape and slant has been eliminated. There seems to be no strong evidence that supports the slant–shape invariance hypothesis under normal visual conditions.

According to the original slant–shape invariance hypothesis, the perception of slant is generated from binocular disparity or perspective information and perceived slant determines the perceived shape. However, the slant may be determined by the known shape of an object and the retinal projection, and the path between the perceived shape and perceived slant may be reciprocal. The visual system may use some algorithms that combine projective shape with slant, or take slant into account in perceiving shape (Epstein, 1973; Massaro, 1973). Although the take-slant-into-account hypothesis also predicts a strong link between perceived slant and shape, the actual link was rather weak. The loose link is contradictory to the hypothesis.

A mere correlation between two variables does not imply causality from one to the other. There exist other possibilities due to which the correlation between perceived slant and shape can occur. For example, shape and slant are independently calculated from slant cues. In fact, shape can be calculated directly from the retinal projection and binocular disparity (e.g., Gillam, 1967). Oyama (1977) calculated and analyzed the partial correlations among physical slant, perceived slant, and perceived shape. The analysis suggests that shape and slant are independently computed under binocular conditions. This independent computation of shape and slant would be consistent with the moderate link between perceived slant and perceived shape.

The other hypothesis for shape constancy is the knowledge and prägnanz hypothesis according to which perceived shape is constructed from prior knowledge or prägnanz of the form. In other words, slanted shape is perceived to be a better form or a more familiar shape. Although perceived shape in the physical shape judgment of figures viewed without slant cues is usually close to the retinal shape, Beck and Gibson (1955) reported that some observers judged the shape of an elliptic retinal image as a circle under the conditions of few slant cues. Furthermore, King, Meyer, Tangney, and Biederman (1976) reported a perceptual bias toward symmetry in the judgment of slanted shape. There appears to be a tendency toward seeing a more stable, natural, and/or familiar organization. On the other hand, Thouless (1931a) and Moore (1938) reported that shape constancy was not affected by the physical shape being a circle or an ellipse. In their studies, only two aspect ratios were used, and the effect of an original width was not examined systematically. Although it is rather obvious that the shape is not solely judged from the familiarity, naturalness, and prägnanz, these factors may affect shape judgment. This paper examines whether the original width of a figure on a picture affects shape judgment. We will show below that the original width of a figure actually affects shape perception, while it does not affect slant perception. This clearly indicates that perceived shape is not a function only of the perceived slant and retinal projection. These results would therefore provide evidence against the slant–shape invariance hypothesis.

Most studies pertaining to shape constancy have used fairly simple shapes such as a circle, a rectangle, and a trapezoid. However, individuals usually view more complex pictures in galleries, movie theaters, and classrooms. Bearing this in mind, it would be more important to understand how complex figures on a picture are perceived. This study also examines the way in which the complexity of pictures affects the compensation process in the viewing of slanted pictures. In the experiment, the picture of a human face, real artistic pictures, as well as those with simple forms were used.

2. Experiment 1

This experiment examined how the perceived width of figures on a slanted picture plane varies with the slant of the plane. Particular focus was placed on the width of the perceived image because a large part of the distortion caused by the slant involves the decrease in width. Following the matching task, observers performed the slant judgment task.

2.1. Methods

Apparatus. Stimuli were generated using an AT compatible computer, and were displayed on a CRT display using a graphic card (Elsa ERAZOR III Lt). The refreshrate of the display was 120 Hz. The display was viewed through a pair of stereo shutter glasses (Elsa 3D-Revelator). The shutter glasses alternated the left and right eyes' views on the screen in synchrony with the shuttering of the glasses (transparent to opaque at 60 Hz). The interocular distance of each observer was measured, and stereo stimuli were generated using this measure. The viewing distance was 50 cm and the display size was 800 pixels × 600 pixels, subtending 39° × 29°. Observers viewed the display in a dark room with their heads supported on a chin rest. The background was a uniform blue field (11 cd/m^2, CIE $xy = (0.15, 0.066)$).

Observers. Five observers participated in this experiment, one being the author himself. The remaining observers were unaware of the purpose of the experiment. All the observers had normal or corrected normal acuity.

Stimuli. Four types of pictures were used; the face of a woman, a symbolic face drawn using lines, a circle (ellipse), and a horizontal bar. The original images were either horizontally magnified or reduced. Five types of width magnification factors were used, i.e., 0.64, 0.8, 1.0, 1.25, and 1.56. Magnification factors less than 1.0 indicate a width reduction, a magnification factor of 1.0 indicates the original width, and values more than 1.0 imply a widening of the original picture. The pictures used in this experiment are shown in Fig. 1. (Note that the original images of the female face were trichromatic, and not monochromic.) The bars, ellipses, and symbolic faces were drawn on a white square canvas. The size of the canvas was 320 pixels × 320 pixels, irrespective of the width magnification factors, subtending 16° × 16° for the frontal presentation. The canvas for the photo was actually a white wall, in front of which the woman was standing, and was slightly darker than that in the other pictures.

Situations in which the picture was rotated around the vertical axis passing through the center of the

