Perception, 2003, volume 32, pages 1059 – 1071

DOI:10.1068/p3425

Haptics and projection: Drawings by Tracy, a blind adult

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Received 15 July 2002, in revised form 3 May 2003

Abstract. Outline drawings in a raised form were made by a blind woman, Tracy, who has been blind from very early in life. Highly practiced in drawing, she reports she is largely self-taught. To invoke matters of projection, she was asked to represent an object with faces slanting away from the observer, a fixed array from different vantage points, and sets of objects in depth. In particular, she drew a cube balanced on a vertex, three objects from different vantage points, receding rows of glasses, and a house. Her drawings included features of parallel and polar projection. Her use of these features may reflect an appreciation of direction from a vantage point, which observers deal with via haptics in everyday tasks. Tracy may have advanced drawing-development skills common to the blind and the sighted.

1 Introduction

We offer here a description of spatial aspects of raised-line drawings by an early-blind adult who has been interested in drawing since she was a child. As there are very few early-blind adults who have practiced drawing, a case history such as this one is of special interest. The drawings contain features characteristic of projection from a vantage point, so they are significant for current debate on haptics and viewer-centred pictures.

1.1 *Projection, direction, and drawings*

Lines in outline drawings can be made raised, and evident to touch. Raised-outline drawings of common objects such as forks, hands, and profiles are identifiable to a significant degree by the blind and the sighted, children as well as adults (Kennedy 1993; D'Angiulli et al 1998). While this broad interpretation of the evidence is well established, the full extent to which pictures belong in more than one sense is still unclear. In particular, one feature of visual pictures that is questionable in tactile drawings is perspective projection (Hopkins 1998, 2000). There is little doubt that a raised-line form that is similar to a flat shape such as a circular plate or a knife can readily be understood as a picture, but an ellipse standing for a brim of a cup might be considered a challenging feature. Kennedy (1974) noted that one might expect tactile pictures of flattish objects (imprints) to be easier for the blind to identify than ones with features in depth (projections), but he found they were identified at the same rate. Lederman et al (1990) and Kennedy and Bai (2002) report similar findings [for discussions, see Arnheim (1990), Heller et al (1995), Lopes (1996, 1997), Eriksson (1998), Holmes et al (1998), Heller (2000), and Landerer (2000)]. Here we will examine drawings by a blind adult for projective features and discuss possible bases in haptics (Gibson 1962; Millar 1994).

Millar and Al-Attar (2002) point out that haptics involves assessing spatial-reference cues, including matters of direction. Haptics gives us access to information on the directions of parts of objects from one's vantage point, and the directions of parts of objects from each other. Accordingly, some features of tactile pictures may represent the directions of parts of objects from the observer. However, a set of directions may be represented on a flat screen via any of several geometries, in particular linear perspective's polar projection (a form of central projection from a vantage point which

entails convergence with distance) and parallel projection (in which parallels do not change their projected width with distance). For convenience, we will use the terms polar and parallel projection for these two systems.

In many studies of tactile pictures, some geometry of projection is relevant to the picture, but which is often unsure. Imprints offer similarity, in which angles are preserved and so true forms are shown (circles represented by circles for example). But the same shape results if polar or parallel projection is applied to a target form parallel to the picture surface. Also, overlap shown by T-junctions in the image is relevant to both polar and parallel projection. Further, if a form is rounded like a ball or cylinder, but has its maximum dimension in a plane parallel to the picture plane, its cross section can be the same form as a parallel or polar projection. Evidently, interpretation of pictures needs to consider several possible bases for a given feature.

In addition, a picture might be identified despite projective features rather than because of them. That is, one might identify a drawing of a cup by a U shape for the bowl, together with a C shape attached to the U, for the handle, while simply ignoring the elliptical shape projected by the brim.

In a drawing task, the subject provides the features depicting the form, and so if a feature relevant to projection is present, and recurs, it is likely that the subject has indeed considered it and deemed it useful. This helps finesse the problem of a subject in a picture-identification study simply ignoring features present in a picture.

