Appendix A

Review of the Experimental Studies of Perception of Pictures

This is a brief exposition of experiments described by various authors. It is not in any way complete. Our main purpose here is to give the reader a general idea about stimuli, viewing conditions, tasks and results of the experiments.

We tried to describe all the experiments using consistent terminology from Section 2.1.2. Thus, on numerous occasions we had to change the original terms to their equivalents.

In most cases we say nothing about theories of perception that the experiments were supposed to test. On the contrary, we tried to separate the experimental data and the theory and to get rid of the bias introduced by the theory into the interpretation of the results.

We subdivided the papers into several sections according to what we believe was the main experimental subject of the paper.

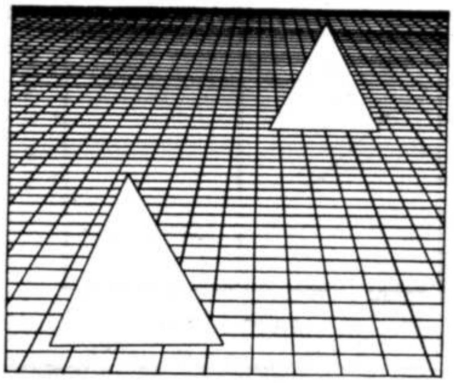


Figure A.1: Stimulus from [Hagen, 1976b] □

A.1 Robustness and Perception of the Picture Surface and Frame

[Hagen, 1976b] Hagen, M. A. "Influence of picture surface and station point on the ability to compensate for oblique view in pictorial perception.," *Developmental Psychology*, 12(1):57–63. 1976.

Experiment

Subjects. Children 4 years old, 7 years old and adults (40 in each group).

Stimuli. Photographs of triangles and squares against a textured background (horizontal plane) (Figure A.1). Three relative sizes of the images in the pictures: bigger was 100%, 85% and 75% of the smaller. wo types of stimuli were used: color prints and slides.

Viewing conditions. Peephole, monocular viewing, two viewing directions - 90 and 45°, viewing distance equal to the projection distance.

Task. The subjects were instructed to point to the bigger object.

Results. Correct station point increased the percent of correct choices for adults and 7-year-old children for slides and *decreased* for prints. For 4 year-old children the percent of correct answers was very small, indicating insufficient understanding of perspective pictures.

[Lumsden, 1980] Lumsden, E. A. "Problems of magnification and minification: An explanation of the distortions of distance, slant, shape, and velocity," In [Hagen, 1980], pages 91–135. 1980.

[Rosinski and Faber, 1980] Rosinski, R. R. and Faber, J. "Compensation for viewing point in the perception of pictured space," In [Hagen, 1980], pages 137–176. 1980.

E. A. Lumsden, R. R. Rosinski and J. Faber describe some unpublished experiments by W. C. Purdy.

Subjects. Unknown.

Stimuli. Texture gradients projected onto a screen. Visible portion of the projection was circular and filled with texture (oblique central projection of a piece of transparent film with a grid of lines approximately 1/8 inch apart.) Two positions of the light source and the film (source-to-film distance remained constant) were chosen so that they resulted in magnification 1.0 and 1.5 of the tilted film. Four projection directions of the film were used: 30°, 40.9°, 52.4°, 62.8° and 71.1°. The projection directions were chosen so that each image coincides with the image one step below if projected from the viewing point.

Viewing conditions. Fixed viewing position on the other side of the screen, binocular viewing (uncertain), viewing angle limited to 25° by an aperture.

Task. Subjects were asked to adjust a rectangular plate to a position parallel with the slant of the textured surface in the picture.

Results. For 1.5 magnification, judged slant corresponds to the depicted slant one step below, that is, the slant is perceived as if the projection was made from the viewing point. For 1.0 magnification (viewing point coincides with the projection point) judged slant was in correspondence with depicted slant with the same constant error.

Note: The equivalence of 1.5 magnification to 1.0 magnification one step below is not surprising, as the distance from the viewing point to the screen remained constant and the resulting stimulus was practically identical.

[Rosinski and Faber, 1980] Rosinski, R. R. and Faber, J. "Compensation for viewing point in the perception of pictured space," In [Hagen, 1980], pages 137–176. 1980.

Experiment 1.

Subjects. Unknown.

Stimuli. Photos and line drawings of gray square parallelepipeds, 6 cm in height and varying in width. Three faces of each parallelepiped were visible. Projection point was 25 cm away from the picture plane. Orthogonal central projection was used.

Viewing conditions. The viewing point was located 25 cm, 50 cm, 75 cm away from the picture on the principal ray. This corresponds to te viewing angles of approximately 55°, 30° and 20° and magnifications 1.0, 0.5, 0.33.

Task. Subjects were asked to estimate the size (more specifically, width) of the objects in the pictures. Estimate were "modulus-free" in abstract units.

Note: it is entirely unclear from the text what were the specific instructions to the subjects and what abstract units were to be used.

Results. There was no significant change in apparent (relative?) size of the objects when the viewing point was changed.

Experiment 2.

Subjects. Unknown.

Stimuli. Computer-generated images of slanted lattices displayed on a CRT. Projection point for the pictures was 28, 56, 84, 112, 225, 337, 450 cm away from the screen. Central orthogonal projection was used. Depicted orientation varied from 0 to 170° in 10° increments.

Viewing conditions. Viewing point was on the principal ray to the picture, 112 cm away; this corresponds to magnifications in the range 0.25 . . . 4.0. Viewing was binocular.

Task. Observers were asked to make direct judgement of the apparent slant in degrees.

Results. Judged depended on magnification/minification; this dependence was more significant for slants closer to 0 or 180° and less significant for the medium range. For magnified pictures dependence was more apparent than for minified.

Note: The task of judging the slant in degrees is quite complicated; it appears that the data were distorted by the absence of experience of matching numerical measure with a particular slant. The main point, however, is that the apparent slant depends to some extent on magnification. Purdy's experiment appears to be more reliable.

Experiment 3

Subjects. Unknown.

Stimuli. Computer-generated images of slanted lattices; in this experiment projection point was always at 112 cm from the screen. The range was 0 - 170° in 10° increments. (same as in Experiment 2.)

Viewing conditions. Viewing point was located on the principal ray 28, 56, 112, 225, 337, 450 cm away from the picture, which corresponded to magnification in the range 0.25 ... 4.0. Viewing was binocular.

Task. Same as in Experiment 2.

Results. Practically no dependence of the judged slant on the magnification was observed.

[Rosinski et al., 1980] Rosinski, R. R., Mulholland, T., Degelman, D., and Farber, J. "Picture perception: An analysis of visual compensation," *Perception & Psychophysics*, 28(6):521–526. 1980.

Same experiments are described in [Rosinski and Faber, 1980] in less detail.

Experiment 1.

Subjects. 10 college students.

Stimuli. Photographs of a slanted striped rectangle, slant varies in the range 30 ... 150° (orthogonal central projection.) Surface was rotated around a vertical axis (exact location of the axis was not specified. [Kubovy, 1986] in his account of the experiment specifies the vertical axis going through the center of the rectangle.) Photographs were cut into trapezoidal shapes coinciding with the outlines of the images of the rectangle.

Viewing conditions. Viewing was monocular, through an aperture, and the photograph was placed in a viewing box where no frame was visible. Viewing direction was either 90° or 135°; the distance from the picture plane was equal to the projection distance.

Task. Subjects were asked to set the inclination of a vertically pivoted palm board to match the apparent slant.

Results.

• Judged slant differed considerably for 90° and 135° viewing direction.

• Define *Projected slant* as equal to the slant of the rectangle that would produce the same image if projected from the viewing point. When the viewing point coincides with the projection point, projected slant is equal to the depicted slant. It was found that the dependence of the judged slant on the projected slant for 135° viewing direction was very similar to the dependence of the judged slant on the depicted slant for 90° viewing direction. The authors conclude that under restricted viewing conditions apparent slant is determined by the projected slant.

Experiment 2

Subjects. Same.

Stimuli. Same.