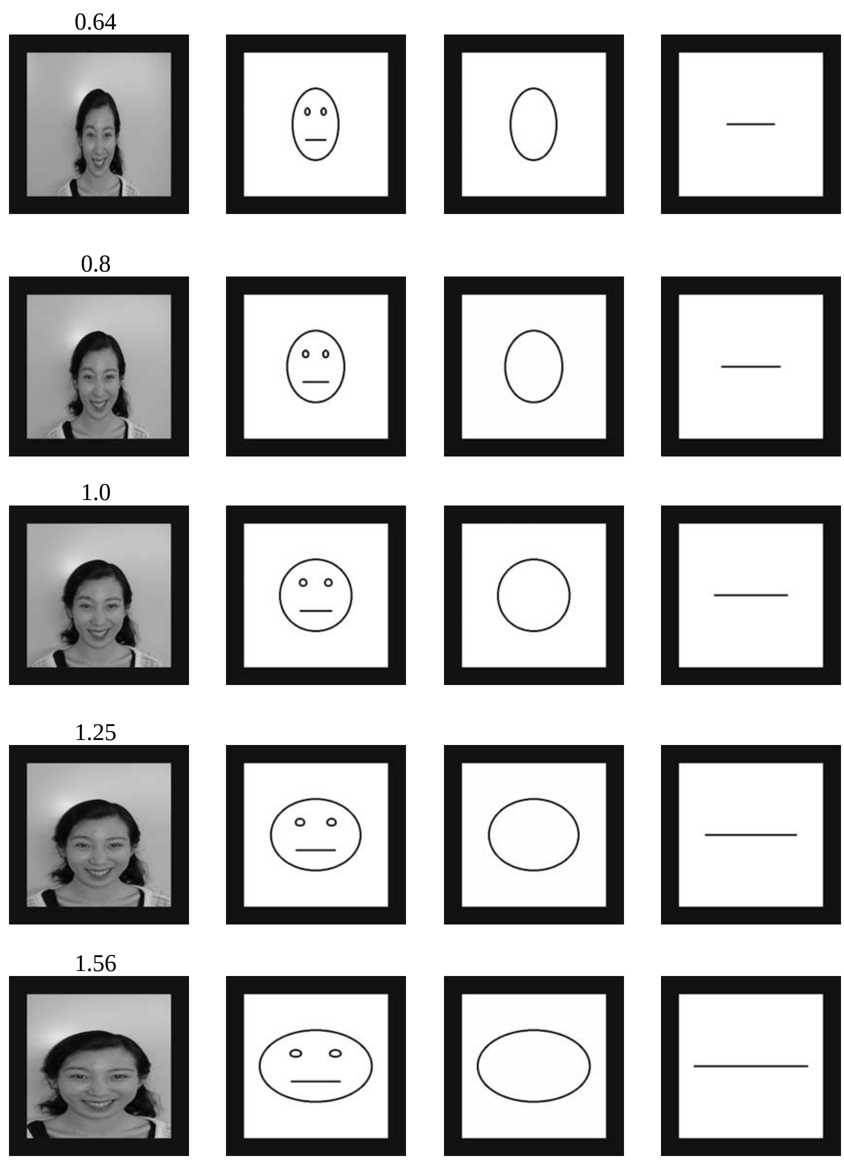

Fig. 1. Pictures used in Experiment 1. Four types of pictures were used: the face of a woman, a symbolic face drawn with lines, a circle (ellipse), and a horizontal bar. The image was horizontally magnified by a factor shown above. The pictures shown in this figure are monochromatic, but in the experiment the face picture was trichromatic.

picture were simulated and these were stereoscopically presented, as illustrated in Fig. 2. The slant of a picture was −60°, −30°, 0°, 30°, or 60° (a slant of 0° indicates a frontal picture, and a positive (resp. negative) slant indicates that the right side of the picture was farther (resp. nearer)).

Procedure: width matching. During a trial, a standard stimulus (a slanted stereo (or frontal) picture) was first presented for 2.0 s, following which the frontal comparison stimulus was presented. The comparison stimulus was the same as the original image, which was presented earlier as the standard stimulus. The width of the reference could be adjusted by pressing on the left or right mouse button. (The width was reduced or magnified 2.5% by one click.) The observers' task was to match the width of the comparison stimulus to that of the standard slanted (or frontal) picture. When the observers pressed the middle mouse button, the standard stimulus was presented again for 2.0 s, following which the comparison stimulus with the adjusted width was presented. Once the observers had adjusted the width of the comparison stimulus by pressing the left or right button, the trial continued. When an observer pressed the middle mouse button without making any further adjustments, indicating satisfaction with the matching, the next trial began. The following was the instruction provided to the observers: "Please adjust the width of the frontal figure so that the width of the frontal figure would be felt equal to that of the slanted figures presented just before, i.e., please adjust the width to the width that you would observe if the slanted picture was brought back to the frontal position. Please pay attention to the illustrated figures, and not to the width of the white canvas. There are no desirable responses. Please adjust the width based on what you perceive, and do not respond using inferences". The last part of the instruction was included to ensure that the observers did not perform the task by making conscious inferences. There were 100 stimulus conditions: four types of pictures × five width magnification factors × five slant angles. Thus, a session consisted of 100 trials of different stimulus conditions. The order of the trials was randomized. Each observer participated in four sessions for this task.

Procedure: slant judgment. After the matching task, observers performed the slant judgment task. For a trial, a slanted (or frontal) picture was first presented for 2.0 s, and then two line segments, as shown in Fig. 3, were presented. (The slanted picture was presented once in every trial and was not repeatedly exposed like in the width matching task.) The comparison stimulus represented a top view of the display plane and the picture. A horizontal line segment, representing the top view of the display, was fixed. Another line segment represented the

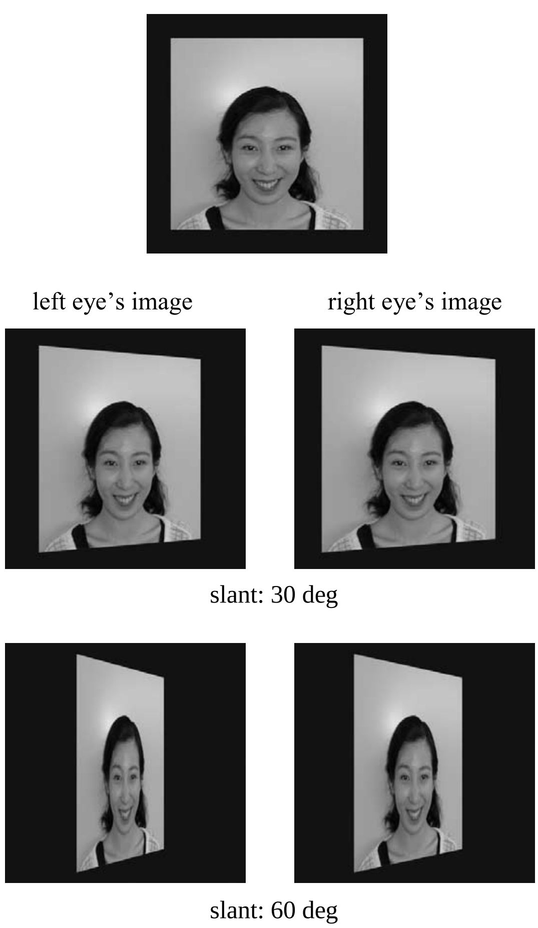

Fig. 2. Examples of stimuli of frontal and slanted faces. Note that the right and left eyes' images for slanted pictures were different, and the images were presented stereoscopically.

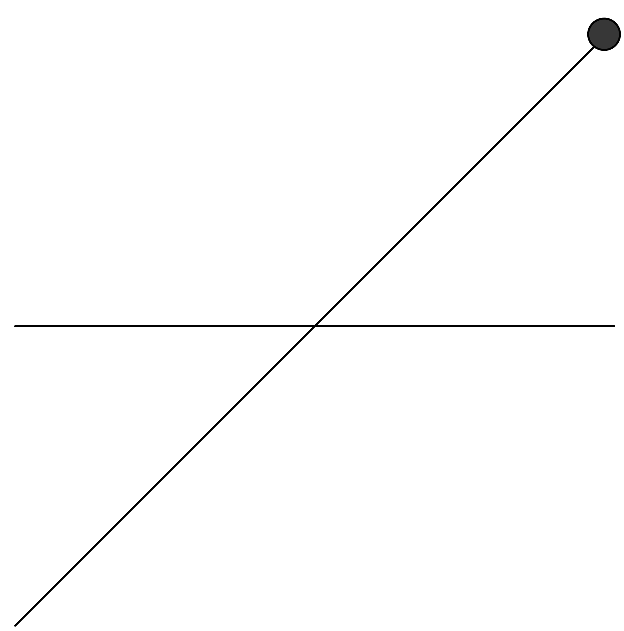

Fig. 3. The comparison stimulus for slant judgment. A horizontal line segment represents the top view of the display. Another line segment represents the top view of the picture, and a red dot was attached to one end of it. The dot could be moved with the mouse.

top view of the picture, and a red dot was attached to one end of it. The red dot could be moved by using the mouse. The observers were instructed to match the angle between the two lines to the angle between the display and the slanted (or frontal) picture that was presented just before. In the matching task, there were 100 stimulus conditions for this task just like in the matching task. For each condition, four trials were conducted. The observers participated in a session comprising 400 trials. The order of the trials was randomized.

