Perspective is a result of the interaction of an energy, an object, and an environment for observation. The force can be light and its obverse, shade, or it can be a push and its reciprocal, a pull. Objects have many kinds of characteristic shape and layout affecting the energy. But conditions for observation always entail a vantage point lying in a terrain at a given direction from the object, as well as the source of the energy. Visual perception takes the outcome of the three factors--illumination, shape, and direction--and must solve the outcome as an equation with three roots. For now, let us focus on direction, which is the basis of perspective.

Imagine a cube of width \( w \) placed in front of the observer's vantage point. The front face might subtend close to 180°, and the rear face would then subtend about 53°. That is, when the angle between lines joining the top and bottom of the front face and the eye is 180°, the rear makes an angle of 53°. If the cube recedes a distance \( w \) equal to its width, the front face would replace the rear face. The rear face would then subtend about 28°. If the cube recedes by \( w \) again, the rear face would then subtend 19°. Successive steps of distance \( w \) make the rear face 14°, 11.4°, 9.5°, 82°, 72°, 6.4°, 5.7°, 52°, 4.8°, 4.4°, 4.1°, 3.8°, 3.6° ... Notice that a move of distance \( w \) produces dramatic angular changes when a close object subtends a large angle. The same shift in distance produces very minor angular changes, however, when the object is farther away and subtends a small angle. It follows that when the object subtends a small angle (or is far away) it can change its distance quite a lot before there is a material effect on the angles subtended by the front and rear faces.

The proportion 3.6/3.8 (or 0.95) is close to the proportions 3.8/4.1 (or 0.93),4.1/4.4 (or 0.93), and 4.4/4.8 (or 0.92). Ergo, a distant cube with a small angular subtends can move a distance equal to several times its width before the projected proportions change appreciably. The proportions 53/180 (or 0.29) and 28/53 (or 0.52) and 19/28 (or 0.68) and 14/19 (or 0.74) are decidedly different. Therefore, a cube subtending a large angle only has to move a short distance before the proportions of the projected angles alter markedly.

These geometrical facts have a major impact on vision's use of perspective. Objects depicted with proportions in keeping with small subtended angles can be viewed at a large range of distances before they look awry. Objects depicted with proportions suitable for large angular subtended can only be viewed at a small range of distances and still look appropriate.

The application of this principle to pictures is straightforward. Consider an observer who is presented with a drawing of a cube showing the rear making an angle of 3.6° while the front angle is 3.8° (a proportion of 0.95). Imagine that the observer appreciates this as a proper drawing of a cube.
Imagine further that the observer judges this drawing to be quite acceptable when it is brought closer, just up to the distance when the front subtends 11.4°. At 11.4° the correct proportions are 9.5/11.4 (or 0.83). This differs from the correct proportions by 0.12 (0.95 0.83). This observer is willing to accept as "still proper" proportions within the range 0.95-0.84. (That is, a picture of the cube can be moved from 3.8° to 11.4° without violating this observer's criterion for a proper cube.) The observer has a tolerance for deviation from correct proportions of about 10 percent. This suggests that if the picture of the cube is moved away from the observer so that the angles subtended by the cube shrink from 3.6° and 3.8° to smaller and smaller angles, the picture will always appear to show a proper cube to this observer. As its angular subtense shrinks, the cube picture will never project proportions that move outside the range 0.95 ± 10 percent.

This geometrical analysis of distance, angle, and criteria for judgments indicates that visual perspective can involve considerable tolerance for change of angle and distance, deeming objects to be depicted correctly provided that the proportions are correct for an object subtending a small angle. The central principle psychologically is a criterion for correct proportion. Added to the psychological principle is a physical ally: the proportions projected by an object such as a cube vary little, for a movement of distance $w$, when the object subtends an angle of about 7°.

The psychological principle and the physical ally are logically independent, but they are closely related in practice. A moment's thought about the rotation and foreshortening of objects explains why. If a cube is set at a fixed distance and rotated, the angles projected by each face as it rotates vary considerably. The front face foreshortens as it rotates to become a side face. This may encourage an observer to set wide criteria when trying to judge correct proportions. In contrast, a rotating sphere has no faces to foreshorten; it always projects a symmetrical cone of light to the vantage point. Consequently, observers have no call to set wide criteria for correct proportions when viewing a picture of a sphere.

Let us check some of these theoretical observations in a demonstration. Consider the cube pictured in figure 6.1. Three of the faces are shown. Since the top of the cube is visible, it is drawn from above. The correct place to view the picture is with the central line of the drawing straight ahead and slightly below the line joining the observer to the nearest point of the page. The two side faces of the cube are shown meeting at the front edge. They are represented by symmetrical foreshortened forms in the drawing. The amount of foreshortening is the proportion between the short line showing the far edge of each face and the long line showing the near edge. The foreshortening ratio is an exact function of the angle subtended by the cube at the correct vantage point for the drawing. If the cube had subtended a larger angle, there would have been more foreshortening, and a smaller angle would have produced less. If the cube had subtended a tiny angle, there would have been virtually no foreshortening.

Vision is sensitive to the relationship between the angle subtended by a cube and the proper amount of foreshortening. To demonstrate this, try increasing the angle subtended by fig. 6.1 by moving it close to the eye. The figure will begin to look distorted, and the distortion will increase as the angle subtended gets larger. The far edge of the cube appears to expand to look larger than the front edge. This shows that if the drawing is to continue to look like a cube, the amount of foreshortening needs to be increased to compensate for the apparent expansion as the figure subtends a larger angle. Evidently there is a correct amount of foreshortening for a given angle subtended. This follows from the geometry of real cubes and the angles they subtend at vantage points (Kubovy, 1986; Veltman, 1991).

Figure 6.1 also shows that vision is only roughly sensitive to the relationship between the amount of foreshortening and the angle subtended. The figure looks quite satisfactory as a cube over quite a range of angles subtended. Strictly speaking, it is only correct at 15°. But it looks undistorted from a range of distances—reading distance, arm's length, two meters, or even ten meters. This range of distances involves changing the angle subtended from much less than 1° to angles 30 or more times larger. (The angle subtended by the moon, the sun, or the thumbnail at arm's length is about half-a-degree.) Since figure 6.1 changes very little over a wide range of angles, it can be called "robust" (Kubovy, 1986).

Figure 6.2 is a cube drawn in parallel oblique perspective. Its sides are parallel, and the line representing the far edge of a side face is not foreshortened in comparison to the line representing the near edge. It could only be accurate at close to zero angular subtense—zero in the limit, strictly
with a real cube at a small angular subtense to be robust. Robustness demonstrates that visual perception links projective factors, sum as subtended angle and foreshortening, with room for some play between them. The relationship between the two does not have to be precise to a single degree of angular subtense. This freedom permits parallel projection to be visually acceptable and allows observers to examine pictures from a wide range of vantage points without noticing distortions (Nicholls and Kennedy, 1991). The projective angle and foreshortening criteria are being used (if only approximately), and the relationship between the two is appropriate, as the demonstrations show. Figures 6.1 and 6.2 look to have far edges that are too long when their angular subtense is magnified sufficiently, and figure 6.3 looks to have far edges that are too short when its angular subtense is minified. Vision has some rough sense of the correct proportions of the angles subtended by parts of an object.