Viewing conditions. Viewing was binocular, the photos were in a frame without a viewing box, no aperture was present. Viewing direction was 135° or 45°, viewing distance was equal to the projection distance.

Task. Same.

Results. There were practically no difference between judged slants. As projected slant in this experiment differed considerably, the authors conclude that the apparent slant is determined by the depicted slant for unrestricted viewing conditions.

[Hagen et al., 1978b] Hagen, M. A., Jones, R. K., and Reed, E. S. "On a neglected variable in theories of pictorial perception: Truncation of the visual field," *Perception & Psychophysics*, 23(4):326–330. 1978.

Experiment

Subjects. 60.

Stimuli. a) Isoceles triangles whose height and base were 2,3,4,5,6 in. The triangles were placed vertically on the table. Distance was measured from a round marker placed on the table 18 in away from the subject. The distance between the markers and the triangles was 6, 10.2, 17.3, 29.5 and 50 in. b) Slides of the scene (6.5×4.5 cm).

Viewing conditions. Viewing was monocular. Three viewing conditions were used for the real scene: fixed position with untruncated field of view, peephole (2 mm), rectangular truncation (6.5×4.5 cm slot 5 cm away). Slides were viewed from the projection point; conditions for the slides coincided with the rectangular truncation.

Task. Subjects were asked to reproduce with a tape the size of the triangles and the distance from the marker to the triangles.

Results.

• The distance was consistently underestimated for the truncated field of view; there was a considerable compression of the scene (i.e. the relative distances decreased.) The effect was similar for the three truncated conditions (slides, rectangular truncation, peephole.)

• Intercept (extrapolated apparent "zero" distance) was the greatest for slides, and significantly non-zero for all conditions except the untruncated viewing.

• Size estimates for the truncated field of view were lower than the estimates for the untruncateed field of view for the real scene; for slides, they were higher at smaller distances, but lower at longer distances.

A.2 Rigidity in Motion Pictures

Subjects. 6.

Stimuli. Orthogonal and oblique (direction of projection 67°) parallel and central projections (projection angle 5.8°) of nearly rectangular rotating rigid and nonrigid solids on a computer display. The images were wireframe with hidden lines removed. Two types of deformations were used for non-rigid solids: affine (angles between edges are unchanged) and non-affine (Figure A.2). Deformations were periodical, with the period equal to the period of rotation. Extent of deformation was 32%, 16%, 8% of the smallest dimension of the solid (?). For the oblique projection the aspect ratio of the objects was changed to make them appear less narrow.

Viewing conditions. Unrestricted viewing conditions; the viewing angle not specified, but constant. Duration of each trial was 10 sec (3 periods of rotation).

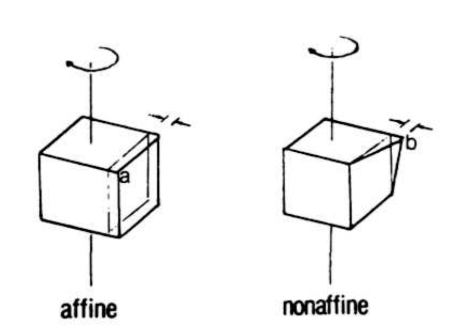
Task. Subjects were asked to rate the rigidity on the scale of 1 to 9, 9 indicating high confidence that the object was rigid.

Results.

• Parallel projection makes it more difficult to detect non-rigidity.

• The change of 23° in viewing direction doesn't make any difference.

• Affine deformations are more difficult to perceive.



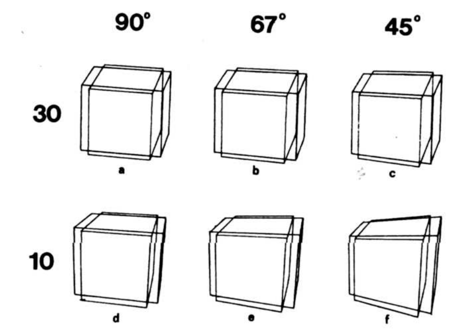


Figure A.2: (Left) Nonrigid stimuli from [Cutting, 1987] □

Figure A.3: (Right) Stimuli from Experiment 2, [Cutting, 1987] □

• Small deformations (8%) are not recognized very well.

Experiment 2

Subjects. Same.

Stimuli. Stimuli of the same type. Central projections were used. Projection angles were 11.5° and 3.8°, projection directions 90°, 67°, 45°, and a variable direction in the range 55°...80°, with the period equal to one half of the period of rotation (Figure A.3).

Viewing conditions. Two viewing angles were used: 11.5° and 3.8°.

Task. Same.

Results.

• For parallel projection we have less non-rigidity perceived for all slants of the screen.

• For perspective projection there is considerable non-rigidity for slant 45°.

• Simulated and physical distance (projection point position and viewing point position) did not affect judgements

• Among non-rigid stimuli non-affine transformations were much easier to perceive.

• Relation between wider angle perspective and viewing direction: 10 radii projection (just 12°!) looked bad from 45° viewing direction.

Experiment 3

Subjects.

Stimuli. Rigid/nonrigid stimuli, 90°, 67°, 45° projection direction was compensated by the viewing direction of the same magnitude, 37.5, 15 ,6 radii projection distances (corresponding viewing angles are 20°, 8°, 3°.)

Viewing conditions. Viewing distances were 37.5, 15, 6 radii.

Task. Same.

Results. Rigidity was preserved, no compensation for slant occurred.

A.3 Size and Distance in Pictures

[Smith, 1958b] Smith, O. W. "Judgements of size and distance in photographs," *The American Journal of Psychology*, 71:529–538. 1958.

Experiment

Subjects. 52 (26 per viewing condition).

Stimuli. 18 Photographs of a plowed field extending from the foreground to distant hills. 15 stakes in each photographs were located on a circular arc 14 yd away from the projection point, the height of the stakes varied in the range 27–83 in in 4 in increments. An 8 ft gap in the middle of the arc permitted subjects to see the 16th stake at a distance. 5 stakes were identical in all pictures; 16th stake was 63, 67, 71 or 75 in high and it was 28, 112, 224, or 448 yd. All 16 possible combinations were used. Two more photographs were obtained by air-brushing out all the detail except for the image of one stake 63 in high at 54 yd from the projection point. On one of them shadows were painted. All photos were 11.875 by 18.625 in.

Viewing conditions. Monocular viewing from a fixed position through an aperture. Two viewing boxes were used: one resulted in 1.33 magnification and the other in 0.4 magnification (the viewing distance was equal to 0.75 and 2.5 of the projection distance). The boxes were black inside, back-lit slides were used. Data for similar pictures from two different studies were used: restricted viewing from the projection point, binocular viewing and real scene viewing.

Task. Subjects were asked to judge the size of the distant stake by matching it with a near stake, estimate the distance to the distant stake and stakes in the foreground in yards and the height of the distant stake in feet. Impoverished photographs were judged either before or before and after the regular photographs.

Results.

• Matches of height and judgements of height in feet didn't vary much with the change of viewing conditions. Height judgements were overestimates.

• The judgements of distance increased for 0.4 magnification and decreased for 1.33 magnification. Standard deviation increased with the distance and was quite high, so only qualitative conclusions are valid.

• Qualitative trend for the impoverished photographs is the same (distance judgements depend on the viewing point) but distances were considerably underestimated if the impoverished photographs were viewed first. Size judgements in impoverished photographs were not significantly different.

[Smith, 1961] Smith, Patricia C., S. O. W. "Ball throwing responses to photographically portrayed targets," *Journal of Experimental Psychology*, 62(3):223–233. 1961.

Experiment 1-2.

Subjects. 50 for Experiment 1, 16 for Experiment 2.

Stimuli. In a room 36 by 30 ft, there were 25 marked target locations at five distances 3, 4.25, 5.5, 6.75, 8 m from the viewer (Figure A.4). The viewer was used with apertures which resulted in approximately $7° \times 5°$, $24° \times 17°$, $41° \times 30°$ fields of view. Below the viewer a curtain could be opened and through this opening the subjects could toss a ball at a target. Next to the viewer another curtain could be opened and through this opening the subjects could observe the targets with unrestricted head motion.