2.2. Results

Width matching. In order to evaluate the degree of shape constancy, a ratio of perceived width to actually simulated width (in the 3-D space) was used. This ratio was termed "PSR" (perceived-to-simulated width ratio). If the perceived width is based on the retinal images of the left (resp. right) eyes, the ratio should be 0.56 (resp. 0.45) for a 60° slant, 0.9 (resp. 0.84) for a −30° slant, 0.84 (resp. 0.9) for a 30° slant, and 0.45 (resp. 0.56) for a 60° slant. (Interocular distance was assumed to be 6.2 cm for the calculation.) It should be noted that the retinal image for the left eye differed from that of the right eye. If shape constancy is perfect, PSR is 1.0. A PSR larger than 1.0 indicates overconstancy.

Since no systematic difference was observed between the positive and negative slants, the data were collapsed across the signs of the slant. The PSRs of one observer and those averaged across all the observers are plotted in Figs. 4 and 5 as a function of the width magnification factor of the original image. The average PSRs for 60° were larger than 0.8 in all the conditions. The PSRs for a 60° slant of the other observers were close to or greater than 1.0; none of the PSRs were close to the predictions based on the retinal image. These results indicate that the observers did not perform the matching task by depending solely on the retinal images.

Regarding the face, symbolic face, and the ellipse, the mean PSRs decreased with the width magnification factor for slants of 30° and 60° while they varied little for a slant of 0°. With respect to the horizontal bar, the PSRs changed little with the width magnification factor. The PSRs for the face, symbolic face, and ellipse were larger than those in the conditions of width magnification factors of 0.64 and 0.8 for 30° and 60° slants, i.e., overconstancy occurred in these conditions. However, underconstancy tended to occur for a magnification factor of 1.56. These tendencies were also observed in the results of the individual shown in Fig. 4. (All the other observers exhibited similar tendencies.)

The PSRs for each picture type shown in Fig. 5 were subjected to a repeated-measure two-way (slants of 0°, 30°, 60° × 5 width magnification factors) analysis of variance[1]. There were significant main effects of the width magnification factor for the face picture ($F(4,16) = 17.7$, $p < .01$), for the symbolic face ($F(4,16) = 10.1$, $p < .01$), and for the ellipse ($F(4,16) = 7.2$, $p < .01$). The main effect of the slant was found to be insignificant. There were sig-

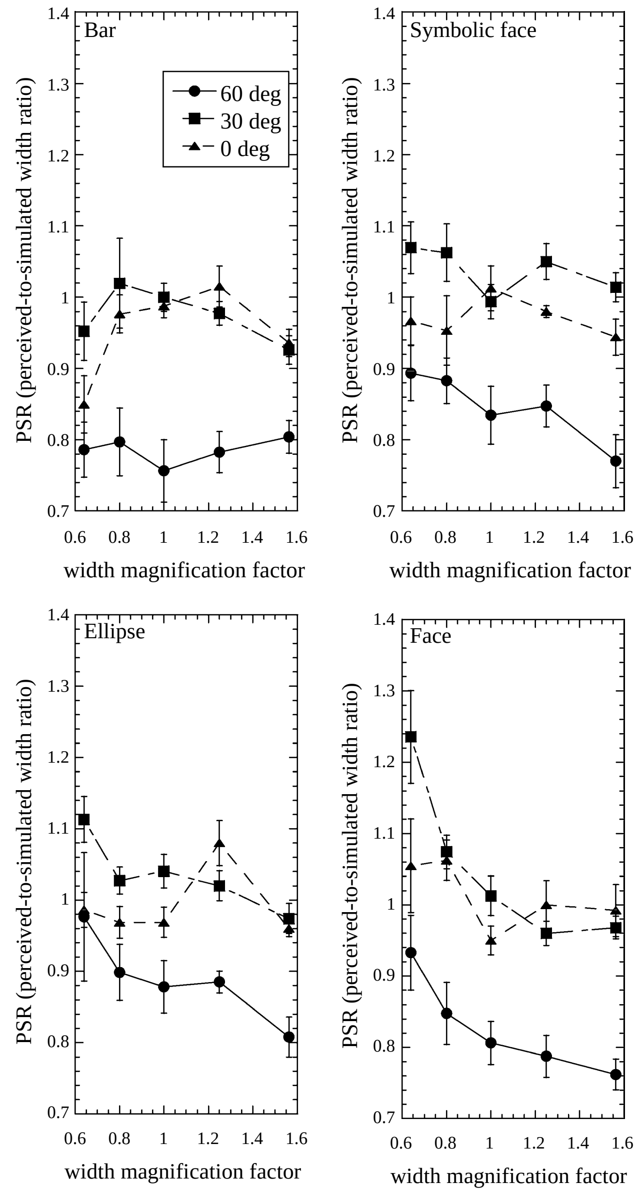

Fig. 4. Results of one of the observers for width matching in Experiment 1. PSR (perceived-to-simulated width ratio) is plotted as a function of the width magnification factor independently for different types of pictures. The error bars show ±1 SEs calculated from the results of four trials in a condition.

[1] A three-way ANOVA (slants × width magnification factor pictures) was also conducted. The results of this three-way ANOVA were essentially the same as those of the two-way ANOVA. However, following the results of the three-way ANOVA are difficult because the results of several simple-effect analyses and post hoc analyses are required for a significant three-way interaction. Thus, the results of the two-way ANOVAs has been presented.