How can these projective criteria arise in touch? Consider a cube set in front of a blind person. The front face has one edge to the left and one to the right of straight ahead. Now rotate the cube 45° horizontally relative to the observer. One edge is straight ahead, and the other has moved closer to it in direction. Now rotate the cube further until the edges are aligned. The angle between them and the observer has gone to zero. I imagine that the blind observer can be quite aware of the changing directions of the edges as the cube rotates. There is no reason why the blind person cannot realize via touch that, for example, the left edge of a frontal face rotates to become the right edge of that face when it is on the back of the cube. Touch can certainly reveal to the blind person that a side face has its edges aligned with him and the front face has left and right edges widely separated in direction. It can also discover that when the cube has an edge to the front, the two faces on either side of the front edge are symmetrically placed, one to the left of the front edge and the other reaching out exactly as much to the right.

Clearly, information about the direction of edges and the extent to which one edge is located to the left or right of another is a matter of direction from a vantage point, foreshortening, and proportions between angles. This information is pertinent to touch as well as vision. Experiments in touch and vision may reveal the same principles of perspective at work in both senses and may well tap a source common to both senses (E. J. Gibson, 1969, p. 23; Spelke, 1987, p. 238-240).

I am not arguing that visual imagery permeates touch or that vision is crucial for providing the quality of spatiality to tactual representation (Katz, 1925; 1989, p. 229, commentary by Krueger, p. 3). I am pointing out, rather, that dealing with direction requires similar abilities in vision and touch (Millar, 1986) and that the two may access a common spatial process in
perceptual analysis—a common spatial sense. Further, pictorial displays may be based on some matters of direction and be intelligible to the blind in much the same way they are to the sighted.

**DRAWINGS AND DEPTH**

Solid objects have parts at different distances from the observer. A picture, on the other hand, is a surface; it has no depth and cannot replicate these changes in distance. How can solid objects be drawn by blind people? Steinberg (discussed in Katz, 1989) argued that the congenitally blind perceive the shapes of three-dimensional objects, within broad as well as narrow confines of tactual space, much as the sighted do in the sense that the structure of the object is adequately perceived (p. 144). How can this three-dimensional shape be portrayed, and can the picture indicate something about the location of the observer?

In a study undertaken with Maryanne Heywood, 13 adult volunteers from BOOST in Toronto (table 6.1) drew some objects made of cubic blocks. One of the tasks was to draw an L-shaped block. Seven of our volunteers drew an L the distinctive face of the object—and left it at that. Three drew the L and then, to show that the object had depth, added other lines that echoed the L shape. Nat and Jay (both early, totally blind) and Roy (late, totally blind) made the extra lines parallel to sides of the L. Jay said that this was "to make it solid."

Nat said "because I couldn't go through the page, I showed the depth with four or five lines. If it were only slightly thick, I would have used just one or two lines." He described this technique as "expanding sideways" in proportion to the depth. Caron-Pargue (1985, p. 118) identified this device in drawings by sighted six-year-old schoolchildren. It might be termed a thickening or build-up technique. It is a rather simplified version of the foldout style, where the shape of all the edges of the side face are drawn following the rules of similarity geometry. It shows there is a side face and gives an indication of its width, but it does not show the shape of the far edge. Three of the volunteers drew two or more faces of the L in foldout style: Dee, early, totally blind; Pau, early, totally blind; and Ray, late, totally blind (figs. 6.4 and 6.5).

Similar results were obtained with a T-shaped block. We then asked the volunteers to draw two objects in which the limbs project in the three spatial dimensions. Held at certain angles, one of these has a Y-shaped silhouette (fig. 6.6) and the other a V-shaped silhouette (fig. 6.7). Twelve of our informants undertook this part of the study.

The Y-shaped block can be considered to be three cubes forming an L shape with an additional cube on top of the vertex. To draw the Y-shaped block, one of the volunteers (Lys, early, totally blind) drew three squares. She said she could not think of a way to show the fourth block, the one that is in the third spatial dimension. Two drew separate units, using the

<table>
<thead>
<tr>
<th>Onset of Blindness and Degree of Loss</th>
<th>Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early (0-2 years)</td>
<td>Cal, Dee, Jay, Lys, May, Nat, Pat, Pau</td>
</tr>
<tr>
<td>Early, light perception</td>
<td>Jim, Nip</td>
</tr>
<tr>
<td>Late, totally blind</td>
<td>Mo, Ray, Roy</td>
</tr>
</tbody>
</table>

**Fig. 6.4. Drawing of an L-shaped block in a foldout style, by Dee (early, totally blind).**

**Fig. 6.5. Drawing of an L-shaped block in a foldout style. By Pau (early, totally blind).**
slanted line to indicate they're on a slant to each other--one's pointing one way and one's pointing the other." Cal (early, totally blind) used an oblique line, saying, "We get into three dimensions. In 3-D graphs they put in another axis at 450 to represent the third dimension. Maybe I could do the same." Pat (early, totally blind), who used a foldout technique, was also able to employ a vantage point. She drew a form standing for a limb of the Y and indicated this showed "the top one." She said, "It's drawn as if I were looking at it from this angle." The direction indicated was above the object. She added a small circle positioned at a 450 oblique to the form depicting "the top one" to indicate her vantage point (fig. 6.8). (Willats says that the use of an oblique is the sighted child's advance in drawing development from the foldout system. It may indeed be an advance, though, alas, our drawing study with Andrea Nicholls found no one path of development toward the use of a vantage point.)

Similar results were obtained in the task where the volunteers drew the V-shape of an object with two limbs, one bar (or parallelepiped) lying beside an upright bar attached to its side. The majority used a foldout technique (fig. 6.9, by Ray, late, totally blind). Obliques and comments on the vantage point appeared infrequently. In one instance, Jim (early, light perception) said of one object, "Looking at it from here, I think this [limb] would be longer than this [other limb]."

To introduce the vantage point explicitly, we asked our informants to draw the objects at a certain orientation with some parts near and some far. Seven volunteered for this study: Cal, Dee, Nat, and Pau (early, totally blind), Ray and Roy (late, totally blind), and Nip (early, light perception).

Many of the drawings used foldout and build-up techniques, and several used conventions such as arrows or printed words such as UP. Four of the volunteers, though, introduced devices using change of width, a kind of convergence, to show depth. Roy drew the nearer limb of an L-shaped block as wide and the farther limb as narrow. Nat drew lines that got thinner to show increasing distance. He said, "The line gets thinner as it gets farther."

Fig. 6.6. Block object with limbs projecting in three dimensions. The object has a Y-shaped silhouette.

Fig. 6.7. Block object with V-shaped silhouette.

Fig. 6.8. Drawing by Pat (early, totally blind) of the object shown in figure 6.6.
It is evident from studies on drawing that the blind commonly draw objects where a shape of a part of the object is depicted by a line form with a similar shape. Blind people also have a clear sense of top, bottom, and sides. They realize, as Ray put it, that "you could make a point of view by drawing only certain pans of the object." Knowledge of the vantage point for a picture is shown by comments that a picture is drawn from the side, front, or top. In trying to show the depth inherent in a solid object, the blind use foldout and other techniques including occasional obliques. Asked to make the orientation of an object evident, so as to show which parts are near and which far, blind subjects make use of convergence. On occasion, the lines themselves are drawn thick and thin. On a very rare occasion, the shape of the outlined region is transformed. The result is a shape that has two functions: to show the shape of a part of the object and to show the orientation of the parts. In a word, it shows the direction of parts of the object from a vantage point.