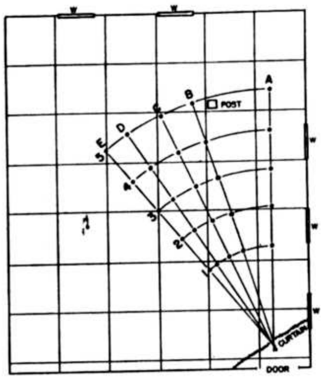


Figure A.4: Diagram of the room of the experiments, [Smith, 1961] □

Viewing conditions. 5 viewing conditions were used: monocular viewing through the viewer with one of the possible apertures, binocular and monocular unrestricted viewing.

Task. Subjects were asked to throw the ball at one of the targets for different viewing conditions (restricted conditions first in Experiment 1, unrestricted conditions first in Experiment 2). Immediately after the toss the viewer or the curtain was closed.

Results. Restricted field of view resulted in larger distance to the point of impact of the ball. There was no significant dependence on the size of the aperture and between monocular and binocular unrestricted viewing. The order of the unrestricted and restricted viewing conditions didn't affect the qualitative relationship between the results for restricted and unrestricted viewing conditions.

Experiment 3.

Subjects. 30.

Stimuli. Same, except that the subjects observed photographs of the scene in the viewing apparatus instead of the scene itself. For unrestricted viewing conditions, the real scene was used. Photographs were made from the correct viewing point; no attempt was made to match the colors or intensities; photographs were black-and-white, with yellow target markers painted on them.

Task. Same. Subjects were not told that photos are used; after the experiment they were asked if they saw anything unusual in the scene visible through the viewer.

Results.

• The data were adjusted in the following way: the difference between means in unrestricted viewing conditions (identical for Experiments 1–2 and 3) was added to the means for restricted conditions to correct for the difference between groups of subjects. Adjusted results were very close for photographs and real scene (restricted viewing).

• There was practically no difference between binocular and monocular unrestricted viewing.

• No subject reported that he had seen photos in the viewer or noted any unusual quality of what he had seen.

Experiment 4. We omit this experiment because we don't find its results relevant to our purpose.

[Smith, 1958a] Smith, O. W. "Comparison of apparent depth in a photograph viewed from two distances," *Perceptual and Motor Skills*, 8:79–81. 1958.

Experiment

Subjects. 52.

Stimuli. 36×45 in back-lit photograph of a corridor 360 ft. long

Viewing conditions. Monocular viewing through a peephole from two viewing distances: 0.53 and 2.53 of the projection distance from the viewing points on the principal ray to the picture (Viewing angle was 86° and 23°, magnification 1.875 and 0.395). A viewing box was used to restrict subject's field of view to the image area.

Task. Subjects were asked to estimate the distance to the front edge of the corridor and the length of the corridor in paces.

Results. The means for the greater viewing distance were more than two times greater than the means for the smaller viewing distance.

A.4 Orientation and Layout

[Halloran, 1989] Halloran, T. O. "Picture perception is array-specific: Viewing angle versus apparent orientation," *Perception & Psychophysics*, 45(5):467–482. 1989.

Experiment 1.

Subjects. 12.

Stimuli. Pictures similar to those used in [Rosinski et al., 1980]. Black-and-white striped rectangles, depicted at 15, 30, 45, 60, 90, 120, 135, 150 165° slant around a vertical axis; the axis was located at the right edge of the rectangle.

Viewing conditions. Unrestricted viewing from the viewing distance equal to the projection distance and the viewing direction of 30, 45, 90, 135, 150°.

Task. Subjects were asked to reproduce the slant with a pointer pivoted around a vertical axis.

Results. For large slants and large displacements (viewing direction of 30 or 150°), exceeding those of [Rosinski et al., 1980], there was a considerable dependence of the estimated slant on the viewing position.

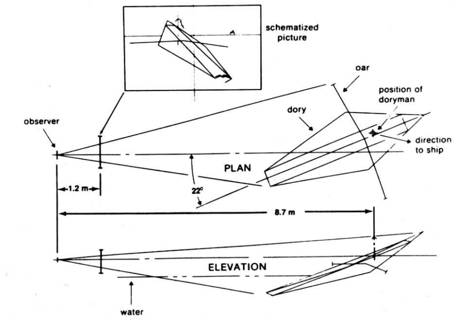


Figure A.5: (Left) Winslow Homer, "The Fog Warning", from [Halloran, 1989] □

Figure A.6: (Right) Scene reconstruction, from [Halloran, 1989] □

Experiment 2.

Subjects. Same.

Stimuli. Pictures from Experiment 1, which depicted 15° and 165° slant transformed in the manner that corresponds to the viewing positions of Experiment 1; two frames were present: the transformation of the frame of the original 15° and 165° pictures and a rectangular frame of the final picture.

Viewing conditions. Viewing point was fixed, viewing direction was 90°.

Task. Same.

Results. No difference from Experiment 1, except for a small nearly constant digression towards picture plane. Compare to the apparent distortions of the pictures of slanted pictures as demonstrated in [Pirenne, 1970].

Experiment 3.

Subjects. 23.

Stimuli. Multicolored reproduction of Winslow Homer's painting "The Fog Warning", 42 by 66 cm. (Figure A.5).

Viewing conditions. Unrestricted viewing from 7 positions; the following are pairs (viewing distance, viewing direction): (2.3 m, 14°), (2.4 m, 30°), (1.7 m, 45°), (1.2 m, 90°), (1.7 m, 135°), (2.4 m, 155°), (2.3 m, 166°).

Task. The subjects were instructed a) to orient the pointer in the direction that the dory in the picture was headed, with respect to the picture plane; b) to orient the pointer in the direction of the mother ship on the horizon from the man's position.

Results.

• There is a consistent shift in both judged orientations with the change in the viewing point. As the viewing direction angle increases, the judged angle of orientation of the boat and of the direction to the ship increases.

• The rotation of the judged orientation of the boat approximately corresponds to the mean rotation of the objects reconstructed using 4 sets of cues (Figure A.6).

Set 1: the fixed height of the man and the length of the boat.

Set 2: the rectangle from the stern width to the corresponding width in the front of the boat.

Set 3: the fixed length and width of the boat, except 14° and 166° viewing directions.

Set 4: oars are of equal length.

The best fit is given by averaging set 4, which results in no rotation, with any of the sets 1-3.

• The change of difference of the angle of orientation of the boat and the direction to the ship is small: 11° over 152° interval the judged angle of orientation of the boat.

Experiment 4

Subjects. 17.

Stimuli. Monochrome reproduction of the picture from Experiment 3.

Viewing conditions. Unrestricted viewing from viewing points from Experiment 3 with the viewing direction 150° (the viewing distance was scaled as the size of the picture was different.)

Task.

a) Subjects were asked to make separates judgement of

1) the plan-view orientation of the dory that is indicated by its long axis, disregarding all other cues;

2) the orientation with respect to the picture plane of a straight line connecting the blades of the oars;

3) the angles between the line connecting the blades of the oars and the boat axis.

To accomplish this, a pair of pointers pivoted on a common axis were used, to represent two sides of the angle to be estimated.

b) Subjects were asked to identify the "correct" boat among 5 plan-view outline drawings with length-to-width ratios of 1.5, 2.5, 3.33, 5.0, and 7.0.

Results.

- Mean length axis orientation was approx. 163°. For a similar viewing position in Experiment 3, the mean orientation was 136°, indicating some influence of other cues.
- The oar-crossing angle implied by separate judgements of the oar direction and the boat axis direction , was 125.7°, while the mean oar-crossing angle, judged directly, was 102°.
- There were strong individual differences.
- The results of this experiment suggest that cues can influence judgments in different ways, depending on the task, and that the ability to separate cues differs among subjects.

Experiment 5

Subjects. 6.