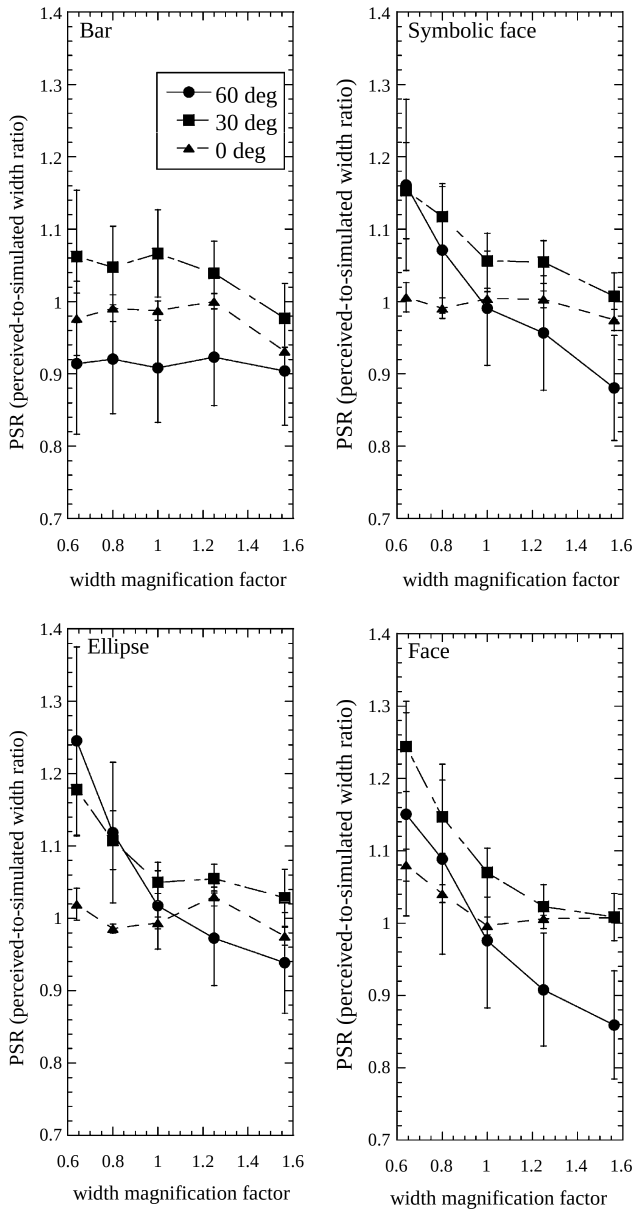

Fig. 5. Average PSR of the five observers in Experiment 1 is plotted as a function of the width magnification factor independently for different types of the pictures. The error bars show ±1 SEs calculated from the results of the five observers. Note that although the error bars indicate the degree of individual differences, they do not reveal the reliability of the effect of the width magnification factor because a repeated-measure experimental design was used.

nificant interactions of slant × width magnification factor for the face picture ($F(8,32) = 7.5$, $p < .01$), for the symbolic face ($F(8,32) = 8.0$, $p < .01$), and for the ellipse ($F(8,32) = 7.2$, $p < .01$). Regarding the face, symbolic face, and ellipse, the simple main effects of the width magnification factor were significant for 60° and 30° slants ($F(4,48) > 4.0$, $p < .01$ for the three pictures) but were insignificant for 0° slants ($F(4,48) < 2.0$). With respect to the bar, no effects were found to be significant at a significance level of 5%. However, there was a marginally significant main effect of the slant ($F(2,8) = 3.6$, $p = .075$), and there was a marginally significant interaction of slant × width magnification factor ($F(8,32) = 2.16$, $p = .058$). The simple main effect of the width magnification factor was significant for a 30° slant ($F(4,48) = 3.5$, $p < .05$) but insignificant for 0° and 60° slants ($F(4,48) < 2.0$). A Ryan's post hoc test indicated that for a 30° slant, there were significant differences between a width magnification factor of 1.56 and the other conditions; however, apart from these, no significant differences were observed between any other pair.

Slant judgment. The results of one of the observers are shown in Fig. 6. The horizontal axis indicates the slant that was actually simulated, and the vertical axis indicates the perceived slant. If the perceived slant is consistent with the simulated slant, the data points will fall on the line with a slope of 1. The functions of the perceived vs. simulated slant have slopes that are lower than 1.0, which indicates that the slant perceived by the observer was slightly smaller than that of the simulated slant. Two out of the five observers underestimated the slant, and slant judgment for the three other observers was fairly accurate. The results averaged across all the observers are shown in Fig. 7. The average perceived slants were slightly smaller than the simulated ones. There were no significant differences in slant judgment between the different types of pictures and different width magnification factors.

2.3. Discussion

The findings of the experiment are as follows: (1) the matched width is much closer to the width of the actually simulated image than that of the retinal image. (2) The width of the image affects the perceived width of slanted pictures, with the exception of that of a very simple form such as a horizontal line. The mean matched faces for a slant of 60° and for width magnification factors of 0.64 and 1.56 are shown in Figs. 8 and 9. The figures show that the reduction of the width due to the slant is compensated for fairly well. However, they also demonstrate that the perceived width is biased toward a more natural width. The difference in perceived width was not caused by a difference in the perceived slant because there was little difference in the perceived slant among different width magnification factors.

The results of this experiment were not consistent with the slant–shape invariance hypothesis. The slant perception was not varied for different width magnification factors, while the matched width was dependent on the width magnification factor for the pictures of the ellipses, symbolic faces, and photographic faces. It should be noted that for the horizontal bar, a reliable decrease of PSR was not seen with an increase in the width magnification factor. A bar does not have a natural or familiar length, while the ellipse or the face does possess a natural,

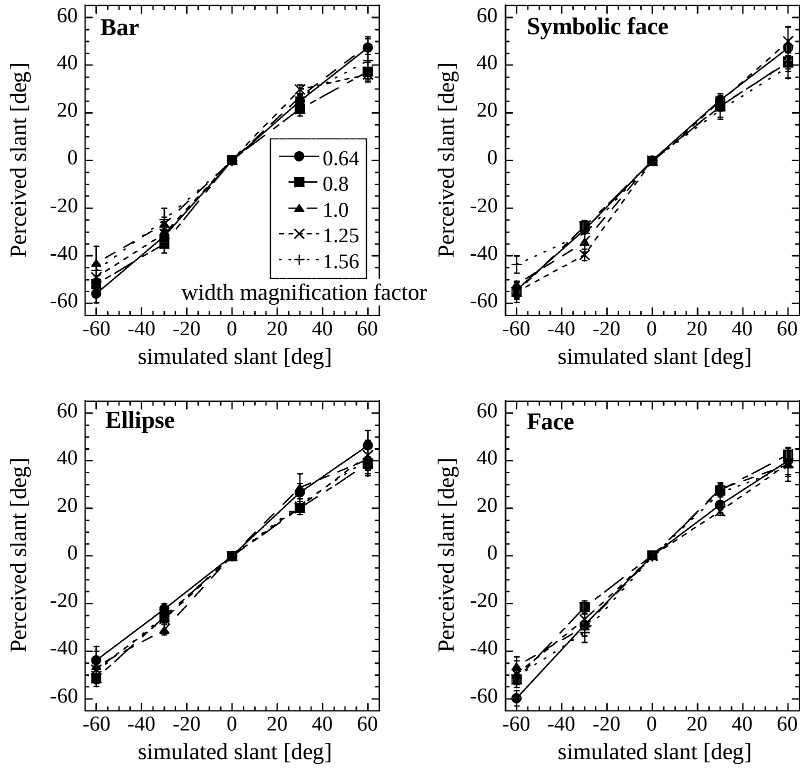

Fig. 6. Results of slant judgment in Experiment 1. The perceived slant for an observer is plotted as a function of the simulated slant. If the perceived slant is consistent with the simulated slant, the data points lie on the line with a slope of 1. This observer underestimated the slants slightly. The error bars show ±1 SEs.