The ideas about the relation between the observer and the object are at times quite advanced in these comments from the blind. But one key idea seems to be missing: the role of the picture surface. A set of directions is a far cry from the set of actual shapes of the faces of the object. In a directional system, a given shape can produce a variable set of directions. The directions of two corners of a table may be wide apart while the directions of the other two corners, farther away, may be close together. Any attempt to depict this fact is quite unlike thinking of the shape on the picture surface as a kind of imprint made by a face of the object. The set of directions of a face of an object has to be carefully related to the plane or orientation of the picture surface, so the move from an imprint system to a directional system requires two new ideas. The first is the shift from shapes of faces to directions of faces. The second is the shift from an imprint system, where the picture surface can be wholly in contact with the object's face, to the directional system, where the picture surface cannot wholly contact the face. Since many theories of pictures and vantage points have foundered when debating matters that arise from the location of the picture surface, I should explain the relation more precisely.

When we consider an imprint system, the orientation of the picture surface to the object is set, fixed, and obvious. On my younger son's door, for example, there is a picture he made in elementary school of a fish on a cloth. To make it, a fish was covered with paint. It was then left on top of a cloth sheet and pushed firmly. The result is an imprint picture of a fish. The picture plane is the side of the fish. In my older son's room there is a pencil drawing he made when he was in junior high school of a room full of desks. Each of the shapes standing for a rectangular desk top is a trapezoid. The picture plane for the drawing of the
Pointing tasks

We asked volunteers to point to objects from different locations. This task involves a sense of direction, which is the basis of perspective. Understanding the direction of objects guides locomotion for the blind as well as the sighted exploring near and distant spaces (Humphrey, Dodwell, Muir, and Humphrey, 1988). It is a principle of perspective that an object subtends a smaller angle when it is far away than it does when it is near. The decrease in angle with distance is familiar to sighted people, but there is an unfortunate tendency to think of the decrease as purely visual. It is, in fact, not restricted to vision. If two people are having a conversation, one on either side of the observer, one voice comes to the observer from the left and one from the right. If the two people walk away from the observer, the directions of the two voices gradually approach one another. If someone is standing midway between two rose bushes, to smell one he turns 90° to the left; to smell the other he turns back 180° to the right. But let the person step back just two paces. Now to smell the roses, he leans forward and only turns a little to the left or right.

Further, imagine someone standing in the middle of a wide avenue pointing to two trees, one on either side. The pointing arms are 180° apart, one arm a straight extension of the other, with a straight line from one fingertip through both arms to the other fingertip. Let there be another two trees 10 meters down the road. To point to them, the pointing arms must converge to form a V. They are no longer 180° apart. To point to two more trees 10 meters farther down the road, the V between the arms would become narrower. And for two more trees another 10 meters down the road, the V between the arms would become narrower still. For a distant pair of trees, the arms should be practically parallel. The pair of trees in the distance subtends a very small angle, whereas the trees on either side of the observer subtend 180°. It is in the nature of direction and perspective that the principle of convergence is not restricted to vision. Rather, it is a general principle that governs hearing, smell, and vision—any perceptual system that encounters objects and locations. Since pain has a location, even pain reveals its directions and perspective to the observer. A child's pain can be in her hand, which she might hold in front of her body at waist height. The child can change the direction of the pain vis-à-vis her head by bringing the injured hand to her mouth. It is now in front of the head rather than below it, above the waist rather than at waist height.

As we walk past a post we are aware that the post is ahead of us, then to the side, then gradually falls more and more directly behind us (Loomis and DaSilva, 1989). Surely blind people become aware of these changing directions by means of several sensory avenues. If so, they should appreciate that as things go into the distance, they subtend smaller angles. Landau and Gleitman (1985) found an ability to deal with change of direction in a blind two-year-old. Likewise, Diane Girard and I asked children in Haiti to point to the corners of a wall from close up and far away. We asked them to point with outstretched arms and measured the distance between their fingertips. If the children have a sense of perspective, they should point with a smaller distance between their fingertips when they are farther away from the wall.

We thought that it might be difficult to measure the angle formed by the arms. It is hard to be sure where the vertex for the angle is. Is it exactly midway between the shoulders? Is one shoulder favored as the base? Or is the vertex in an imaginary locus on an extension of the arms, behind the body? For our purposes, it is not necessary to find the answer. Whether the vertex is behind the shoulders or nearer one shoulder than the other, in our task the distance between the fingertips should shorten if the person understands how direction works.

Eight blind Haitian children ranging in age from nine to 18 years, mean age 13.1 years, participated in the study (table 6.2). They were led by the arm alongside a wall from the middle of the wall to one comer, then to the other comer, then back to the center of the wall while lightly brushing it with their
TABLE 6.2
Haitian children pointing at the corners of a wall from near (1 m away) and far (3.5 m away): Distance between fingertips is measured in centimeters.

<table>
<thead>
<tr>
<th>Distance from Wall</th>
<th>Jan</th>
<th>Mim</th>
<th>Jea</th>
<th>Yur</th>
<th>Ron</th>
<th>Jag</th>
<th>Ros</th>
<th>Jac</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 m Away</td>
<td>119</td>
<td>112</td>
<td>112</td>
<td>147</td>
<td>130</td>
<td>165</td>
<td>145</td>
<td>117</td>
</tr>
<tr>
<td>3.5 m Away</td>
<td>84</td>
<td>102</td>
<td>102</td>
<td>97</td>
<td>84</td>
<td>107</td>
<td>109</td>
<td>91</td>
</tr>
</tbody>
</table>

Decrease with Distance

| Distance | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |

Note: All the children are totally blind except Jan, who has light perception. Onset of blindness is assessed conservatively, from the date of admission to their residential school or the date of an eye operation. Other medical records are scanty or absent.

The wall was about 4.5 m long. The children were asked to step backward from the center of the wall until they were standing about 1 m from the wall. From there, the children pointed to the corners, left arm outstretched to the left corner and right arm outstretched to the right corner. The distance between the left and right fingertips was measured. Then the children were walked backward to a point 3.5 m from the wall, and they pointed again to the corners with both arms outstretched.

The results were that all the children decreased the distance between their fingertips when pointing from the farther distance ($p < 0.01$ on a sign test). There were no exceptions. Variability was quite striking, ranging from a decrease of 10 cm from 112 cm (9 percent) to a decrease of 58 cm from 165 cm (35 percent).

The age of onset of the children's blindness, an important factor in evaluating the test results, is hard to assess given the lack of standard medical records in Haiti and the children's own hazy recollections. We have usually used the school's date of admission as a conservative estimate of the onset of blindness. Occasionally we have had a medical record of an eye operation. Malnutrition is the most common medical explanation for the children's blindness. Deprivation often had had several other ill-effects including general difficulties with attention and comprehension. Furthermore, the education of the children had not been steady or comprehensive by any means.

None of our volunteers had gone beyond the fifth grade, and several were still below grade 2. Despite the intellectual deficits of the children, their performance was consistent. The implication is that the vantage point test appears to be understood by people who are poorly educated and "unlikely to be testwise"--that is, unsophisticated in following complex instructions and appreciating rather artificial testing procedures and their intentions.