1.2 *Mixtures of projections*

Drawing tasks can be designed to incur issues of projection. Notably, a subject can be asked to represent an object with faces slanting away from the observer, a fixed array from different vantage points, and arrays of objects in depth. The results from the sighted often contain mixtures of features from different projection systems (Willats 1997; Milbrath 1998), mixtures that recognition studies have not yet attempted to explore. It is rare that anyone draws following the rules of perspective comprehensively (Kennedy and Juricevic 2002). A group of features might be partially coordinated views along with multiple local graphic solutions (Golomb 2002, page 30). A particular projective feature may be the starting point for a drawing, but when other features are added to this scaffold, the new features may be imprints, or simply convenient ways to complete the drawing (Freeman 1986). Features of projection such as convergence may be applied to just one or two components of a scene (Landerer 2000, pages 13 – 170). A "unitary conception that dominates the composition [is] rarely achieved by children or adolescents" writes Golomb (2002, page 30) about sighted children.

As Milbrath (1998, page 156) notes, our ability to draw using projection depends on spatial knowledge. Projective features are based on general knowledge of the space to be represented, relating this to a picture surface and a vantage point. For example, verticals and obliques on the 2-D picture surface may be successful in showing edges receding in depth to the extent these dimensions match projective characteristics of the 3-D scene. That is, the orientation of the picture surface with respect to the scene needs to be considered. Developmentally early pictures with projection do not match a scene dimension chosen at random with a picture dimension chosen at random. The spatial knowledge of the scene dimensions and the 2-D picture-surface dimensions are not two separate entities, to be matched by fiat. For example, up – down in the picture is not generally used to stand for left – right in the scene. Only some of the possible correspondences of scene and picture dimensions are commonly adopted (Cox 1992). Typically, the projective features used first in drawing development in the sighted are ones that would be present on picture planes parallel to the target form in the scene and orthogonal to a line from a vantage point to the target object. The result is that the vertical orientation of a target object is often preserved in developmentally early

projective pictures, and front faces are drawn as similar forms though receding sides are foreshortened (Nicholls and Kennedy 1992).

The dimensions of the scene and the 2-D picture surface are accessible through haptics as well as vision (Millar 1994). Hence, the blind may develop the same notions of space and picture surfaces as the sighted in many respects. If so, projective features in drawings by the blind would be similar to those from the sighted.

In the present study, a blind subject, Tracy, was asked to undertake drawing tasks for which projection would be relevant, for example a cube balanced on a vertex and a vertex to the fore. The question at issue was would she use some forms of projection for some features of the referent, and if so which ones? If successful identification in previous studies on haptic pictures was based on ignoring projective features and detecting true forms in their midst, then few if any projective features would be evident in the drawings. If projection is relevant to haptics and the blind, then slant, change of vantage point, and depth would affect features in the drawings. If projection is handled feature by feature, piecemeal, rather than applied to all parts of a depicted scene, then the drawings would present mixtures of features from different geometries. We present Tracy's drawings, examine them for projective features, or conformity to other kinds of rules, and compare them to drawings in studies on sighted children.

2 Method

2.1 *Subject*

Tracy, from New York, is an adult woman aged forty, totally blind from childhood. She lost her sight during her first 24 months as a result of retinal blastomas. She gained her experience in making drawings after her loss of sight. She reports enjoying drawing as a child. She still enjoys drawing, and draws on her own initiative. She reports she was given general encouragement in response to her drawings rather than explicit instruction. She often drew her toys (eg a toy house) or domestic objects (eg pets). She regards herself as largely self-taught. For example, she reports making a drawing of a toy horse, and then, dissatisfied with the result, comparing it to the model and making another drawing which she deemed better, and then re-examining her horse and making still another drawing which she deemed better, repeating the process until she herself was satisfied. Asked about a drawing of a cat, she reported that her drawing was of her own cat. However, she uses some devices which are formally taught in geometry classes such as arcs to indicate angles. Asked explicitly whether sighted people have taught her to draw, she said that sighted people such as her parents have been positive about her drawings but generally do not make detailed comments or give suggestions. Tracy has participated in previous studies of tactile pictures (Kennedy 2000). She was invited to participate further because she was one of the most adept and motivated early-blind subjects with total loss of vision we have tested in studies on tactile pictures (Kennedy and Merkas 2000; Kennedy 2003).