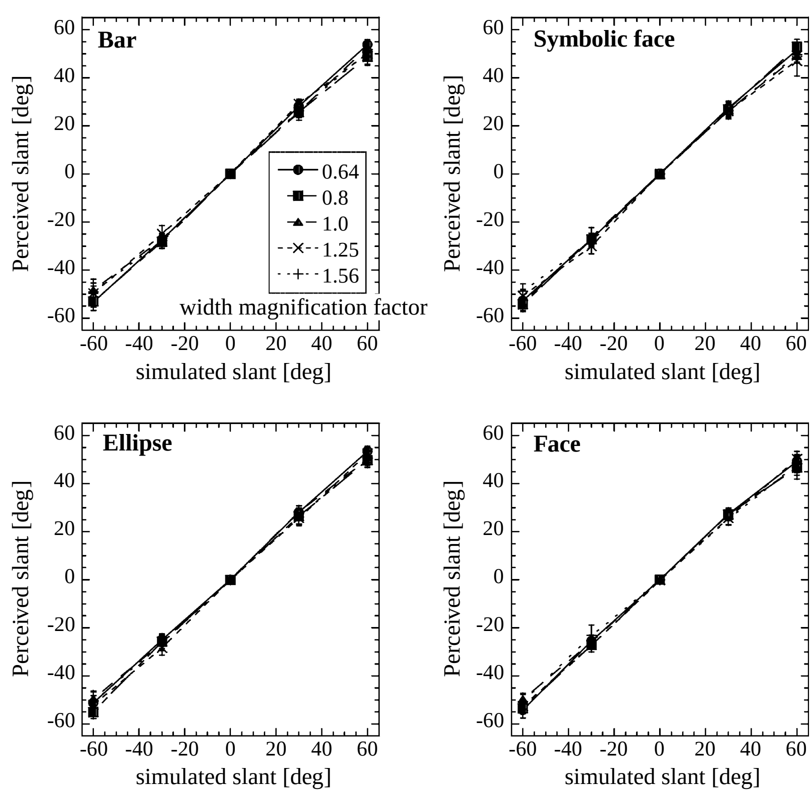

Fig. 7. Results of slant judgment in Experiment 1. The perceived slant averaged across all the observers is plotted as a function of the simulated slant. The error bars show ±1 SEs.

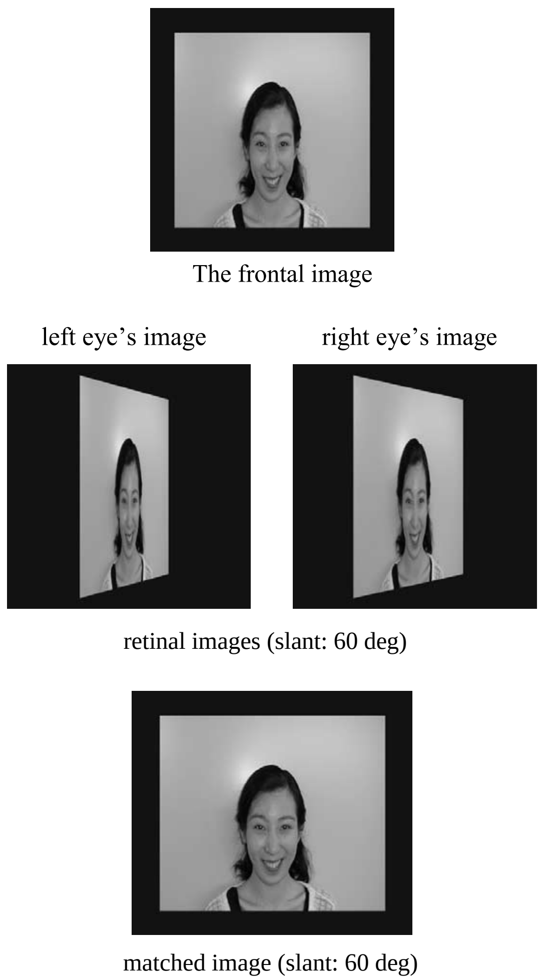

Fig. 8. The frontal image of the face stimulus for a magnification factor of 0.64 is shown in the upper portion. The left and right images of the picture slanted by 60° are shown in the middle section. The mean matched image is shown in the lower part.

familiar, or good width. The results of this experiment suggest that naturalness, familiarity, and/or prägnanz affects the degree of shape constancy. It must be noted, however, that familiarity and/or prägnanz cannot explain all the results in this experiment. The perceived width was not always the most natural one; on the other hand, it tended to vary with the width magnification factor.

In order to examine the relationship between the perceived slants and perceived widths, the slants corresponding to the perceived widths were computed[2]. (It must be noted that under the assumption of the slant–shape invariance, the slant can be calculated from the retinal width and perceived width.) The perceived slants were plotted as a function of the slants corresponding to the perceived widths in Fig. 10. If the slant–shape invariance hypothesis holds, the data points should be on the diagonal line with a slope of 1. However, most data fall below the diagonal line. Further, for the ellipse, symbolic face, and photo face, the points shift from left to right with an increase in the width magnification factor. Although the data points for a 60° slant are shifted slightly upward with the increase in the width magnification factor for the ellipse and photo face, the effect on the perceived slant was observed to be not statistically significant. In addition, the upper shifts are much smaller than the horizontal shifts. On the other hand, for the bar, all the data points except one data point are cluttered around the two points (56°, 50°) and (34°, 27°)[3].

[2] It is also possible to convert the perceived slants to the corresponding widths, and the perceived widths are plotted as a function of those corresponding to the perceived slant. However, it is difficult to observe the effect of the width on the degree of shape constancy directly from this plot since the width itself was varied in this experiment. Hence, the perceived widths were converted to the corresponding slants.

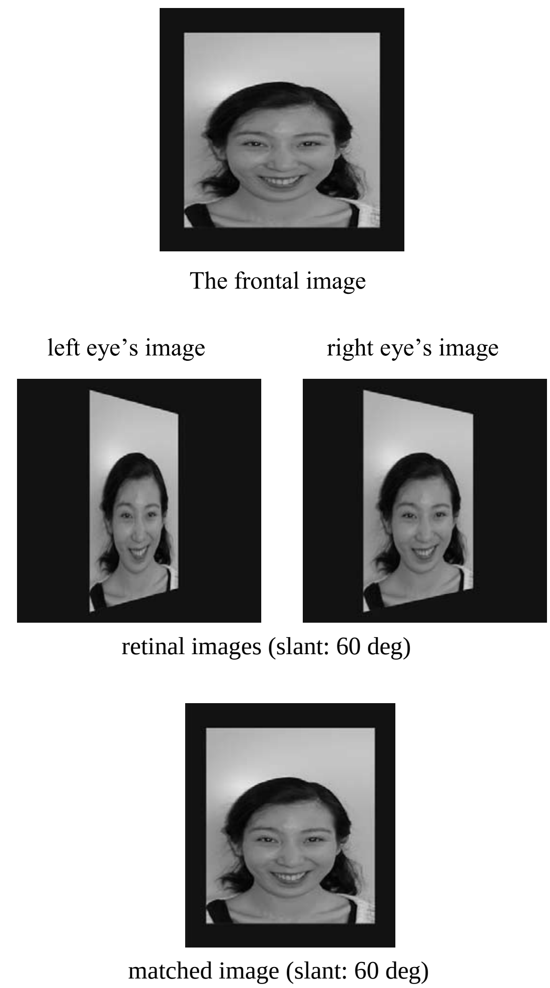

Fig. 9. The frontal image of the face stimulus for a magnification factor of 1.56 is shown in the upper portion. The left and right images of the picture slanted by 60° are shown in the middle. The mean matched image is shown in the lower part.

[3] The point of a 30° slant for a 1.56 magnification factor is shifted horizontally from the other points of a 30° slant. This shift corresponds to the significant difference between a width magnification factor of 1.56 and the others for a slant of 30°, as reported in Section 2.2.