Stimuli. 3 stimuli similar to [Goldstein, 1987] (Figure A.12), except they were perspective line drawings: each depicted a 15.2 cm ball with one or two 1.9 cm square dots on it. One dot was located on the intersection of the central perpendicular to the picture plane and the sphere (the image of this dot was in the center of the image of the ball), the other one was on the big circle of the ball, which lies in the plane perpendicular to the picture plane, rotated 60° from the position of the first dot.

Viewing conditions. Unrestricted viewing, the viewing distance equals the projection distance (46 cm), viewing direction was 160°.

Task. For the two-dot picture, subjects were asked to indicate the angle between dots with reference to the center of the ball, for the single-dot pictures subjects were asked the dot's direction from the picture plane. Pointer arrangement from Experiment 2 was used.

Results. For single-dot pictures the average judgements were 147.5° for the center dot and 32.8° for the side dot, resulting in the relative angle of 114.7°. For the two-dot pictures, the mean judgement was 67.7°.

Experiment 6

Subjects. 10.

Stimuli. Same as in Experiment 4.

Viewing conditions. Same as in Experiment 4, and also from the viewing point on the principal ray 42 cm away from the picture.

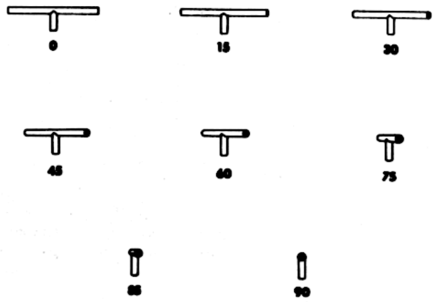


Figure A.7: (Left) Stimuli from Experiment 1 [Goldstein, 1979] □

Figure A.8: (Right) "The Village of Bequigny" by Theodore Rousseau, [Goldstein, 1979] □

Task. Subjects were asked to indicate spatial orientation of the dory using a pointer with two degrees of freedom.

Results.

• Mean judged about angles were 118.7° for 90° viewing direction, and 172.6° for 150° viewing direction. Compared to the Experiment 3, the rotation between positions was twice as much.

• Mean judged pitch (angle between the axis of the boat and the horizontal plane) was 22.8° and 28.8°; 5 observers indicated no or little increase, others indicated substantial increase.

[Goldstein, 1979] Goldstein, E. B. "Rotation of objects in pictures viewed at an angle: Evidence for different properties of two types of pictorial space," *Journal of Experimental Psychology: Human Perception & Performance*, 5(1):78–87. 1979.

Experiment 1.

Subjects. 5.

Stimuli. Line drawings of rods (Figure A.7) with different swings around a vertical axis. Depicted swings were 0, 15, 30, 45, 60, 75, 85, 90°. The 0° rod was 59 mm across.

Viewing conditions. Viewing was monocular; position of the right eye was fixed. The pictures were rotated so that the viewing direction was 15°, 45°, 70°, 90°, 110°, 135° and 165°. The viewing distance was 55 cm, corresponding to the viewing angle of approximately 6° for 90° viewing direction.

Task. The task was to set the direction of a pointer parallel to the direction of the horizontal rod in the picture.

Results. All the rods appear to be rotating as the viewing direction changes. The amount of rotation increases with depicted angle from 60° for the 0° rod, up to 149° for the 90° rod.

Experiment 2.

Subjects. Same.

Stimuli. Black-and-white photograph of the painting "The Village of Bequigny" by Theodore Rousseau (Figure A.8)

Viewing conditions. Same as in Experiment 1. The viewing angle was 17° for the viewing direction 90°.

Task. Observers were asked to judge the orientation of the road (A), the rut in the road (B), the house (C), and the line defined by two trees (D).

Results. Road rotates 150°, the house rotates 103°, the trees rotate 91°, the rut rotates 38°. Mostly confirms the results of the Experiment 1, although the house rotates more then the direction between trees, while appearing to be more perpendicular to the road with 90° viewing direction.

Experiment 3.

Subjects. Same.

Stimuli. Similar to those in the Experiment 1, but the length of the horizontal rods was only 1 mm (only disks are left).

Viewing conditions. Same as in Experiment 1.

Task. Same as in Experiment 1.

Results. The amount of rotation significantly increased for small angles (up to 115° for 15° rod), but remained unchanged for larger angles. The differential rotation decreased.

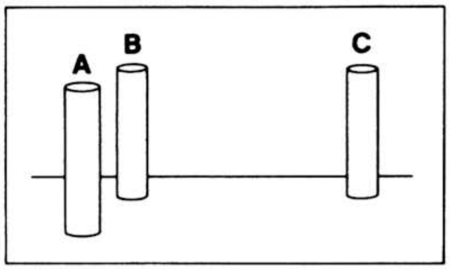
Experiment 4.

Subjects. Same.

Stimuli. Same as in Experiment 2.

Viewing conditions. Same as in Experiment 2.

Task. Observers were given a sheet of paper with two parallel lines on it indicating the direction of the road. The task was to indicate the position of the rut, of the house and of the trees relative to the road.



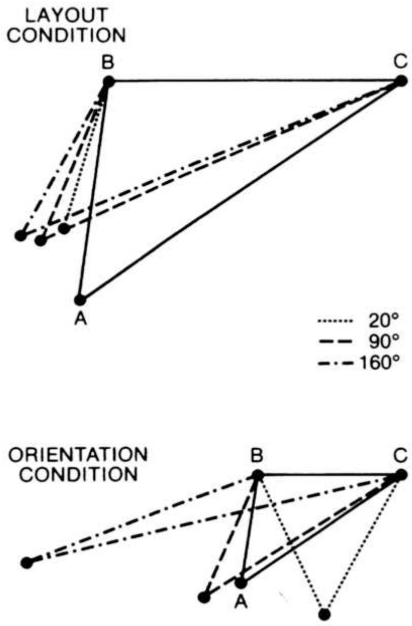


Figure A.9: (Left) Stimuli from Experiment 1, [Goldstein, 1987] □

Figure A.10: (Right) Results for Experiments 1 and 2, [Goldstein, 1987] □

Results. There was little dependence on the viewing direction. There was some change in the relative distances, but almost no change in the orientation.

[Goldstein, 1987] "Spatial layout, orientation relative to the observer, and perceived projection in pictures viewed at an angle," *Journal of Experimental Psychology: Human Perception & Performance*, 13(2):256–266. 1987.

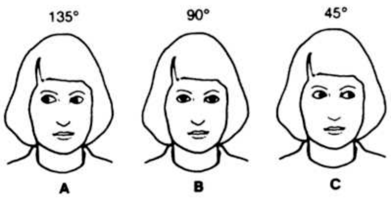
Experiment 1

Subjects. 5.

Stimuli. Black-and-white photographs of three vertical dowels with horizontal stripes on a homegeneous white surface against a homogeneous white background (Figure A.9). The size of the picture was 10.2 by 12.7 cm.

Viewing conditions. Monocular viewing from a fixed position, with viewing distance equal to the projection distance and viewing direction 20° , 45°, 70°, 90°, 110°, 135°, 160°. Viewing direction was changed by rotating the picture.

Task. Observers judged the spatial layout of the dowels by arranging three discs on a piece of paper.



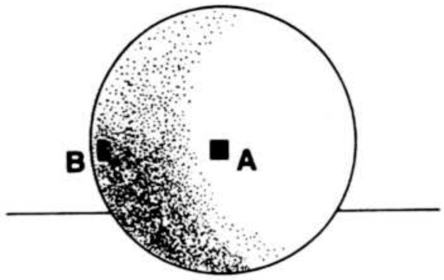


Figure A.11: (Left) Drawings of the face stimuli from Experiment 3, [Goldstein, 1987] □

Figure A.12: (Right) A line drawing of the sphere from Experiment 6, [Goldstein, 1987] □

Results. Averaged results are shown in Figure A.10 for viewing directions 20°, 90°, 160°. Size BC was scaled to the same size for all observers. Judged layout changed only slightly with the viewing direction.

Experiment 2

Subjects. Same.

Stimuli. Same.

Viewing conditions. Same.

Task. Observers were asked to set a pointer parallel to the directions BA, BC, CA.