2.2 *Apparatus*

Tracy's drawings were made with a raised-line drawing kit from the Swedish Organisation for the Blind. She made the drawings on a plastic sheet (21.5 cm by 31.5 cm) resting on a rubberised board, using a ballpoint pen. The result is raised lines when the pen writes on the sheet, making the sheet pucker. Conveniently, the long thin lines of puckers are raised on the side from which pressure is applied.

2.3 *Drawing tasks*

Tracy was first asked to draw a cube, orientation unspecified. Then she was asked to draw a cube balanced on a point with three faces towards her, which requires showing features at different distances from the observer. The orientation of the cube-on-a-vertex was demonstrated to her with an 8.5 cm-wide wooden cube, placed in front

of her, which she explored with both hands at first, and then occasionally with one hand during the course of drawing.

Next, she was asked to use several vantage points in drawing three differently shaped objects set on a rectangular mat on the table in front of her ie Piaget's 'three-mountains' task (Heller and Kennedy 1990). The first vantage point was her own, the next was the vantage point of someone on the other side of the mat, the third was the vantage point of someone on the side of the mat to her left, the fourth was from the side to her right, and the last was from someone above the mat. These were demonstrated to Tracy with a doll, 18 cm tall. For the vantage point above the mat, the doll was held above the mat with its feet pointing to the vantage point on the side of the mat to Tracy's right. The objects to be drawn were the 8.5 cm-wide cube, a wooden ball 9.5 cm diameter, and a wooden cone 9 cm tall on top of a 9 cm diameter base. The rectangular cardboard mat on which they sat was 44 cm $\times$ 30 cm, with the long axis parallel to Tracy's median plane. The ball was placed in the middle of the mat's near side from Tracy's vantage point, the cube in the far left corner, and the cone in the middle of the right side.

Next, Tracy was asked to draw two rows of plastic drinking glasses (tumblers, 9 cm tall) with three glasses in each row. The glasses were arranged on a table in two rows stretching away from Tracy. The pair of glasses near to her were about 5 cm from the side of the table, the next pair some distance further along the tabletop (about 25 cm from the side of the table), and the third pair still further away (about 50 cm from the side of the table) but within reaching distance. Each pair of glasses was about 35 cm apart left to right and, if the rows had been extended, Tracy would have been sitting in the middle of the rows.

Finally, Tracy was asked to draw a house, and then a model house with a peaked roof from two vantage points. The house was the 8.5 cm cube with a folded card as the roof (6 cm to the peak). One vantage point was at the table end to which the roof presents an inverted V shape. One was to the front, to which the roof presents a slanted rectangle. The front of the house and the roof are both rectangles as true shapes, but differ in slant.

3 Results

Most of Tracy's drawings can be described as using similarity of shape, some suggest parallel projection with foreshortening and one likely used polar perspective.

Tracy made three drawings of a cube (figure 1). The first was a quadrilateral (representing a face with a similar shape) with arcs in the corners (based on a convention). She said the arcs were to mark places with corners, being a device for showing angles that she has been taught in geometry class. When asked to show what part of the cube the quadrilateral showed, she touched the vertical face of the cube in front of her.

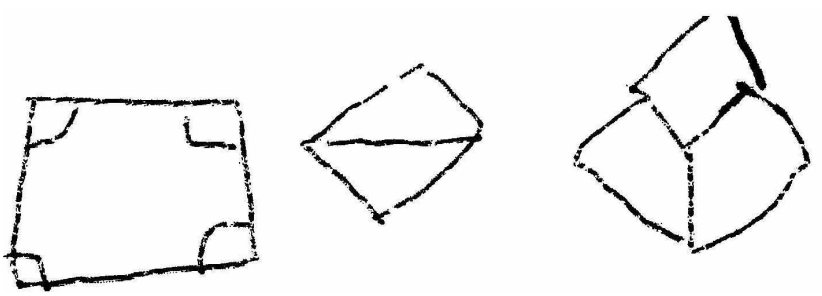

Figure 1. Three drawings by Tracy, a totally blind adult: a cube, a false start, and a drawing of a cube standing on its vertex.