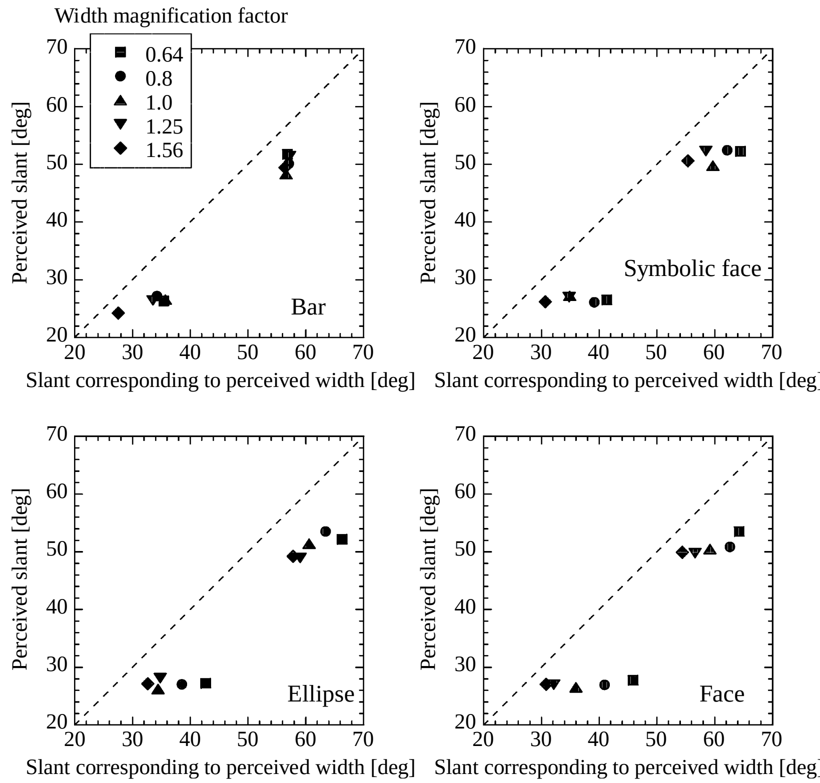

Fig. 10. The perceived slant was plotted as a function of the slant corresponding to the perceived width.

Hence, the effects of the width magnification on the perceived width for the circle, symbolic face, and photo face cannot be attributed to the effect of the width magnification factor on the perceived slant. Thus, these results are inconsistent with the slant–shape invariance hypothesis.

It is reasonable to state that the most natural ellipse is a circle, and that the most natural face is one with an average width. However, the natural width of the symbolic face is unclear. When it is regarded as a face, the natural shape should have an elliptic contour. If the surrounding line is focused on, the natural shape is a circle. If the natural shape for the symbolic face is elliptic and the perceived shape regresses to the natural picture, the results for the symbolic shape should differ from those for the ellipse and the face because the width magnification factor of the regression point for the symbolic face is different from that for the ellipse and face. On the other hand, if the observers focus on the surrounding line of the symbolic face, the results should not differ for the three figures. As shown in Fig. 5, the results for the three figures were very similar. This suggests that the observers judged the width of the symbolic face by focusing on the surrounding contour. The observers were instructed to adjust the natural width for the four pictures just after the experiment. For all the observers, the adjusted widths for all the four figures were those with a magnification factor of approximately 1. (After the task, some observers reported that there was no natural width for the bars.) These results are consistent with those obtained in the width matching task.

Simulated width/height ratios have been shown to have a significant effect on the perception of elliptic pictures on a slanted canvas. Further, King et al. (1976) and Beck and Gibson (1955) reported that familiarity or prägnanz affects shape perception of slanted objects. Thouless (1931a) and Moore (1938), however, reported that the physical width/height ratios have little effect on the shape perception of slanted ellipses. There are no clear reasons till date, explaining why the above researchers did not evidence the familiarity effect. Further research is required to clarify the discrepancy between the studies.

There were no systematic differences observed in perceived width between the ellipse, symbolic face, and the photo face. This suggests that complexity has little effect on the perceived width of slanted pictures. On the other hand, Campione (1977) reported that complexity affects shape constancy, and shape constancy is inversely proportional to the degree of simplicity. However, Campione's definition of complexity with respect to figures appears to be somewhat inconsistent with the impression of the researchers of this study; Campione (1977) considered a square to be more complex than a circle, both of which appear relatively simple. Although Campione (1977) explains the results in terms of complexity, they can also be explained through the high constancy of regular shape (Sedgwick, 1986). There was little shape constancy for an amoeba-like shape, but a much higher degree of shape constancy for the other shapes such as a square, circle, and triangle (Campione, 1977). This result seems to be consistent with the results of this experiment. Since the amoeba-like shape does not have natural width, the difference between this type of shape and the regular shape in Campione's study may be comparable to the difference between the bar and the other pictures in this study.

There are several types of shape judgments. One is the judgment of physical shape (objective shape) and another is the judgment of retinal shape (projective shape). The judgment of phenomenal or apparent shape has also been carried out. While judging phenomenal shape, observers are asked to judge the shape based on the appearance, a spontaneous impression, or "the way it looks". A number of researchers have suggested that this task is extremely ambiguous, and they doubt whether phenomenal shape judgment is truly possible (e.g., Sedgwick, 1986; Todorovic, 2002). There is some evidence suggesting that observers in the phenomenal task adopt either retinal or physical shape judgment and even an individual tends to switch between the two criteria in each trial (e.g., Lichte & Borresen, 1967; see Sedgwick, 1986 for review). Observers were instructed to judge the width if the slanted picture was brought back to the frontal plane. They were also asked to follow their phenomenal impression. Thus, the instructions can be considered as being in between the phenomenally focused and the physically focused instructions.

It has been suggested that since ambiguous instructions lead to combined results of retinal and physical criteria, a clear projectively or physically focused instruction should be provided to the observers (e.g., Todorovic, 2002). However, the strong physically focused instruction may encourage observers to use conscious inference. For example, the observers' responses may be cognitively biased to some extent to increase the accuracy of their responses. In addition, a degree of cognitive bias may differ to quite a great extent across individuals. The strong physically focused instruction still remains ambiguous at this point. Although the phenomenally focused instruction does not necessarily ensure that the observers did not use conscious inference, it should serve to reduce the possibility of the use of conscious inference.

Since the observers in this experiment were instructed to attend to the contents and not to the width of the white canvas, they might have attended largely to the contents depicted in the display, especially if they were confused by the physically and phenomenally mixed instruction, which might have been somewhat ambiguous. This might have caused the observers to consciously match the width so that the picture would look natural. However, it is unlikely that they used such a strategy. The observers accurately matched the width of the pictures for a 0° slant, and a degree of constancy was fairly high for the 30° and 60° slants, so much so that overconstancy was observed in many conditions. These results indicate that the observers knew that the physical width should be matched. Further, naturalness was never mentioned prior to the task. In addition, the very reason behind the phenomenally focused instruction was to discourage the observers from using conscious strategies. Nevertheless, the possibility that the observers adopted this kind of strategy could not be completely denied. Since instructions highly affect the performance of shape constancy, different results might be obtained with different instructions. Further studies are required to explore the effects of instruction on how naturalness is used in shape constancy.