To confirm this finding, however, it is necessary to try the test with children for whom we have more precise knowledge of age of onset of blindness. The Tucson children we tested in drawing studies, the records indicate, are congenitally blind. For our pointing studies, we tested nine of them--eight who had participated in our pictorial tests and one other, a girl age 12 who has extremely low vision (table 6.3).

All of the Tucson subjects decreased the distance between their fingertips when pointing from afar ($p < 0.01$ on a sign test). Even if the most extreme convergence is taken from the set of results (it was from the child with low vision and she may have too much vision to be counted as blind for this task), the results remain significant. The results from Haiti and Tucson were always collected using a test procedure where the "near" measure was taken first and the "far" measure second. The reason was to preserve as "natural" a test procedure as possible. To control for the order in which the measures were taken, we modified the procedure in Phoenix, with four blind volunteers, Di (age eight, early, totally blind), Ram (age 10, early, totally blind), Gale (age 15, early, light perception), and Jel (age 22, totally blind, but low vision from birth to age 7-8). I asked the Phoenix subjects to point from afar first. In this study we used two vertical rods (supported by bases on the floor) joined by a string instead of two corners of a room with a common wall. The string was 4.5 m long and 73 cm high at midpoint. The subjects were asked to point to the rods, left arm to the leftmost rod and right...

TABLE 6.3
Tucson children, congenitally blind, pointing at the corners of a wall from near (1 m away) and far (3.5 m away).

<table>
<thead>
<tr>
<th>Distance from Wall</th>
<th>Distance between fingertips (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 m Away</td>
<td>140 145 145 137 91* 102 142 102 97</td>
</tr>
<tr>
<td>3.5 m Away</td>
<td>112 86 140 94 20 48 56 56 46</td>
</tr>
</tbody>
</table>

Decrease with Distance

| Distance | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |

*This subject may have too much vision to be counted as blind.
arm to the rightmost rod. All four volunteers diverged when pointing from the nearer distance. The results suggest that convergence arises on the more distant measure, rather than on any measure near or far that happens to be taken second.

The success on this vantage point task encourages some further questions. Is convergence appreciated by the blind on smaller scales than the 1–4 m scales used in our tasks? Meters are a scale on which most of domestic life is lived. But some of the objects we use everyday; such as cups, are a mere few centimeters in size, graspable and manipulable by one hand. Is there an intuitive sense of perspective when the scale is so reduced that one can feel the whole object at once and the distinction between the front and the back is unclear? Barber and Lederman (1988) call this scale "manipulatory space."

Further, we can ask about the vertical scale. People in our pointing tasks are using the horizontal--the location of objects to left and right. Is vertical perspective (up and down) also well defined? Sighted people know that as they walk away from a building, the top is at first directly above them, but later it is at 45°, and as they walk still farther away, the roof eventually may be only a few degrees above the horizontal. Do blind people appreciate the principle? To find out, Jay Campbell and I tested eight congenitally blind adults in Toronto on small-scale tasks and vertical tasks as well as larger scales and horizontal arrays.

The Domestic Horizontal test involved pointing to poles linked by string and set 2.5 m apart. The volunteers pointed from 60 cm back from the center of the string (which was removed while pointing was being tested) and from 2.5 m back. A plumb line was dropped to the floor from the extended fingertip and the location of the plumb line on the floor was noted, allowing the left and right positions of the subject's pointing finger to be recorded.

The Domestic Vertical test called for pointing to the top and bottom of a 188 cm stand from the same near and far distances as in the horizontal conditions. Subjects felt the stand, stood back, and then pointed to where the top and bottom of the stand had been. (The stand was removed while pointing occurred, otherwise some subjects when nearby might have brushed against it.)

The Manipulative Horizontal and Vertical tests involved pointing by moving a wrist rather than the whole arm from the shoulder. The subject put a wrist on a block of wood and swiveled the hand left and right, or up and down, pointing with the index finger. The subjects were seated at a table, on which the block rested. The two stands for the horizontal condition were only 13 cm tall and were connected by a 30 cm string. The vertical condition used a 30 cm pole. The distance from the pole or the center of the string to the edge of the block was 13 cm or 30 cm.

The four tasks--Domestic Horizontal and Vertical, Manipulative Horizontal and Vertical--were undertaken in random order. There is considerable variability in the size of the movements the subjects made in responding, especially on the Domestic scale. Accordingly, I shall report the direction of change-convergence or divergence.

On the Domestic Horizontal scale, all the subjects converged with distance. The other three conditions usually resulted in convergence, but there were occasional ties or divergent results. On the Domestic Vertical scale, six subjects converged, one diverged and one did not change. On the Manipulative Horizontal scale, six subjects converged with distance, two diverged. On the Manipulative Vertical scale, five converged with distance, two diverged, one did not change. The subjects clearly grasped the principle involved, though their performance was uneven. Overall, the change is in the direction of convergence on all four conditions for four subjects and shows more convergence than divergence for three subjects. With the exception of one subject, for whom the number of converging results equaled the number of diverging results, seven out of eight subjects offered a majority of converging results ($p < 0.05$ on a sign test).

The variability between conditions is considerable, including seven convergence changes greater than 40 percent, though convergence with distance is evident overall. The mean convergence is 24 percent. The mean divergence is only 11 percent. The Manipulative Vertical conditions appear to be the least well defined, though the differences between conditions are dwarfed by the individual variability. In sum, on two functionally different haptic spaces-the space of manipulation and the space of domestic movement (the space for walking in a room)--convergence is evident with distance.

Following the Domestic and Manipulative tests, we asked the subjects about pointing to tops of tall buildings from near and far, like from across the street and from miles away. Every person we interviewed indicated that to point to the edge of a roof it is necessary to point straight up when standing at the front door of a building, at an acute angle when on the other side of the street, and at lesser and lesser angles when farther away.

In pointing to the corners of an extended object, some blind people try to use the full extent of the arms to show the actual length of the desk, while swiveling only the fingers and hand to show the directions of the corners. Two systems are competing here. One shows unchanging length, the other changing direction. The direction of one comer is indicated by swiveling the left hand using the left wrist as the vertex, whereas the other comer is indicated by the right hand using a different vertex, the right wrist.

Thus, pointing tasks run across the same difficulty that arises on occasion in drawing, namely, the mixing of direction with some other property of
spatial relations. When we point, length mixes with direction if we try to show extent and angle at the same time. In drawing, we might try to draw the shape of the object at the same time as we show the direction of its edges. This creates no problem if the vantage point is directly above or to the side of, say, a rectangular table. A drawing of such a table from above represents it as a rectangle. But a three-quarter View—that is, from a vantage point intermediate between the top and the side—requires us to draw a trapezoid, not a rectangle. At once a clash between criteria of direction and similar shape arises.

The pointing studies indicate that blind people, young and old, educated and uneducated, have a strong sense of the convergence principle crucial to perspective. Hence it is not because they lack an appreciation of convergence that they rarely employ three-quarter views in their drawings. More likely, it is because a novice does not consider direction-based criteria when drawing. A specific task and explicit instructions can draw attention to the criteria; sighted children, for example, will then use depicted occlusion (Cox and Martin, 1988) and height in the picture plane (Ingram and Butterworth, 1989). Often, direction criteria can produce a conflict with similar-shape criteria. When they do, the directional system is rejected by many people. When directional criteria are used to note what will be to the front and what will be behind, to organize the set of features to be shown and the set of features to be omitted, there is no clash with similar-shape criteria. It is only when the vantage point is intermediate between the front and the side that the clash with similar-shape criteria arises.