She then made a first attempt to draw the cube sitting on a vertex. The result was a quadrilateral with a diagonal. She said this was a false start, and drew again. This time she drew a Y shape and, when asked, she indicated this stood for the front vertex of the cube by touching its corners and the related lines in the Y form one at a time in order. She then completed three quadrilaterals by adding two lines in a V shape to each of the V shapes of the Y. This drawing suggests use of projection since features at different depths and orientations are shown in one plane.

Tracy made five drawings of three objects on a mat, and all were correct for their respective vantage points. In addition, the forms were similar in shape to their referents; interior lines were used to show curvature, and the conventional arc marked corners. Also some features suggest foreshortening.

The upper drawing in figure 2 is the drawing showing the array from the vantage point of a doll to Tracy's right, and the lower drawing is from a vantage point of the doll held above the array (feet pointing to Tracy's right). The ball is shown by a circle with concentric arcs in the interior. The cone is shown by a triangle, with some interior arcs across the triangle in the lower version, which are to suggest the referent is rounded, according to Tracy. The cube is shown by three parts of a square, open at the top. The lower drawing contains two arcs at corners, and a line close to the extreme left but exterior to the open-top square, to indicate the receding side of the cube. Excluding the arcs for corners, Tracy included interior lines or exterior lines in thirteen of the fifteen drawings of the three objects. The rectangular mat is shown by three parts of a rectangle, open at the top. Tracy drew a similar arrangement for the vantage point above the array as for the vantage point to her right, but said she had drawn it "smaller because the doll was taller". Indeed, the right side of the rectangle was drawn 5.3 cm long for the vantage point on the right, and diminishes to 4.4 cm for 'above', and likewise the vertical line for the left front corner of the cube was shortened from 1.6 cm to 1.3 cm. However, the vertical height of the cone and the vertical diameter of the ball were unchanged.

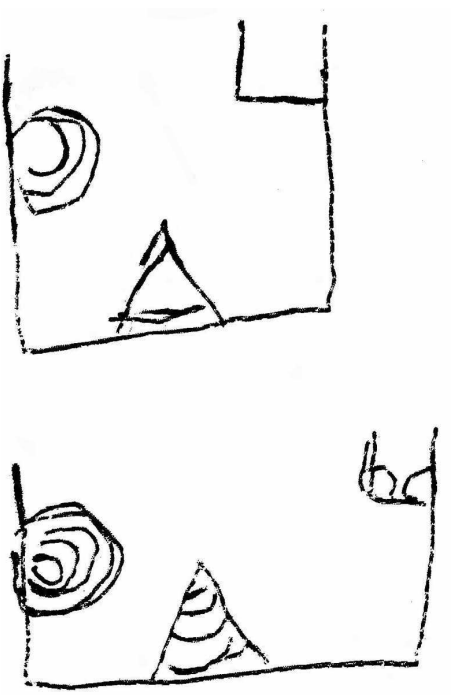

Figure 2. Two drawings by Tracy of three objects on a mat, each depicting a cone (lower middle), a ball (middle left), and a cube (upper right).

The drawing showing the vantage point opposite to Tracy's correctly showed the cube in the bottom right corner, the cone in the middle left, and the ball in the upper middle. The drawing for the vantage point on the left correctly put the cube on the bottom left, the cone in the upper middle, and the ball in the middle right.

Figure 3 shows Tracy's drawing of two receding rows of glasses, which uses foreshortening and height in the picture plane. She drew the glasses as U shapes (similarity of form). She used two large U shapes (2.1 cm tall and 3.5 cm apart) for the pair of glasses near the observer, two smaller U shapes (1.4 cm tall and 1.9 cm apart) spaced closer together for a pair of glasses further away, and two still-smaller U shapes (0.6 cm tall and 1.1 cm apart), spaced even closer together, for the glasses furthest away on the table. The further the glass, the higher the U on the picture plane. Also, the space from the bases of the glasses in the lowest row of glasses to the bases in the middle row is 3.5 cm, but the distance from the bases of the middle row to the bases of the upper row is slightly less, 3.0 cm. The drawing involves foreshortening: diminution in size of objects, diminution in left–right spacing, and (slightly) diminution in vertical spacing.