3. Experiment 2

In Experiment 1, the stimuli consisted of a photo of a face and simple forms. Shape constancy for a fairly simple shape such as a triangle or ellipse has been examined in most studies. However, in a movie theatre, individuals frequently view a wide variety of scenes in an oblique manner. Even in galleries, the variety of complex paintings often tend to be displayed such that individuals are required to view them in an oblique fashion. In Experiment 2, various real artistic pictures were used and their width perception was investigated when the pictures were viewed obliquely.

3.1. Methods

Two sets of digitized artistic pictures were used. One set (Set I) consisted of artistic portraits: (A) "La Joconde" ("Mona Lisa") by Leonardo da Vinci, (B) "Self-Portrait" of Vincent van Gogh (1889, Musee d'Orsay, Paris), (C) "Girl with a Pearl Earring" by Jan Vermeer, and (D) Saint Mary's face, one part of "Holy Family with St. Anne" painted by El Greco, shown in Fig. 11. The face of Saint Mary is very thin, which is a characteristic of mannerism. This picture was used to examine the effects of the elongation of faces as has been shown in Experiment 1. The other set of pictures (Set II) was selected from various categories: (E) "The Grand Canal, Venice" by J.M.W. Turner, (F) "Sunflowers" by Vincent van Gogh (January 1889), (G) "Still Life with Apples" by Paul Cezanne, and (H) "Fragment 2 for Composition VII" by Wassily Kandinsky. The pictures were on a square white canvas. The size of the canvas was the same as in Experiment 1. Pictures were slanted, together with the canvas.

First, the observers performed the width-matching task for the pictures belonging to Set I. For Set I, the

Fig. 11. A picture used in Experiment 2. Saint Mary's face, which comprises one part of "Holy Family with St. Anne" painted by El Greco. This figure is monochromatic, but the picture used in Experiment 2 was trichromatic.

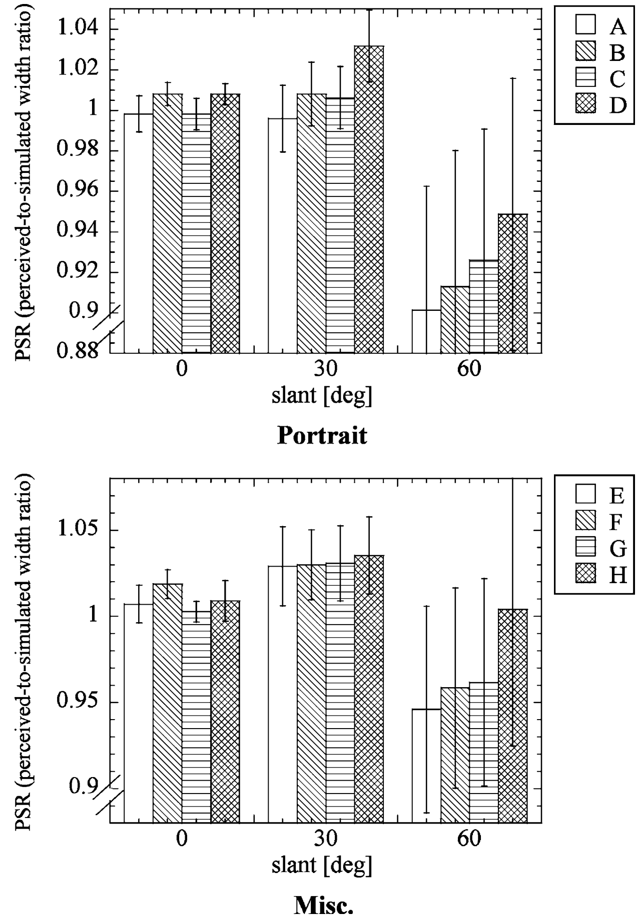

Fig. 12. Results of width matching in Experiment 2. PSR (perceived-to-simulated width ratio) is shown. The error bars show ±1 SEs. (A) "La Joconde" ("Mona Lisa") by Leonardo da Vinci, (B) "Self-Portrait" by Vincent van Gogh (1889, Musee d'Orsay, Paris), (C) "Girl with a Pearl Earring" by Jan Vermeer, and (D) Saint Mary's face, one part of "Holy Family with St Anne" painted by El Greco. (E) "The Grand Canal, Venice" by J.M.W. Turner, (F) "Sunflowers" by Vincent van Gogh (January 1889), (G) "Still Life with Apples" by Paul Cezanne, and (H) "Fragment 2 for Composition VII" by Wassily Kandinsky.

observers were told to pay attention to the width of the faces drawn in the pictures. Then they performed the width-matching task for the pictures in Set II. For the latter, they were asked to judge the width on the basis of the impression of the entire picture. Finally, they performed the task of slant judgment for all the eight pictures used for the width matching. The other points were the same as in Experiment 1.

Seven observers participated in this experiment. One of the observers in this experiment was the author. The other observers were unaware of the purpose of the experiment, and had not participated in Experiment 1.

3.2. Results

The results are shown in Fig. 12. The PSRs (ratios of perceived width to simulated width) for Set I were close to 1.0 for a slant of 30°. For a slant of 60°, they were approximately 0.9, i.e., the observers underestimated the width of the pictures. For Set II, PSRs were slightly larger than 1.0° for a 30° slant and slightly smaller than 1.0° for a 60° slant except for picture H. Considering that the width of the pictures reduces by about 50% for a slant of 60°, compensation for width reduction due to the slant was fairly good, although there were substantial individual differences as shown by the error bars.

A repeated-measure two-way (picture (A, B, C, and D) × slant (0°, 30°, and 60°)) analysis of variance for Set I showed a marginally significant main effect of picture ($F(3,18) = 2.65$, $p = .08$). The main effect of slant and the interaction of the picture and the slant was not significant ($F(2,12) = 0.94$, and $F(6,36) = 1.67$, respectively). However, a one-way analysis of variance for each slant showed significant main effects of the picture for 30° and 60° slants. The main effect of the picture for a 0° slant was not significant. A Ryan's post hoc test showed significant differences between picture D and the other pictures (A, B, and C) for a 30° slant, and significant differences between D and A, and between pictures D and B for a 60° slant at a 5% significance level. This indicates that the PSR of Picture D (the face picture of El Greco) was smaller than that of the other pictures for slants of 30° and 60°. For Set II, the two-way (picture × slant) ANOVA and one-way ANOVAs for each slant showed no significant effects. For a 60° slant, the PSR appeared to be larger for picture H than for picture E. This was because an observer adjusted the width of picture E for a slant of 60° to a large value. If this

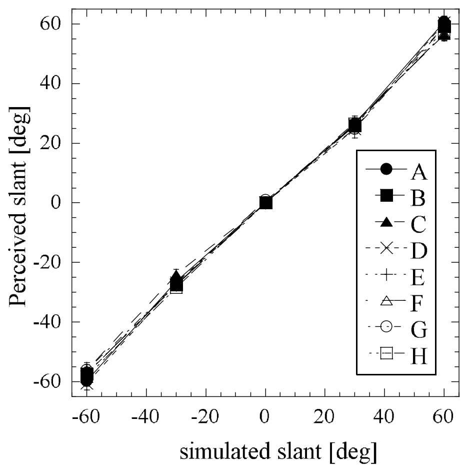

Fig. 13. Results of slant judgment in Experiment 2. The average perceived slant across all the observers is plotted against the simulated slant. The error bar shows ±1 SEs. (Most of the error bars are smaller than the symbols.) To find out what A, B, ..., H stand for, see the caption of Fig. 12.

particular data are removed, the apparent difference will disappear.