**JUDGMENT TASKS**

Evidently, blind people as young as five or six years old understand that an object subtends a smaller angle as it recedes from a vantage point. This knowledge, however, is not revealed in many drawings of objects. There is no evidence of vantage point geometry in the foldout drawings common in sketches from many blind adults as well as sighted children. But occasionally vantage points are mentioned spontaneously. To what extent do blind people realize that vantage point geometry is an advance on foldout geometry? To study this question, we had blind volunteers compare different kinds of drawings of objects.

Paul Gabias and I designed tasks that compared foldout geometry to perspective (vantage point) geometry. The first task involved comparing two different drawings of a table, one in perspective. The second task required only one drawing of a table, with two different rationales or descriptions, one using the notion of a vantage point. The tasks were undertaken by 15 blind volunteers, adults recruited from colleges in New York City.

Our drawings were raised-line drawings on 20 x 30 cm plastic sheets. We told the volunteers that we had prepared these drawings ourselves on the basis of sketches made by blind people. We said that our drawings were tidied-up versions of the sketches, to remove any differences in line quality or skill in execution that might give away the age of the sketcher. One pair of drawings showed tables, one table in foldout style and one in vantage point style (fig. 6.10). The foldout drawing shows the parts of the table as though they were splayed out on a flat surface. Two of the legs go up the page from the central square, two go down. The vantage point table is shown as though from the side—a central, slim rectangle and two legs coming down. The blind volunteers were given the pictures accompanied by instructions explaining which lines stood for the top of the table and which stood for the legs. They were told that one drawing showed the table and all four legs, and the other showed the table from the side, with only the front legs drawn.

If a judgement about the drawings were based on complexity, measured in terms of number of features shown, then the foldout table would be deemed better, as it shows all four legs. But the drawing from the side considers not only the features of the object but also the relation between the observer and the object, thereby introducing a principle over and above the arrangement of features in the object. The drawing from the side is observer-centered whereas the foldout drawing is object-centered.

Another drawing showed a table depicted as a rectangle with four lines for

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**Fig. 6.10.** Drawings showing tables, one done in foldout style and one using a vantage point.
the legs radiating from the corners (fig. 6.11). This "star" table was accompanied by two descriptions, one in foldout style and the other in vantage point. The volunteers were told that two people had drawn the same design. One had explained that in drawing the star table he had shown the shape of the tabletop, the juncture of all four legs at the corners, and the symmetry of the table. The other person had made exactly the same drawing while explaining that the only place from which all four legs and the top of the table were in front of the observer is underneath the table, so he had shown the table from underneath. If a judgment about the systems is to be based on showing not only the features of the table but also its relation to the observer's vantage point, then the second rationale would be deemed superior. The volunteers were told the two rationales and then asked which drawing came from an older person.

Of the 15 blind volunteers for these tests, four were totally blind from birth, two had some light sensitivity for a time and are now totally blind, two once had some ability to detect gross objects and are now totally blind, five have had light sensitivity since birth, one has light sensitivity now but until the age of 12 could distinguish shadows from objects, and one still can detect gross objects in bright light.

The results for the first pair of tables were as follows: 11 out of 15 subjects judged the vantage point table as more likely to have been drawn by an older person. The results for the star table were similar: 11 out of 15 subjects judged the vantage point description as more likely to have come from an older person. Only one person described both the vantage point conditions as likely to have been drawn by a younger person. (The results are significantly different from chance at the 0.01 level, X2 = 112.1 d.f. Eight blind subjects judged both vantage point drawings as "older," and only one judged both as "younger," p < 0.05, binomial test.)

The one person who judged both vantage point versions of the table as younger was totally blind from birth. He felt that the vantage point description of the star table indicated that the "artist" failed to understand that the same shape could be produced from above. And he considered that the foldout table with two legs up and two legs down was superior because no matter what the orientation of the page, the table is still drawn appropriately.

The results are enlightening. They indicate that these blind subjects deem a perspective drawing to be more sophisticated than a nonperspective drawing, even when the nonperspective drawing shows more of the parts of the object. But several intermediary steps are possible between foldout and perspective drawings. Accordingly, a more strenuous test of the ability of blind people to assess vantage point effects can be devised. A series of drawings of an object say a cube-can run the gamut from foldout to perspective convergence. In our next study, volunteers were asked to compare such drawings of a cube with drawings of another object, a table, and then match drawings made according to similar systems.

The procedure in the test hinged once again on the star table, with two different descriptions or explanations. The star table was to be compared with four different drawings of a box or cube (fig. 6.12). Again, our volunteers were told that our figures were tidied-up versions of sketches by blind people.

One drawing of the cubic box presented five squares arranged in a cross a central square with four squares attached one per side. The subjects were told that the person who drew this version of the box said he had shown the

Fig. 6.11. Star-like drawing of a table, which could be a foldout or a vantage-point drawing.

Fig. 6.12. Drawings of a box, in four different projections.
front face in the middle, and that the top and bottom squares show the top and bottom sides of the box. The squares on either side of the middle square were said to show the faces of the box to the left and right of the front face.

An alternative drawing of the box showed two squares attached at the top side. The person who drew the box this way, we informed our volunteers, said he had shown the front face and top of the box. He said you should not show any other faces because they are facing away from the observer and are hidden behind the parts he had shown.

The third version of the box was one square with a rectangle half the size of the square attached along the top side of the square. The person who drew this version, it was reported, said that the front face should be shown as a square and the top face as narrower—as a rectangle—because it does not face directly toward the observer.

The last version of the box was two symmetrical trapezoids joined along their longest side. We reported that the person who drew the box in this way said that the nearest corner of the box has to be shown longer than the others, and that the front face and top have to be shown on an angle if both are drawn. Besides the four versions of the cubic box, the volunteers were also given the star table and the two different descriptions.

After the descriptions of all the drawings were given, the subjects had to repeat them back in their essentials. If someone displayed a misunderstanding of a rationale, the description was given again until it could be repeated by the volunteer.

The volunteers were 24 congenitally blind adults, four recruited from colleges in New York City and 20 recruited at a convention for the blind in Philadelphia. Fourteen of the subjects were totally blind, nine had light perception, and one could detect gross objects. Five were totally blind from birth and one from six months of age; five others had gone blind by age three years. Three had had light perception for a period, but by age 13 two were totally blind and the remaining person could see no light by age 2. Eight of the volunteers said that they had never been exposed to haptic pictures, and 16 admitted some very limited exposure to them. Eight of these 16 said that they found the particular pictures they had come across in the past helpful or clear; eight indicated that the pictures they had encountered were unhelpful.

The star table versions and the cubic box drawings were compared. Volunteers were asked to consider one of the two descriptions of the star table-say, the vantage point description. Then they were asked to pick the most compatible version of the cube. That is, volunteers had to predict which version of the cube was most likely drawn by the person who drew the table using the vantage point system. Then the other three versions of the cube had to be ranked in order of likelihood. Once all the selections had been made for one description of the star table, it was time to turn to the other description, and the process was repeated. A rank of 1 was given to the most likely version and 4 to the least likely version. The average rank for a drawing, combining the judgments of all 24 subjects, is given in table 6.4.