Results. Total changes of the directions were: BA – 123°, CA – 79°, BC – 29°. The layouts, reconstructed from the directions are shown in (Figure A.10). These layout differ greatly from each other.

Experiment 3

Subjects. 7.

Stimuli. Seven photographs of a frontally oriented human face with different gaze directions resulting from looking at seven different targets, positioned at 15° intervals in the range of directions from 45° to 135°. (Figure A.11).

Viewing conditions. The viewing was monocular; position of the right eye was fixed. The pictures were rotated so that the viewing direction was 20°, 45°, 70°, 90°, 110°, 135°, 160°.

Task. The task was to set the direction of a pointer parallel to the direction of the gaze in the picture.

Results. Total rotation of the judged direction of the gaze was 137° for the depicted gaze of 90°, and only 38° for the 45° gaze, and about 40° for 135° gaze. Total amount of rotation increased towards 90° gaze.

Experiment 4

Subjects. 4.

Stimuli. Similar to the photographs from Experiment 3. in addition to the frontal position of the face, three additional head orientations were used (75°, 60° and 45°).

Viewing conditions. Same.

Task. Same.

Results.

• The results were qualitatively similar to the results of Experiment 3. The maximum of total rotation is shifted to smaller angles for 60° and 45° head orientations.

• Judged gaze direction is relatively independent from the head orientation.

Experiment 5

Subjects. 4.

Stimuli. Line drawings of two vertical cylinders similar to those used in Experiments 1 and 2. Black-on-white pictures were used for viewing in the light and negatives were used for viewing in the dark.

Viewing conditions. Similar to Experiments 3 and 4. Two modes of viewing were used: in the light, regular line drawings, and in the dark, back-lit negatives.

Task. Subjects were asked to orient a pointer in the direction parallel to the direction from cylinder A to cylinder B.

Results. Viewing the picture in the dark, when the picture frame and surface are invisible, increases total amount of rotation of the judged direction for oblique orientation.

Experiment 6 (not numbered in the paper).

Subjects. 3.

Stimuli. Photograph of a sphere with a marked point either at 90° horizontal direction from the center of the sphere or at 120° (counted from the direction parallel to the picture plane). (Figure A.12).

Viewing conditions. Exact conditions unknown. Viewing direction was 20°.

Task. Subjects were asked to judge the directions from the center of the sphere to the dots (presumably, using a pointer).

Results. The average judgements of the orientations of the points A and B were 25° and 153°, which results in calculated angular separation of 128°.

A.5 Rectangular Corners

[Perkins, 1972] Perkins, D. N. "Visual discrimination between rectangular and nonrectangular parallelepipeds," *Perception & Psychophysics*, 12(5):396–400. 1972.

Experiment

Subjects. 27.

Stimuli. 128 drawings of boxes, some of which could have been and some of which could not have been orthogonal parallel projections of rectangular boxes according to the first Perkins' law (Section 2.3.1.) There were 16 different drawings, the rest were produced by rotating the original drawings by 0, 45°, …315°. The original drawings all had angle C 120° (Figure A.13, and angle A varied from 70 to 170°. Three edges radiating from the central vertex were 3 cm, size of the pictures was 4.5×6 in

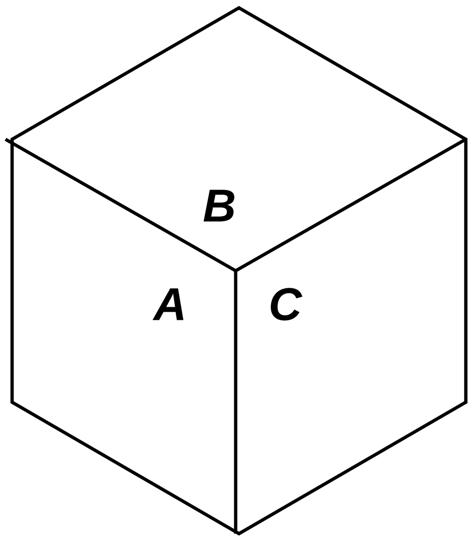
Viewing conditions. Unrestricted viewing from a position 6 feet away from the pictures. Three methods of presentation were used: –"straight", when pictures were presented one by one;

– "samples", when two pictures with A equal to 70° (nonrectangular case) and 120° (rectangular case) were permanently displayed next to the judged picture;

– "pairs", when pictures were sorted into two piles and the "rectangularity status" (rectangular, nonrectangular, borderline) was different for corresponding cards in two piles.

Task. In the first two cases, the task was to say if the box in the picture appeared to be rectangular. In the last case, the task was to say which box appears to be more rectangular.

Results. For each procedure the percentage of correct judgements for rectangular pictures was close to 90%, for nonrectangular it varied from 81% for the "straight" procedure, to 9% for "pairs". Any box was shown in 8 orientations. Distribution of the number of rectangular judgements (maximum 8) is shown in Figure A.14.



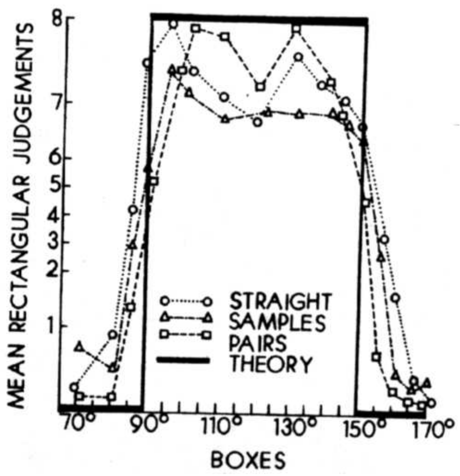


Figure A.13: (Left) One of the stimuli for [Perkins, 1972] □

Figure A.14: (Right) Results of [Perkins, 1972] □

[Perkins, 1973] Perkins, D. N. "Compensating for distortion in viewing pictures obliquely," *Perception & Psychophysics*, 14(1):13–18. 1973.

Experiment

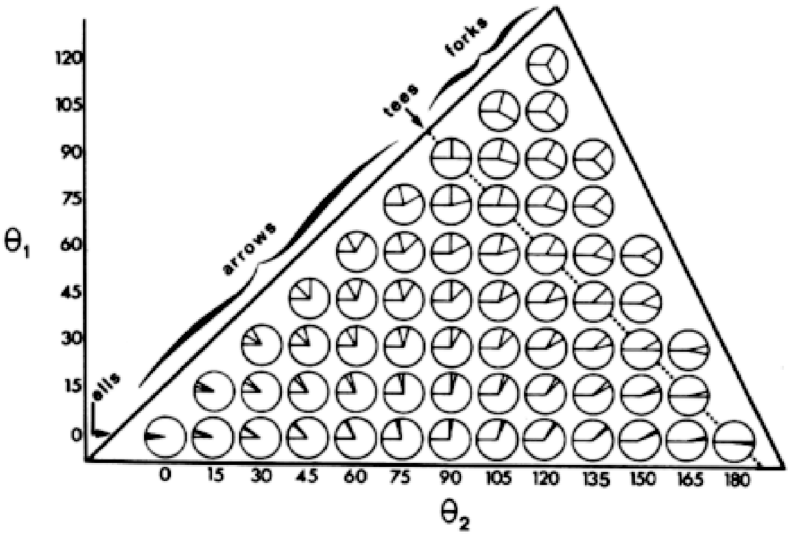
Subjects. 16.

Stimuli. Same as in [Perkins, 1972].

Viewing conditions. First, subject judged rectangularity of the pictures from 90° viewing direction, the viewing distance 6 ft. (32 cards only). Next, two viewing directions were used: 40° and 26°. A suspended wire frame ensured correct viewing direction, otherwise viewing conditions were unrestricted. The choice of the viewing directions was motivated by the following observation: classification of the reprojection of the drawings into an oblique plane according to the Perkins' laws change for a large number of pictures around 30°. In the neighborhood of 40 and 26° classification of these projections were stable (cf. Section 2.5.1).

Task. Subjects were asked to judge each picture as rectangular or nonrectangular box.