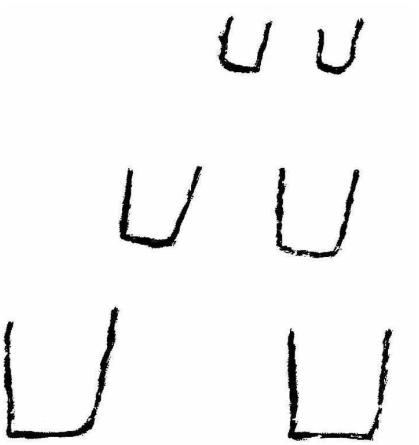

Figure 3. A drawing by Tracy of two rows of tumblers.

Tracy noted that the U shapes on the right were not aligned and commented that she had moved the upper U too far to the right.

When asked to draw a house, given no model, Tracy drew a house from the gable end with a chimney, a front door, and a window (figure 4), using similarity of form. Then she drew a model of a house, first from the gable end showing the inverted-V roof and second with the roof to the fore, depicting the roof as a rectangle (figure 5), again using similarity of form. Tracy said that the drawing of the house with a rectangle

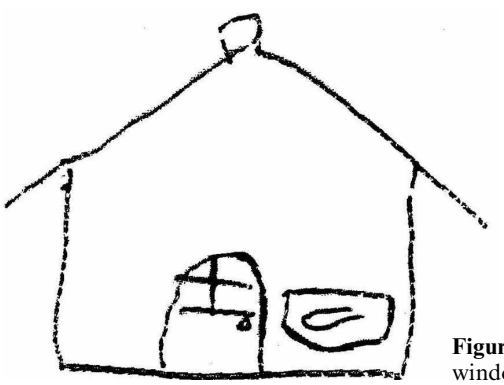

Figure 4. A drawing by Tracy of a house, with a door, window, and chimney.

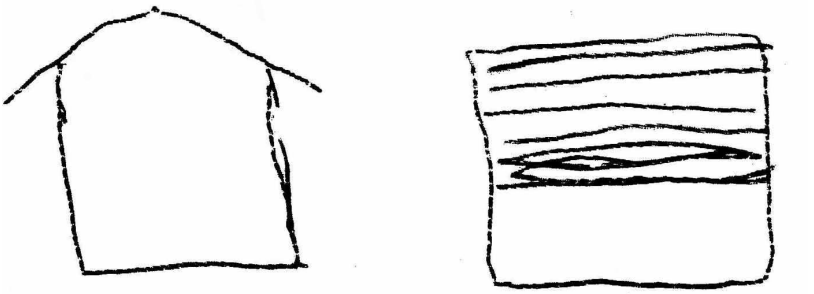

Figure 5. Two drawings by Tracy, showing a gable end of a house and the same house from a vantage point in front of a rectangular side with a rectangular roof on top.

for the roof did not show the roof's slant. She added a texture of horizontal lines to the quadrilateral showing the roof. The texture has no consistent gradient top to bottom, since its widest spacing is for a pair of lines in the middle, about 0.4 to 0.7 cm in width, and the top space is 0.2 to 0.3 cm wide, and the bottom 0.3 to 0.5 cm wide. This use of the presence and absence of texture to distinguish surfaces at different slants involves the invention of a convention.

4 Discussion

Tracy's drawings include features from more than one kind of projection (with some ambiguities that require care in interpretation), mixed with use of similar forms. The receding-glasses picture features a polar projection.