When the vantage point table was the basis for judgment, the most likely version of the cubic box was said to be the two trapezoids (mean rank 1.75). The next most likely was deemed the square and rectangle (2.42), then the two squares (2.83). The least likely version was said to be the foldout drawing of five squares (3.0).

In complete contrast, when the foldout (no-vantage-point) table was the basis for judgment, the most probable drawing of the cubic box was deemed to be the foldout five squares (mean rank 1.63). The next most likely was judged the two squares (2.29), third was the square and rectangle (2.79), and the least probable drawing was said to be the two trapezoids (3.29).

There was considerable agreement among the volunteers, and one set of judgments is exactly the reverse of the others. The blind volunteers seemed to have a coherent assessment of the role of vantage points in the drawings. As aspects of vantage point geometry were introduced, the fit to the table drawings was made in an orderly and appropriate fashion. In the first drawing, all the sides were present and folded out; in the next, some sides were omitted in keeping with a vantage point; in the third drawing, not only were sides omitted but the picture used compression of shape relevant to facing away rather than toward the observer; and in the final drawing, angles were used that vary from the 900 in the actual object, with a side shown elongated.

<table>
<thead>
<tr>
<th>Drawing of Cube</th>
<th>Vantage point</th>
<th>No vantage point</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rationale</strong></td>
<td>Foldout</td>
<td>Two Squares</td>
</tr>
<tr>
<td>Vantage point</td>
<td>3.0</td>
<td>2.83</td>
</tr>
<tr>
<td>No vantage point</td>
<td>1.63</td>
<td>2.29</td>
</tr>
</tbody>
</table>
because it was near the observer. Overall, the order from all sides being shown to a drawing with angles changed from 90° was properly assessed by the blind.

The consistency of the judgments is well shown in detail in table 6.5, which notes the number of subjects putting a table in a particular rank. The most favored rank usually dwarfs the other ranks. The eight favored ranks have a mean of 14.4. The remaining ranks have a mean of 3.4. The steps from first rank to second are often large: 17 to 3, 12 to 4, 16 to 3, 11 to 6, 15 to 4, 13 to 9, 15 to 4, and 16 to 5. The concordance in the judgments is statistically significant ($W_{no\ vantage\ point} = 0.304$, $P < 0.001$, $W_{vantage\ point} = 0.186$, $P < 0.01$).

Twelve of the 24 subjects ranked the foldout cube drawing first, the two-squares version second, the square-and-rectangle version third, and the two-trapezoid version last when fitting the cube drawings to the no-vantage-point version of the star table. The probability of anyone order of ranking being assigned to the set of four cubes is one in 24, so to have half of the volunteers concur is unlikely to be due to chance ($p < 0.001$). Furthermore,

| TABLE 6.5Frequency of judgments of versions of the cubic box, when the basis for judgments is a vantage point rationale for the star table and when the basis is a no-vantage point rationale. |
|----------------------------------|---|---|---|---|
| Foldout Cube                     | Rank |
| No Vantage Point                 | 16 | 2 | 2 | 3 |
| Vantage Point                    | 4  | 4 | 4 | 12 |
| Two Squares                      | No Vantage Point | 2 | 16 | 3 | 3 |
| Vantage Point                    | 3  | 4 | 11 | 6 |
| Square and Rectangle             | No Vantage Point | 2 | 4 | 15 | 3 |
| Vantage Point                    | 1  | 13 | 9 | 1 |
| Two Trapezoids                   | No Vantage Point | 3 | 2 | 4 | 15 |
| Vantage Point                    | 16 | 3 | 0 | 5 |

the order that these volunteers chose is exactly the one we would expect if the judgments were based on an understanding of perspective.

Nine of the 24 subjects produced the sequence that ranks the two trapezoids first, the square and rectangle second, the two squares third, and five squares last when the judgments were based on the vantage point description of the table. Again, this number of subjects concurring on an order is unlikely to occur by chance ($p < 0.01$) when the possibility of a given ordering is one in 24. And again the order on which they concurred suggests that judgments were based on the appreciation of some perspective system.

The results imply that the blind generally concur on some impressions of perspective in drawings. They concur on what is developmentally more sophisticated, and they concur in ranking drawing systems that approximate convergent perspective.

Morton Heller and I continued this investigation of blind people's understanding of perspective by studying the ability to deal with several pictorial vantage points around a fixed scene. The volunteers were given a scene with three objects in it. They made drawings from their own vantage point and from others. In addition, they were offered drawings and had to identify the vantage point suggested by the drawing.

The objects in the scene were a wooden cube (9 cm3), a wooden cone (9cm diameter at the base by 8 cm high) and a wooden ball (9 cm diameter). Figure 6.13 shows a plan view of the objects mounted on a rectangular base 30 cm by 42 cm and an elevation. The cube was to the observer's left; in depth it was at the middle of a narrow side of the rectangle. The cone was centered at the far side of the rectangle, midway along a long side of the rectangle. The ball was to the observer's right, at a near corner of the rectangle. The objects were inside the rectangular perimeter, close to the edges but not overlapping them. The volunteers, blind or sighted, first drew the individual objects from above and the side, then identified drawings that we had made of each object from above and the side and presented in a random order. The drawings of the objects from the side contained a line standing for the edge of the table from the side. Feedback was given to ensure that the volunteers knew what each drawing we had made represented.

Next the observers drew the objects arranged on the rectangular base. Initially they were asked to draw the scene life-size, from above, then they were asked to draw it on a reduced scale. Next the observers drew the array from their own vantage point, the front side. Then it was drawn from a vantage point 90° to the side, as though for someone sitting near a short side of the rectangle. Next it was drawn for someone sitting on the far side of the
rectangle 180° away, and finally for someone at 270°, the remaining short side of the rectangle. After the drawing part of the study, the volunteers attempted to identify pictures suggesting various vantage points (fig. 6.13). Five pictures were presented, one for each of the vantage points used in the drawing part of the study.

The participants were 18 blind adults recruited from workshops for the blind in North Carolina. In addition, there were nine sighted adult volunteers recruited from a college campus in Winston-Salem and 11 sighted adult volunteers from Toronto. The blind adults included nine early blind and nine late blind. Of the early blind subjects, seven were congenitally blind and two had lost sight before age three months. None of the early or late blind individuals had more than minimal light perception. None could see form or hand movements. The characteristics of the blind volunteers are shown in table 6.6.

On the drawing task, the volunteers were assigned a score from 0 to 5. In each side-view drawing, the objects had to be arranged in the correct order to be scored as correct. One point was given for drawing both of the top views correctly—that is, for putting the cube in the left center, the cone in the rear center, and the ball in the right foreground. The mean number of correct drawings out of five was 3.4 (s.d. = 1.5) for the early blind, 4.2 (s.d. = 1.1)


<table>
<thead>
<tr>
<th>Early blind*</th>
<th>Late blind</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (Years)</td>
<td>Light Perception</td>
</tr>
<tr>
<td>26</td>
<td>Yes</td>
</tr>
<tr>
<td>34</td>
<td>Yes</td>
</tr>
<tr>
<td>35</td>
<td>Yes</td>
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<td>36</td>
<td>Yes</td>
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<tr>
<td>33</td>
<td>No</td>
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<td>50</td>
<td>No</td>
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<td>51</td>
<td>No</td>
</tr>
<tr>
<td>52</td>
<td>No</td>
</tr>
</tbody>
</table>

*Onset of blindness for early blind volunteers was before age 3 months.
for the late blind, and 3.9 (s.d. = 1.4) for the sighted adults who undertook the task blindfolded (F < 1, not significantly different from chance).