Results. All boxes for each of the two viewing directions could be classified into one of four categories, using four possible combinations of two criteria: whether the picture satisfies the first Perkins' law, and whether the projection of the picture onto the plane perpendicular to the viewing direction satisfies this law. The borderline case was excluded.



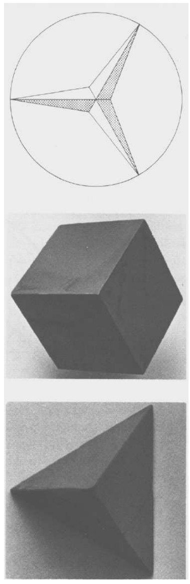


Figure A.15: (Left) Stimuli from [Shepard, 1981] □

Figure A.16: (Right) Three-dimensional objects from [Shepard, 1981] □

Judgements were made mostly according to the classification of the picture, not of the projection. In the cases of a conflict, the percent of judgments coinciding with the picture classification was lower, but still high (above 68%) in all cases except orthogonally nonrectangular, projectively rectangular (43%). There was very little projective influence at 41°.

[Shepard, 1981] Shepard, R. N. "Psychophysical complimentarity," In *Perceptual Organization*, Kubovy, M. and Pomerantz, J. R., editors, pages 279–343. Lawrence Erlbaum Associates, Publishers, Hillsdale, New Jersey. 1981.

Experiment

Subjects. Unknown.

Stimuli. 61 line drawings consisting of three radial lines meeting at different angles at one point (Figure A.15.)

Viewing conditions. Circular aperture in front of the drawing, otherwise unrestricted viewing.

Task. Subjects were asked if each pattern could be a projection of a a corner of a cube (all three angles 90°), of a tetrahedron (all three angle 60°) or of a planar "Mercedes-Benz" sign (all three angles 120°) (Figure A.16.) Subject could rotate each drawing in its plane around the center with a remote control.

Results. Dashed lines in Figure A.17 indicate the boundaries of the areas of orthogonal parallel projections of corresponding spatial corners. For the corners there is no difference between orthogonal parallel and central projections assuming that the principal ray of the central projection goes through the point where the lines meet. The size of the circles is proportional to the fraction of positive answers.

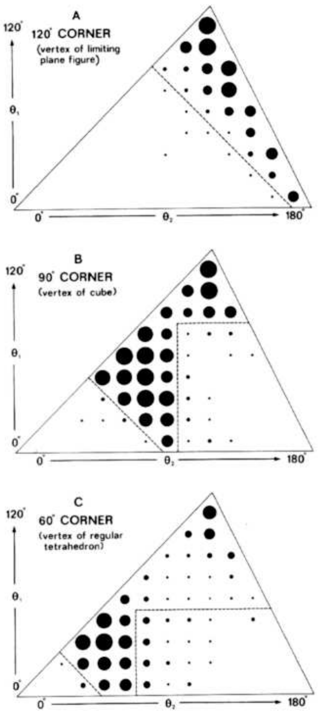


Figure A.17: Results of [Shepard, 1981] □

• For the cubic corner there is close agreement of 50% threshold of positive answers with orthogonal projection boundaries. This confirms Perkins' first law.

• For the "Mersedes-Benz" figure the agreement was less than for the cubic corner, and for 60° corner even less. However, most of the change was in the direction of decreasing the ranges of acceptable configurations.

A.6 Foreshortening

[Nicholls and Kennedy, 1993a] Nicholls, A. L. and Kennedy, J. M. "Angular subtense effects on perception of polar and parallel projections of cubes.," *Perception & Psychophysics*, 54(6):763–772. 1993.

Experiment 1

Subjects. 14.

Stimuli. Line drawings of a cube, orthogonal parallel projection and central projection with 15° and 33° projection angles.

Viewing conditions. Projections were viewed monocularly, viewing angles were 35°, 15°, 5°, 4°, 2°.

Task. The subjects were asked to compare the pictures with a standard (the picture with the projection angle 35° viewed at a distance corresponding to the viewing angle 15°.)

Results.

• Moderate parallel foreshortening (15°) was always the best; parallel projection was second best and strong parallel foreshortening (35°) was the worst.

• Parallel projection is perceived as distorted only at close distances; only for 35° it was worse than strongly convergent.

Experiment 2

Subjects. 45.

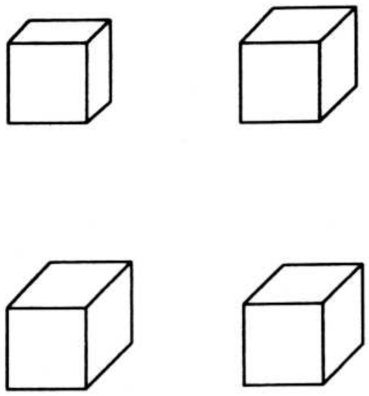
Stimuli. Same as 1, but the image with moderate degree of parallel foreshortening (15° projection angle) positioned at the distance corresponding to the viewing angle 5° was used as standard.

Viewing conditions. Same.

Results. Order of preference was preserved, except for the closest distance, when the pictures with the strongest parallel foreshortening was preferred over the parallel projection (no parallel foreshortening,) but they were still judged to be slightly worse than the pictures with moderate parallel foreshortening.

Experiment 3.

Subjects. 15.



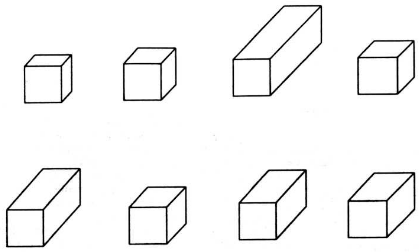


Figure A.18: (Left) Stimuli from [Nicholls and Kennedy, 1993b], Experiment 1 □

Figure A.19: (Right) Stimuli from [Nicholls and Kennedy, 1993b], Experiment 2 □

Stimuli. Same.

Viewing conditions. The viewing angles were 50°, 45°, 40°, 35° and 30°. Standard image (15° projection, moderate degree of parallel foreshortening)set at a position corresponding to the viewing angle 45°.

Results. Moderate parallel foreshortening was still rated the best at all distances, but now parallel projection had lower ratings than strongly divergent.

[Nicholls and Kennedy, 1993b] Nicholls, A. L. and Kennedy, J. M. "Foreshortening and the perception of parallel projections.," *Perception & Psychophysics*, 54(5):665–674. 1993.

Experiment 1.

Subjects. 90.

Stimuli. Line drawings of a cube in oblique parallel projection. One face was always depicted as a square, oblique lines representing the lateral edges of the cube met the horizontal at 45, 30, 60°, the degree of perpendicular foreshortening (the ratio of the length of the edges of the front to the length of the oblique lines) was 1:0.38, 1:0.65, 1:0.73 and 1:0.81 (Figure A.18).

Viewing conditions. Unrestricted viewing.

Task. Subjects were asked to choose best drawings among the set with a fixed angle.

Results. 1:0.65 ratio was consistently preferred.

Experiment 2.

Subjects. 144.

Stimuli. Three wooden blocks with square cross-sections with length-to-width ratios of 0.65, 1 and 2; line drawings with receding lines equal to 0.4, 0.5, 0.65, 0.8, 1.1 , 1.2, 1.5, 2 of the front edges (Figure A.19).

Viewing conditions. Unrestricted viewing.

Task. The subjects examined one out of three wooden blocks. After that, they were asked to choose the best drawing.

Results. .

For 1:0.65 block 1:0.42 picture was preferred, for 1:1 block 1:0.65 was preferred, and for 1:2 block 1:1.6 was preferred. In first two cases the preferred perpendicular foreshortening was 1:0.65, in the third case 1:0.8. About 40% of the subjects made the dominating choice.

Experiment 3.

Subjects. 72.

Stimuli. Same blocks as before, but the pictures were either frontal orthogonal parallel projections or frontal orthogonal central projections. (Figure A.20).

Viewing conditions. Unrestricted viewing.

Task. Same.

Results. For parallel projection, 1:0.65 and 1:1 blocks, the preferred perpendicular foreshortening was 0.8, for 1:2 block - 1:1. For central projections it was 0.5 and 0.65 respectively. About 30% of the subjects made the dominating choice.