4.1 *Imprint, cross-section, or projection*

Tracy's first drawing of the cube is a rectangular form, an imprint. It has similar angles to the face. It could be a cross-section, polar projection, or parallel projection. The final drawing of the cube suggests some use of projection. It could not be an imprint or cross-section. The object features depicted in the image are at quite different depths and orientations from the observer's vantage point. Three frontal faces protrude toward the observer's vantage point to meet at a vertex and six edges of occluding surfaces are set further back. Referents in different planes are imaged on one plane, so the picture has features of projection. However, as a polar or parallel projection, the drawing is inconsistent. The uppermost quadrilateral has a rectangular form, but the lower quadrilaterals have especially long lower obliques, so they each contain two right angles (drawn roughly), an obtuse angle, and an acute angle. In a consistent parallel projection, the lower obliques would equal the upper oblique limbs of the Y, and in a polar projection they would be shorter.

Two simple considerations favour treating the central-Y picture as a projection: one to do with regions of the picture surface denoting faces and one to do with line depicting edges of occluding surfaces (Willats 1997, page 125; Milbrath 1998, page 68). The fact that Tracy depicts three and only three faces is a rather basic indicator that projection is at issue (Cox 1992). With the cube balanced on its vertex, only three facets faced the observer. Also, an edge of an occluding surface of a cube, provided by a convex corner between two surfaces, only occludes from particular vantage points. Movement of the observer reveals the erstwhile back surface.

4.2 *Drawing development and local solutions*

While Tracy is not a child, and has general knowledge and cognitive skills not available to children, it may be useful to compare her solutions to drawing tasks to those common in drawing development. Nicholls and Kennedy (1992) found less-sophisticated pictures of a cube common in 7–9 year-old sighted children include 'foldout' sketches

in which many faces are shown, attached to one another, including ones that are not in front. Willats (1997, page 195) describes foldout drawings as derived from an object-centred description. Tracy's cube drawing is more sophisticated than a foldout version, and so could be derived from an observer-centred description in Willats's terms.

While projection is relevant to the figure, no single projective geometry can account for it all. It uses the true shape of one face, partly preserves some right angles in other faces, and partly uses parallel obliques [a mixture which Willats (1997, page 182) describes as near oblique]. Its obliques require special attention. The side faces are each drawn with parallel obliques attached to the stem of the Y. The upper oblique is the limb of the Y and the lower one is attached to the base of the Y. A drawing like this could be following a rule such as: draw a face as a true shape and represent side edges by oblique lines (Willats 1997, page 184). However, we need to account for the different lengths of the obliques, and to explain why obliques are effective representations of faces at a slant to the frontal plane. A simple account would be that differences in lengths are accidental features of the difficulty in applying motor skills without visual guidance. But the differences are marked, and may reward further thought.

Michelmore (1978) reported sighted children often draw the upper oblique of a side face shorter than the lower oblique (as in Golomb 2002, figure 49, from a boy aged twelve). Nicholls and Kennedy (1992, 1997) found the shorter upper oblique of the side face to be present in drawings from teenagers and adults. They pointed out the feature to subjects who had drawn it, and provided guidelines with dots to make it easy to see the lengths of the lines. Given an opportunity to make a second and 'better' drawing, the difference was repeated, suggesting that the feature was intended.

The short oblique may arise from retaining right angles at the top and extreme left and right corners of the side faces (Landerer 2000, page 197). Tracy drew the central Y first, then the top. The lines for the top meet at four right angles. Tracy then finished the drawing by adding V shapes, including lines at right angles to the limbs of the Y. The quadrilateral for the left face has a second right angle at its leftmost corner (and vice versa on the right).

Once the Y was drawn, it offered a scaffold for subsequent lines. Presumably building on the limbs of the Y and using right angles results not only in parallel obliques but also in the lower oblique having a relatively long route back to the base of the Y to close the depiction of the side face. If so, the difference in length of obliques is an entirely local solution, a consequence of earlier decisions: projection is used to select object aspects to be depicted, a feature is chosen as a starting scaffold, similarity governs some angles, and the faces are closed as convenient.

The argument that projection, scaffolding, and preserving right angles creates differences in lengths of obliques may apply to the sighted subjects in Michelmore (1978), and Nicholls and Kennedy (1997). Writing about sighted children of age 9 – 10 years, Willats (1997, page 183) argued that quadrilaterals used in cube drawing "are intended to represent square faces [and] the child will try to retain as many right angles in them as possible". We have added "as many as the starting scaffold allows". Tracy's starting Y contained only one right angle in keeping with the true angle of a corner of one face, and constrained the number of right angles possible thereafter.