On the identification task, the participants could score up to 10, since there were five drawings to recognize and each was administered twice. The number of correct identifications was 6.7 (s.d. 2.4) for the early blind, 8.3 (s.d. 1.8) for the late blind and 7.4 (s.d. 2.7) for the sighted. The differences between the groups are not significantly different from chance [F (2,24) = 1.2, P < 0.05].

In Toronto, we tested 11 sighted adults (mean age 45 years), who undertook the tasks visually. They were recruited from among visitors to the Ontario Science Centre. The objects were shown to the participants visually, and they responded by making paper-and-pencil drawings. They also looked at black-line versions of the raised-line drawings in the identification tasks. To keep the visual conditions of the tasks somewhat comparable in procedure to the tactual ones, we arranged screens so the participants could not look at the array while drawing or making the identification. A vertical screen hid the objects while volunteers responded. But if during the trial observers wanted to check back with the array of objects, the drawing they were making or trying to identify was covered by a horizontal screen before the array was uncovered. When participants wished, the array was screened again and then the drawing they were considering was uncovered. In this way, the visual exposure was successive, rather like the tactual condition in which the blind observers could first explore the array tactualy and later examine the raised-line drawing, then return to the array if they wished and turn back to the drawing.

The mean score of the sighted adults on the drawing task was 3.4, identical to the score of the early blind. Their mean score on the identification task was 7.5, midway between the scores of the early blind and late blind, and not significantly different from either.

We have tried these vantage point tasks on 15 children ages 6-14 years. Five ages 13-14 were recruited at the Ontario Science Centre and 10 ages 6-12 from a summer camp. The mean number of correct drawings was 2.6 (and the mean number from both of the groups was also 2.6). The early and late blind adult subjects scored higher, at 3.4 for the early blind and 4.2 for the late blind.

The lesson of the vantage point study is that blind people have the same ability as sighted people to envisage the pictorial role of a vantage point on a simple scene. The task, which Heller and I adapted from a task called the three-mountains test by Jean Piaget, reveals that blind people are no more spatially egocentric than sighted people in their drawings of the three objects.
blind can use egocentric directions from a fixed location and lists of bodily turns to left or right in a route without regard to overall directions (north, east, south, west). Yet it is quite a leap from the idea that some people use egocentric direction as a mnemonic for spatial arrangements to the idea that "congenitally blind individuals cannot represent spatial layout" and are "locked into egocentric spatial coding" (Dodds et al., 1982, p.11). Over the telephone I often give people directions to my house that are just sequences of left and right turns, but I expect that my visitors could use a map if I sent one to them by fax. Presumably, congenitally blind people might be able to follow a map too (Berla, 1982) with a raised-line fax.

A more sophisticated argument about touch and space is made by Barber and Lederman (1988). They argue that simple quantitative comparisons reveal little about the qualitative differences between vision and touch as they create their own distinctive representations of spatial arrangements. They insist that attention needs to be paid to heuristics for processing and representing space in each modality. The stamp of the input heuristic will be found on the resulting representation, they think, and they contend that cognitive factors are hallmarks of tactile representations of space. Cognitive heuristics assist touch especially in the apprehension of space, supplementing its more direct perception: "The result of a heuristic rule is combined with the information derived from other sources to achieve a composite representation of space" (p. 100).

Barber and Lederman attempt to use a distinction made by Rieser, Guth, and Hill (1986) and Rieser, Lockman, and Pick (1980). The information acquired during action can allow knowledge of the layout around the observer to be continuously "updated" perceptually (Gibson, 1979). Or, we can use an item of information obtained "cognitively" to change what both Rieser and Lederman call a cognitive map, a "higher-level construction that unifies the sensory input obtained temporally" (Barber and Lederman, p. 100). Logically, it is possible for perceptual information given by a spatial layout to be encoded cognitively (for example, in words), and this in turn could change the cognitive map. Hence in this theory perceptual information could be used directly (perceptual updating) or indirectly (cognitive mapping). Evidently, the fact that the input is perceptual cannot dictate how it is used. The same ambiguity arises with cognitive (such as verbal) input. Our intuitions about east and west directions may have become turned around as we walk around in a subway, but a word from the wise can help put our impressions to rights. Note that in an ambiguous situation, even a slight hint can tilt the balance between one percept and another.

Is it possible to discern what "internal representation" is the basis for perceptual intuitions about space? There is a devilishly difficult logical problem facing any possible indicator of the basis. Space can be expressed in many different ways. It can be described verbally or shown by a map or by coordinates from a given point, or as geographic directions, a picture, or a flow chart, and so on. Further, any descriptive system has its subordinate systems. Maps can be flat or spherical. They can be created by Mercator projections (on cylinders), perspective projections, equal-area projections, or projections that allow the north (and south) poles to be shown by several points and the east and west extremities of the area to be represented twice each in a kind of wraparound. The center of a map's projection can be a particular spot (for purposes of tourism or navigation), or there may be no central spot (the map can be laid out as an endless belt). Once someone knows a physical medium of representation he or she can imagine using it. Most people use many means of representation, both physically and in imagination. It would be inappropriate to ask someone which system he or she always uses, for certain systems match certain purposes. People select the system to suit the needs of the moment. A friend of mine is likely to give directions to her house with a mixture of norths and souths, landmarks, turns to left and right, and useful hints about speed and time.

Not only can space be represented in different ways; each way can be translated into another. A square route can be translated into "ahead one mile, turn left and go a mile, turn left again and go a mile, turn left again and go a mile. You are now back where you started from." A square form can also be described in coordinates from two axes or drawn as a picture. It can be sequential or simultaneous. Understanding the form means knowing how to translate from one system to another, especially from perception to cognition to action. Johnson-Laird (1989) notes that we use general logical skills as well as ones sensitive to context.

In principle, there is no single test that can tell what representational system is being used by someone who knows how to translate from one system to another. As a result, investigators attempt in various ways to supplement tests such as pointing, which is often thought to favor perceptual understanding, and verbal description, which is often thought to favor more cognitive matters. They ask their subjects questions about strategy, or they time the response lags. Researchers who are interested in map-like understanding and in pointing tasks may attempt to distinguish perception-based maps from cognitive maps by showing that responses are swift to pointing tasks and slow to verbal ones. It is possible, however, that the splitting of knowledge into subtypes can be taken even further. Lederman, Klatzky, and Barber (1985) argue that perceptual and cognitive maps in vision are not quite like those in touch, and Barber and Lederman conjecture...
that maps of the near space of manipulation could be different from those of ambulatory-scale space. Alas, there is no reason in principle to stop the subcategorizing at this point.