[Hagen and Elliot, 1976] Hagen, M. A. and Elliot, H. B. "An investigation of the relationship between viewing condition and preference for true and modified linear perspective with adults," *Journal of Experimental Psychology: Human Perception & Performance*, 2(4):479–490. 1976.

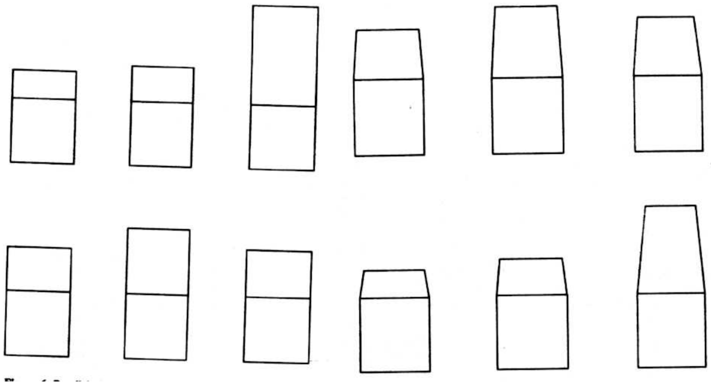


Figure A.20: Stimuli from [Nicholls and Kennedy, 1993b], Experiment 3 □

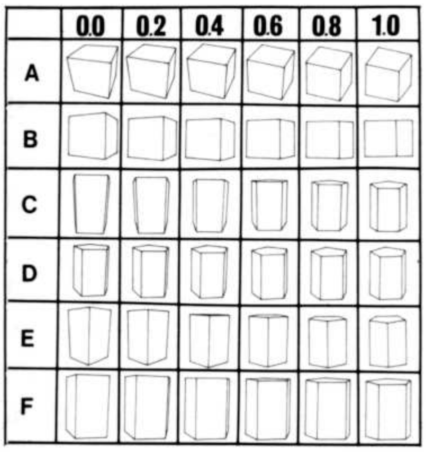


Figure A.21: Stimulus from [Hagen and Elliot, 1976] □

Experiment 1-2.

Subjects. 24 college students in Experiment 1, 33 college students in Experiment 2.

Stimuli. 7 sets of images of polyhedra (Figure A.21) generated by the method described in [Reggini, 1975] (see also Section 4.1), convergence degree from 0.0 to 1.0, Angular size from 19° to 58°.

Viewing conditions. a) monocular peephole, from fixed distance, from 90° and 45° viewing directions. b) free viewing. 3D solids were shown prior to the experiment.

Task. a) assign rank in the range 1 to 6. b) Sort the pictures from the most to the least natural looking.

Results. Parallel projection is consistently rated the best from both viewing points. For the free viewing the result is same; the only exception are the pictures of cubes (0.8 is the most frequently chosen).

Experiment 3

Subjects. 20 college students.

Stimuli. Same.

Viewing conditions. Viewing point coincided with the projection point for the degree of convergence 0.0 (regular perspective.) Monocular viewing, peephole.

Task. Subjects were asked to rank the pictures from most to least natural looking or from most to least accurate drawing.

Results. Parallel projection has the highest rating. No dependence on the form of instructions was observed.

Experiment 4.

Subjects. 28 college students.

Stimuli. Sets D,F from Experiments 1-3.

Viewing conditions. Viewing point coincided with the projection point for the degree of convergence 0.0. monocular viewing, peephole. Stimuli were presented three at a time, each picture was oriented perpendicular to the viewing direction.

Task. Subjects were asked to choose the most and the least natural drawing from each triplet.

Results. Parallel projection was chosen as the most realistic more frequently than any other degree of convergence.

Note. This study was critisized by other authors. The images in sets C, E, F differed not only in the degree of convergence, but also in visibility of faces of the polyhedra. The use of Reggini's perspective seems to be unnecessary, because the degree perspective convergence (parallel foreshortening) could be varied simply by changing the viewing point.

[Hagen et al., 1978a] Hagen, M. A., Elliott, H. B., and Jones, R. K. "A distinctive characteristic of pictorial perception: The zoom effect," *Perception*, 7(6):625–633. 1978.

Experiment 1.

Subjects. 60 college students.

Stimuli. Picture sets D,F from [Hagen and Elliot, 1976]. 3 types of stimuli: a) black and white line drawings, normal light; b) Dayglo (fluorescent paper), under normal light; c) Dayglo stimuli under ultraviolet light.

Viewing conditions. Monocular viewing, peephole, the viewing point coincides with the projection point for the degree of convergence 0.0. Three pictures from the same set were presented simultaneously. The viewing direction was 90°. 3D objects were shown to the subjects before the experiment.

Task. Subjects were instructed to choose the most realistic and natural looking drawing out of three.

Results.

- Under the normal light parallel projection was preferred for all types of stimuli.
- For Dayglo stimuli under ultraviolet light there was no particular preference.

Experiment 2.

Subjects. 20.

Stimuli. Dayglo stimuli from Experiment 1 under ultraviolet light.

Viewing conditions. Monocular viewing with head motion allowed.

Task. Same as in Experiment 1.

Results. Results are similar to those obtained under normal light - parallel projection is preferred.

Experiment 3.

Subjects. 20.

Stimuli. Same.

Viewing conditions. Binocular viewing with fixed position of the head.

Task. Same.

Results. Slight change in the direction of normal light preferences, but not nearly as radical.

A.7 Visual field

[Finke and Kurtzman, 1981] Finke, R. A. and Kurtzman, H. S. "Mapping the visual field in mental imagery," *Journal of Experimental Psychology: General*, 110(4):501–517. 1981.

Experiment 1.

Subjects. 30.

Stimuli. A circle 76 cm in diameter, with eight radial lines. A disk 2.5 cm in diameter was placed in the middle; each half of the disk contained gratings 1, 3 or 9 cycle-per-degree (cpd). Gratings had the same number of cpd and were perpendicular to each other (Figure A.22). The disk in the middle was oriented so that the gratings were parallel or perpendicular to one of the drawn diameters of the circle.

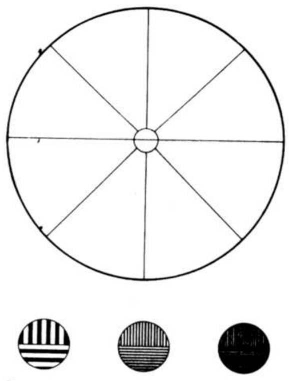


Figure A.22: Stimuli from [Finke and Kurtzman, 1981] □

Viewing conditions. The viewing point was fixed 28 cm away from the disk, resulting in the angular size of the small disk approximately 5°. and the size of the circle approximately 104°. Viewing was binocular.

Task.

a) Subjects were asked to move their eyes along each diameter, until they could not see that the disk in the middle consists of two distinct parts. A small red dot on the end of a rod was used as a fixation point.

b) The subjects were trained to *imagine* the pattern in the middle (the actual pattern was removed) and the same experiment was performed.

Note. The details of instructions are important for part b); see the paper for details.

Results.

• The average field size both for real and imagined stimuli decreased with increase in the spatial frequency of the gratings: 31.2 for 1 cpd, 27.9 for 3 cpd, 14.3 for 9 cpd.

• The measured visual field was longer horizontally than vertically (aspect ratio 1.27, 1,24, 1.17 for 1,3,9 cpd respectively.)

• Imagery fields were in close correspondence with the perceptual fields.

Experiment 2.

Subjects. 10.

This experiment was designed to check the influence of knowledge or expectations on the results of part b) of the previous experiment. Subjects were asked to guess the outcome of the experiment that was described to them (actual stimuli were demonstrated).

Results. Resulting field sizes for 3 and 9 cpd gratings were considerably lower than in Experiment 1; the field size estimate for 3 cpd was closer to the 9 cpd estimate contrary to the results of the Experiment 1. Average predicted visual fields were circular (no eccentricity). 3 subjects, however, did predict considerable eccentricity in the correct direction.