It is instructive that the drawing began as a central Y with a vertical stem. In depicting a cube's vertex, the Y represents a feature in three dimensions. (A 2-D corner would leave an L junction as an imprint.) Tracy first drew a quadrilateral, but then discarded this drawing and began the drawing she deemed acceptable, so the Y is not a consequence of an entirely local solution driven by having initially drawn a face, then subsequently tackling the problems of getting two faces to join at an edge and then adding a third (Freeman 1986; Golomb 2002).

4.3 *Vantage points and vertical order*
In Tracy's 'three-mountains' drawings, the order of the objects is rearranged aptly to suit the directions of objects from each vantage point. Both horizontal and vertical order from the imagined observer are consistent.

The mat is shown by a similar or true shape, the ball by a circle, the cube by a square, and the cone by a triangle. All could be cross sections, or have a debatable basis in projection. For example, the cone is a triangle with a flat base, as if the vantage point was level with the base, a vertical picture plane was orthogonal to the line to the object from the vantage point, and projecting rays were parallel to the base. The mat is drawn as a rectangle as if projected vertically. The triangle is most surely a mixture of systems, since its curvature is shown by arcs but the base is horizontal. The curves would be horizontals if parallel projection had been used systematically. Evidently, the overall drawing is at best a mixture so far as projection is concerned.

4.4 *The use of vertical order (height in the picture plane)*
Tracy used increasing height in the picture plane to show which of the three objects was close, and which were far—this deserves comment. One intriguing possibility is this entails projection. In showing depth along a ground surface, height in the picture plane replicates the directions of objects from a vantage point. Consider a mat beneath our feet, as we stand on say a long airport corridor. Let there be a chair 2 m away and a manhole cover 1 km away. The mat is directly below, and the foot of a chair leg is higher in direction (say 45° above the mat in elevation). In direction, the manhole cover is almost another 45° higher still. Visually, we would elevate our gaze 45° to saccade from mat to chair leg, and almost the same again to change our fixation from the chair leg to the manhole cover.

Objects higher in direction from a vantage point in the real array are depicted by forms higher in the picture plane, and hence also higher in direction. This account can explain how obliques show depth. Some sections of an oblique line are relatively high in the picture plane, and the base of a distant object on a ground plane is also relatively high in direction from the observer's vantage point. The match in relative height may be the basis for the depiction. It follows that if an object above head height (a cloud) recedes in distance it becomes low in direction (Kennedy and Mirabella 1998), and can be depicted by sections of an oblique lower in the picture plane.

All the obliques in the drawing of the cube with a central Y in figure 1 suit this higher-in-picture-plane/higher-in-direction principle. However, we caution that the obliques in the image depict corners that were physically tilted—set physically part way between vertical and horizontal—as well as receding in depth.

4.5 *Close verticals as foreshortening*
The lower drawing in figure 2 was Tracy's last in the 'three-mountains' task. It was the one that included most interior arcs in the circle and triangle. It may be her most complete drawing in this set. Consequently it is interesting that the cube was drawn with two vertical lines on the left. The target cube was on the right side of the mat. Therefore, the receding left side of the cube was exposed from her vantage point. In two other drawings, the cube was drawn on the line depicting the near edge of the mat. In these, the drawing with the cube on the right side of the mat had lines depicting the receding and exposed left side of the cube, and the drawing with the cube on the left side of the mat had lines depicting the receding and exposed right side of the cube. As in figure 2, the lines in these drawings that depicted the receding exposed sides were close to the line for the near corner of the cube, suggesting the side is shown with foreshortening. (Only three drawings included these lines depicting the receding side. As in the upper part of figure 2, in two drawings with the cube high in

the picture plane and shown as at the rear of the mat, the extra lines for the receding face were omitted.)