Nothing is settled by the studies on the basis of mental representation because there is nothing that prevents a person from coding in one way and decoding to answer the test. The logical problems arise in principle in tests of mental imagery in the sighted as well as the blind. Often sighted subjects are asked to undertake a task that involves a continuous transformation of imagery. Close correlations between the time needed to solve a spatial problem in imagination and orderly transformations such as steady rotation are taken as evidence that imagery involves rotation as well as motion to and from an object. But while this evidence is particularly unconvincing is on the issue of the "basic" mode of representation (Millar, 1986). It is always possible to argue that the method of representation is being chosen by the individual being tested from a set of methods, much like choosing one or another projection for making a map. Furthermore, the orderly transformation being used has to be understood as it proceeds, unlike thinking in abstractions, where new combinations of symbols can be decoded later. Visual imagery rarely uses colors, for example, unless we expressly want it to, and when colors are used they often follow the laws we know, not the sensory laws per se. Similarly, chiaroscuro—the illumination laws—is rarely involved in imagery, and usually only when expressly willed. Imagery can be independent of the sensory laws of form, especially the subtleties of perspective that are not consciously known by the observer but are vitally present in vision proper. Thus the sensory bases of perspective, laws of form, color, and chiaroscuro are only partially reflected in imagery, which has more to do with general awareness of form than input-gathering machinery and the laws it incorporates. Hence blind people behave on spatial-imagery tasks much as sighted people do (Kerr, 1983; Finke, 1989).

The general principle that "touch, the major spatial modality for blind people, is different from vision in the way it extracts information from the environment, and in the emphasis it gives to different types of information" (Hollins, 1989, p. 62) does not lead clearly to the supposition that there are major cognitive differences in the ideas of space used by the sighted and the blind. Likewise, the fact that near space is explored by reaching and more distal space by walking does not lead straightforwardly to the idea that the two spaces have major differences in arrangement so far as perception and cognition are concerned. It is dangerous to conclude that each operation used to explore a resource is highly independent. Science, as well as general knowledge, is threatened by this kind of operationism. Common sense tells us that walking along a grassy path and a gravel road have pretty much the same outcome. Science, similarly, rests on the principle that two different operations can measure the same thing.

It is reasonable that the blind could use two different representational schemes and be unable to transfer knowledge instantly from one to the other. Sighted people asked to describe a block letter T as a series of left and right turns, starting at the bottom left vertex, cannot do so without considerable effort. I have encountered blind people who could recall spatial directions I was giving despite the sudden interruption of a telephone call, and others who report that they have enormous trouble understanding spatial tasks. The safe conclusion is that there is nothing about touch as a method of perception that prevents spatial understanding being based on it. Appreciation of each of the major principles of spatial layout can be achieved either through vision or through touch. Whether this is "spatial perception," "cognitive mapping," "perceptual-information-based cognitive mapping," or any combination of sensory-perceptual systems one can devise is in principle virtually unanswerable in the general case.

For any system that allows translation between schemes, the task and the observer's estimation of the best way of solving the task are deeply influential. The observer can be given a task that is about space and perspective. But although the method chosen to solve the task may be useful for the spatial problem, it can alter the task quite a lot. It is crucial of course that the person realizes that the method of solution is relevant to space and knows the meaning of each part of the method so far as space is concerned. One might, for example, reverse A-B-C-D to D-C-B-A because we realize that this is a good way to figure out the order of things left to right for someone sitting opposite. Verbal reversal, we know, is relevant to a 180° turn. The understanding is spatial though the method involves words.

One way to discover the mixtures of spatial understanding and nonspatial labels in a representational scheme used by the blind is to ask them point-blank what heuristics or problem-solving strategies they use in a spatial task. Barber and Lederman (1988) found, in a group of congenitally blind observers undertaking a spatial task, that four imagined an analog clock face with the numerals on the periphery as targets, one imagined a spoked wheel with targets on the fingers and thumb, four kept track of a "start" position, and two specifically mentioned a mental "map." Only one did not describe a method. Adventitiously blind observers relied on what they called a visual map in eight cases and the image of a clock or a hand in four others. Barber and Lederman's volunteers apparently had good spatial skills. They
appreciated which features of the task were spatial, how they were arranged, and how they could be represented spatially in a slightly different fashion (such as by a clock face). The volunteers use spatial models to solve spatial problems.

Rieser, Guth, and Hill (1986) asked their blind observers to walk around a spatial arrangement and then to point out the directions of locations. They contended that the observers "perceptually updated" their understanding of space continuously. That is, they were aware of the changes in direction that occurred during walking (Klatzky et al., 1990), and did not imagine clocks, hands, or other devices. Similarly, Bailes and Lambert (1986) found that blind adults understand a spatial arrangement of straight line segments as a pattern without reporting any need to recode and decode.

I discern no contradiction between studies where spatial apprehension is reported as merely an intuition or percept about an arrangement and studies like Barber and Lederman's where a model is used to solve a task. It takes spatial understanding of the task to know which spatial properties are relevant. The same kind of understanding underlies the model. Any manipulation of the model has to be followed and interpreted by spatial skills. It would be self-contradictory to argue that the blind do not have immediate, direct apprehension of spatial arrangements because they use spatial models to solve imagery tasks. I therefore conclude that Barber and Lederman's results show that spatial understanding by the blind is often advanced enough to be employed as models in imagination, in addition to its use in apprehending spatial arrangements physically present to the observer. The basis on which blind people represent knowledge of space is sensitivity to the relevant spatial variations around them, followed by selection of appropriate models which contain those variations, albeit labeled in familiar forms like numerals on a clock or names for fingers. These forms mark the spatial variations but do not precede them.

Thus, blind and sighted people organize spatial information along similar dimensions and therefore image in similar ways (O'Donohue, 1991). Kerr (1983) argues this case, noting one minor exception. She found that blind adults were somewhat slower than the sighted to image an array, verify statements about the imaged array, and recall and describe the array. Differences in time to respond, however, are not differences in spatial principles, just as e=mc2 said slowly or quickly entails the same principles.

Hollins (1989) concludes that the blind have coherent spatial imagery but adds that blind people may often imagine "in the round" rather than "just like a picture." He devised an interesting test of his conjecture, comparing mental "pictures" to mental "statues." Hollins asked blind subjects to image a flat checkerboard with 8 by 8 squares. He then dictated which squares were filled in. The result was an image of a dog. Hollins also asked subjects to image a large cube made up of 4 by 4 by 4 smaller cubes. The image of the cube uses three dimensions, like a statue, and the checkerboard uses two, like a picture. Hollins dictated which of the small cubes should be filled in. The result took the form of an armchair. Hollins found that the longer a person had been blind the better he or she was able to form and recognize the mental "statue" in comparison to the mental "picture."

Haber, Haber, Levin, and Gramata (1988) tested blind adults who were highly proficient at navigating within their environments. They were asked about a familiar space involving several rooms with more than a dozen objects located therein. Each volunteer was asked to judge distances to the objects from where he or she was seated. The procedure also involved estimating the distance between each pair of objects. A highly accurate map of all the locations, with a slightly reduced scale, could be drawn on the basis of the judgments from anyone of the subjects, whether congenitally blind or adventitiously blind. Judgments from the observer's location were about as accurate as judgments of distances between pairs of objects. This important study shows that spatial understanding in a blind person who is reasonably skilled at using the environment reflects proportional distances and good understanding of the vantage point, as well as distances between two objects away from the vantage point.

Problems in perspective entail consideration of the direction of parts of the object from a vantage point, as well as convergence of the directions of the parts as the object recedes into the distance. The blind appreciate vantage point principles, relevant directions, and convergence. This is not to say that they can solve any and all perspective problems. There are many unsolved riddles in the relations between perception, perspective, and depiction, and it is hardly likely that blind people can explain them all any more than sighted people can. Rather, the conclusion is a more modest one. Key principles that create perspective effects are understood by the blind because perspective is a science of direction, and direction is as relevant to touch as it is to vision.