Note. Experiment 3 was mostly irrelevant for our purposes and is omitted.

A.8 Straightness and Curvature

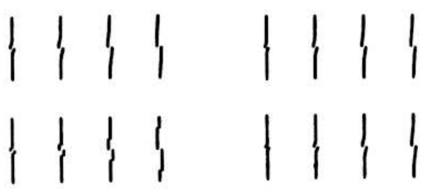
[Watt et al., 1987] Watt, R. J., Ward, R. M., and Casco, C. "The detection of deviation from straightness in lines," *Vision Research*, 27(9):1659–1678. 1987.

Experiment 1.

Subjects. 3 (authors).

Stimuli. Various perturbations of a straight line segment presented on the screen of an oscilloscope. The segments were 60 arc min. in length, the size of the perturbations along the line was in the range 5–40 arc min. There were 3 types of perturbations: vernier-like, bump-like, S-like. Each type of perturbation had various types of smoothing: none (discontinuous constant bumps), Gaussian, linear (Figure A.23, Figure A.24, Figure A.25).

The maximal amplitude of the perturbation in the direction perpendicular¡ to the bump varied. The



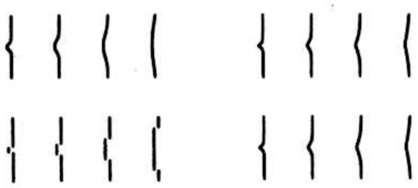


Figure A.23: (Left) Vernier-like stimuli from [Watt et al., 1987] □

Figure A.24: (Right) Bump-like stimuli from [Watt et al., 1987] □

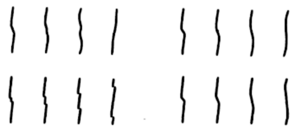


Figure A.25: S-like stimuli from [Watt et al., 1987] □

resolution of the display was 0.3 arc min. The direction (sign) of the perturbation varied randomly. The orientation of the line varied randomly in a 4° range around the vertical axis.

Viewing conditions. Unrestricted viewing from the distance 2.8 m.

Task. The subjects indicated the sign of the presented stimulus, if they could not decide, they guessed.

Results. On the basis of the data, threshold amplitudes for various stimulus types and size were computed.

• The threshold amplitude was never below 3 arc sec.

• For vernier perturbations the threshold decreased with size of the perturbations; for the other two types it decreased for smaller sizes of the bump, but increased for larger sizes.

• The best fit to the data was provided by the hypothesis that the threshold is determined by the area of the maximal bump with respect to the least-square-root straight line through the data (threshold value 0.3 arc min.^{2}), if the amplitude is greater than 3 arc min.

Experiment 2a.

Subjects. Unknown.

Stimuli. Pairs of lines on the screen of an oscilloscope. One of the lines was straight, the dots of the other line were perturbed according to a Gaussian distribution with varying means. The length of the lines varied.

Viewing conditions. Same.

Task. Subjects were asked to choose the perturbed line.

Results. According to a computer simulation, the largest bump rule would produce threshold vs. length dependence with exponent -0.37. Probability summation (bumps are detected with some probability) rule gives exponents between -0.37 and -1.0. Complete summation (all bumps are used) corresponds to the exponent -1.0. The exponents found in the experiment were significantly less than -0.37 and greater than -1.0 (weak probability summation).

Experiment 2b.

Subjects. Unknown

Stimuli. Bump-like perturbation with no smoothing from the Experiment 1 was used. Line length was 15, 45 , 30 arc min. A wide range of perturbation lengths was considered.

Viewing conditions. Same.

Task. Same.

Results. It appears that for larger perturbation sizes (more than have of the line) the bumps on the ends of the line are detected rather than the large bump in the middle. This results in increase of the threshold for larger perturbation sizes (cf. Experiment 1).

Experiment 3a.

Subjects. Unknown

Stimuli. Lines with two Gauss-like bumps on one side, with length 60 arc min. displayed on the screen of a oscilloscope. A random Gaussian perturbation with variable standard deviation and zero mean was added.

Viewing conditions. Same.

Task. Same as in Experiment 1.

Results. Amplitude threshold was plotted against the standard deviation of the added noise. Assuming the existence of internal noise in determination of position of the points it was estimated to be approximately 3 arc sec.

Experiment 3b.

Subjects. Unknown.

Stimuli. Lines with three types of perturbations: the first, second and third derivatives of a Gaussian with variable spatial extent.

Viewing conditions. Same.

Task. Same as in Experiment 1.

Results. Threshold decreases up to certain size of the perturbation, than slightly increases. This critical size value is relatively independent of the type of the perturbation approximately 5 arc min.) This might be an indication that there is a limit for spatial integration.

[Ogilvie and Daicar, 1967] Ogilvie, J. and Daicar, E. "The perception of curvature," *Canadian Journal of Psychology*, 21(6):521–525. 1967.

Experiment

Subjects. 5.

Stimuli. Black curved lines 1.5 mm wide on a 5×7 in photographic plate. The radii of curvature were 2.62, 3.15, 4.06, 5.55 and 10.1 m. Two chord length were used: 122 and 51 m. Define normalized curvature as the chord length divided by the radius of curvature. Normalized curvature approximates the displacement of the end point of the line with respect to the tangent at the starting point expressed as a fraction of the chord length. For 122 mm chord length it was equal to 0.047, 0.039, 0.030, 0.022, 0.012.

Viewing conditions. The viewing point was 10.1 m away from the display, resulting in angular subtens of the lines of 412 and 17 arc min. A 90 cm aperture was used to restrict the field of view to 2.75°. Viewing was monocular.

Task. Lines were presented to the subjects in different orientations (vertical, horizontal, oblique 45°). Subjects were asked to indicate if the line is curved up or down (left or right). Each line was presented 20 times, 6 lines were presented in random order.

Results. Calculated average thresholds were best correlated with the segment angular area which was calculated using an approximate formula ($2\ \times$chord length $\times$sagitta / 3, where sagitta is the distance from the middle of the arc to the chord.) Threshold was in the range 3.1-3.9 log sq. sec. (0.4 - 2.2 sq. min.)

A.9 Verticality

[DiLorenzo and Rock, 1982] DiLorenzo, J. R. and Rock, I. "The rod-and-frame effect as a function of the righting of the frame.," *Journal of Experimental Psychology: Human Perception & Performance*, 8(4):536–546. 1982.

Experiment 1.

Subjects. 12.

Stimuli. A luminous vertical rod inside a luminous frame. The tilt of the frame could be adjusted.

Viewing conditions. Unrestricted viewing from a fixed position, viewing angle 54°, in a dark room (only the frame and the rod were visible.)

Task. The subjects were shown the frame tilted at 20°. After 4 min., the subjects were asked to adjust the frame to the vertical position. After that, the rod tilted at 14° and the frame tilted at 20° in the same direction were shown. The subjects were asked to adjust the rod to the vertical position (the frame remained tilted). Same experiment was done with the head of the observer tilted at 45°.

Results. The average righting effect (the tilt of the single frame after adjustment) was 7.7°; the average rod-and-frame (RFE) effect was 11° and 8.7° for counterclockwise and clockwise directions. When the head was tilted, the effects increased.

Experiment 2.

Subjects. 10.

Stimuli. Similar to the Experiment 1, with an internal frame added (angular subtense 32°).

Viewing conditions. Same.

Task. The outer frame was presented in an upright position for 4 min. Than adjusted if the observer perceived it as tilted. After that it was returned to the objective vertical. Then the inner frame was added at a tilt of 20°. and Experiment 1 was performed with the inner frame as the frame. Same experiment was performed with tilted head.

Results. No righting effect or RFE were observed in both cases.

Experiment 3.

Subjects. 10.

Stimuli. Same as Experiment 2.

Viewing conditions. Same.

Task. Similar to Experiment 2, but with outer frame tilted and inner frame vertical.

Results. Approximately 8-9° righting effect for both frames and 5.8° RFE were observed. When the head was tilted, the righting effect increased for both frames, RFE effect increased mostly insignificantly.