The results of slant judgment are shown in Fig. 13. There was little difference in slant judgment between the pictures.

3.3. Discussion

It has been shown that the distortion occurring due to the slant, owing to the characteristics of mannerism in the picture by El Greco, was more compensated for than the other face pictures. However, this was not caused by a difference in the perceived slant for different pictures. There was little difference in slant judgment between the pictures. This implies that when the width of an original picture is unnatural, the phenomenal percept of the width is biased toward the natural width of the pictures. Thus, a slanted portrait is phenomenally regressed to a more natural picture.

Although the naturalness of the width has a significant effect on the width perception of the pictures, this effect is fairly small. The difference between picture D and the other face picture was less than 5%. Moreover, for a slant of 60°, the perceived width was about 90% of the original pictures. With the exception of extremely distorted pictures, the effect of prägnanz or naturalness could be stated as being negligible. This suggests that people perceive the width of most pictures fairly accurately, irrespective of the view, as in the case of viewing a picture from the side in a crowded gallery.

4. General discussion

This study has examined the shape constancy of figures drawn on a picture. It was found that the perceived width for slanted pictures was much closer to that of the real images than to the width of the retinal projections. In addition, the naturalness or prägnanz of pictures affects width perception; the perceived width of slanted pictures tends to be phenomenally regressed to their natural width. However, the phenomenal regression to natural pictures does not explain all the results in this study. If it were the case, perceived width would be constant regardless of the width of the original images; however, perceived width varied with that of the original images, as illustrated in Figs. 8 and 9. Regardless of the width of the original images used in this study, the width reduction due to the slant of the images was compensated for reasonably well. Furthermore, under some conditions, overconstancy occurred. These results suggest that the visual system compensates for width reduction of a slanted picture to a considerable degree using only the slant information of a picture.

The width of the original figures affected shape perception, though it did not affect slant perception. This result contradicts the slant–shape invariance hypothesis, which claims that perceived shape is a function of only the retinal shape and perceived slant. Furthermore, there exists substantial evidence that perceived shape does not have a unique relation with the perceived slant and retinal projection. In defense of the slant–shape invariance hypothesis, some researchers have argued that perceived slant may not reflect the registered slant actually used for shape computation in the visual system (e.g., Hochberg, 1971). Naturalness may affect registered slant but not perceived slant. If registered slant cannot be measured by perceived slant, however, it will be impossible to test the registered slant–shape hypothesis (e.g., Sedgwick, 1986). (Moreover, any possible results may be explained by the registered slant–shape hypothesis because any variable may affect the immeasurable registered slant.)

The visual system may compute shape using naturalness, familiarity, and/or prägnanz, as well as the slant and retinal projection. One candidate of shape may be computed from the slant and retinal projection, and the other may be computed from naturalness. The two candidates are combined in some ways, as suggested by the weak-fusion model for depth cues (Young, Landy, & Maloney, 1993; Landy, Maloney, Johnston, & Young, 1995). An alternative possibility is that the visual system computes slant and shape independently using several sources of information in different ways. In any case, the process may be interpreted as the optimal estimation of shape using several cues for slant and shape. Further computational and empirical studies are required to reveal how the visual system uses naturalness for the computation of slant and shape.

4.1. Perception of slanted pictures

Goldstein (1987) proposed that three attributes of pictorial space should be distinguished in order to discuss the perception of slanted pictures, i.e., layout, orientation, and projection. He demonstrated that the layout in a picture is independent of its view. On the other hand, perceived orientation relative to the picture plane is dependent on the position of the observer. The orientation of a pointing rod or a portrait's gaze appears to rotate so that a constant direction is maintained relative to the observer (see also Koenderink, van Doorn, Kappers, & Todd, 2004). These findings suggest that the visual system compensates for distortion in different ways with regard to different attributes of slanted pictures (Cutting, 1988).

Perception of a projection in pictorial space would be regarded as the perception of a shape drawn on a picture. Hence, studies on this attribute would be relevant to the present study. Busey et al. (1990) examined the third attribute of pictorial space, projection. Face pictures with a slant around the vertical axis of 22° were viewed as no more distorted than frontal faces. However, 44° slanted pictured faces appeared more distorted than the original faces. They argued that part of the reason why an individual can look at moderately slanted pictures without perceptual interference is that the distortion is within the bounds of acceptability. They also reported that an image of a slanted frame attached to the slanted picture did not reduce the perceived distortion and that distortion is not compensated for by the perceived slant. However, they did not confirm whether their observers perceived the slant accurately. Even if the slant is judged accurately from the frame cue, slant perception is much less vivid when the slant is induced only by the frame cue than when the slant is induced by binocular disparities as well as by the frame. It has been reported that the degree of shape compensation is smaller for monocular viewing than for binocular viewing (e.g., Kaiser, 1967; Thouless, 1931b). The observers in their study seemed to view their stimuli binocularly with no binocular disparity although the description regarding the points was unclear. Assuming that this is the case, the stimuli are not so effective in the inducement of slant perception since the binocular disparities indicate the frontal picture. This may be the reason why they did not find evidence for compensation of distortion in slanted pictures while it was found in this study. This suggests that binocular disparities could play a role in compensation.

There are a number of studies that support the compensation hypothesis. It has been reported that observers have tendencies to see the frontal shape and not the retinal shape even when a shape is viewed in a slanted picture. However, it has been suggested that there does not exist a need for compensation mechanisms specific to slanted pictures to explain these results; they can be explained by normal shape constancy (e.g., Rogers, 1995). The retinal image of a picture is the projection of the picture that may also be a projection. When individuals view a picture obliquely, the retinal image is distorted from the picture, and they have to track the double projection in order to see the picture accurately. The visual system must use the slant of the picture to recover the picture image, and must then recover the 3-D shape from the picture ignoring the slant. This implies that the picture must first be regarded as a planar object, and then as a projective image. The duality of a picture makes double tracking very difficult. The evidence for the compensation hypothesis in previous studies shows that the perception of a slanted picture does not depend solely on the retinal images. Although it is unlikely that the visual system completely tracks the double projection for a slanted picture, the results in this study suggest that shape constancy should work for perception of slanted pictures. Further research is needed to reveal what roles shape constancy plays in the perception of slated pictures.

Individuals tend to be insensitive to distortion in slanted pictures. This study has revealed that perceived shape on a slanted picture phenomenally regress to the natural picture. A possible reason for the insensitivity to distortion in slanted pictures is that observers adopt a more natural interpretation (perhaps unconsciously) and diminish the impression from the distorted retinal images of slanted pictures.

Acknowledgments

I thank Yuko Ishisaka for assistance in the preliminary experiments of this research. The major part of this work was carried out while the author was working at Chiba University.

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