In each case the particular receding side Tracy depicts is in keeping with the imagined vantage point. This suggests projection is relevant. The closeness of the lines for the side suggests foreshortening. However, foreshortening in a single dimension (such as left – right or vertically) is produced by parallel projection. Hence, the foreshortening here indicates projection but not what kind, polar or parallel. (The fact that in the lower part of figure 2 the line for the further edge of the side of the cube is shorter than the line for the near corner is likely an accident since in another drawing with such additions the lines for the far and near edges are equal in length.)

4.6 *Closer with distance or true form*

One revealing comment from Tracy was that a vantage point from above would reduce the array's size. If Tracy's comment that the image is "smaller because the doll is taller" is to do with distance, it suggests polar projection, as distance is not relevant to the foreshortening produced by parallel projection. Fortunately, the rows-of-glasses drawing, figure 3, a remarkable drawing, offers much more decisive evidence about polar projection.

The drawing has the hallmark of polar projection, since increasing distance is shown by decreasing sizes of the U shapes (vertically and horizontally) and decreasing spaces between the U shapes (vertically and horizontally). Polar projection requires convergence both horizontally and vertically. Decrease is most evident in the case of the U shapes, but in addition the space from the base of the glasses in the lowest row of glasses to the bases in the middle row is 3.5 cm, and the distance from the bases of the middle row to the bases of the upper row is slightly less at 3.0 cm.

In drawing a house, Tracy explicitly recognised the problem that she had simply drawn two rectangles, one the wall and one the roof. Nothing indicated a difference in slant. Tracy added texture to the upper rectangle to distinguish the two, but she did not modify the texture to reveal which part of the roof was near or far. Evidently, the use of convergent sides to indicate slant did not occur to Tracy. She retained rectangularity, in accord with the drawing of a cube balanced on a vertex in figure 1, and her drawings of the mat in figure 2.

4.7 *Conventions and spatial comprehension*

Some individual object shapes or faces are represented by true shapes (eg right angles by right angles) in all of Tracy's drawings, though the location of objects with respect to a vantage point influences selection of faces to show arrangements of groups of objects and some foreshortening (Milbrath 1998, pages 221 – 223).

Cautionary notes are in order, since there are many roads to Rome. We have argued Tracy's drawings suggest some use of projection and direction of parts of the scene. Notably, figure 3 shows convergence, and could well be derived from awareness of the directions of receding glasses. But an alternative account of the glasses drawing is that Tracy began with an object-centred description and has learned a rule such as "use convergence and change of scale with distance to represent spatial relations in the third dimension". Is the basis of the drawing a spatial awareness that includes directions from a vantage point, or an awareness of distances combined with a rule that produces suitable changes in direction, given only distance from a vantage point? At what juncture in making a single drawing do distance and direction become relevant? The route cannot be established on the basis of the destination. But here we have mustered several tasks that involve changes in distance and direction to show that several vantage point tasks are tackled aptly by Tracy. As the vantage point was changed in relation to the scene, Tracy altered her drawings in appropriate ways: drawing a cube, three objects on a mat, and a house. If she had derived her drawings

from object-centred descriptions without regard for a vantage point, she would have been unable to make appropriate modifications.

A severe criticism of our account would be that Tracy has been taught a series of conventions and applied them in the fashion of a habit or painting-by-numbers. This seems unlikely as a general account. Some of the tasks are unusual (eg cube on a vertex, three objects on a mat from above and to the right, receding rows of glasses). Also she corrected her own false start. Further, her drawings contain idiosyncratic mixtures of features, rather than a single projective system which might have been taught or copied. We cannot rule out influences from other people on Tracy. Like the sighted, she is surrounded by commentary on pictures. But we suggest any comments that influence her may well depend mostly on her own comprehension of depiction, and much the same goes for many sighted children and adults.

Golomb (2002, page 31) describes sighted children as drawing objects, wherever they are in the scene, as having a preferred frontal orientation, and showing canonical orientations, well into adolescence. These forms are ones that would be projected to a picture surface orthogonal to a line joining the vantage point to the depicted form. Likewise, Willats (1997) describes vertical oblique as a form of projection in which rectangular mats are shown as rectangles, profiles of people are true, and there is no convergence with distance. He notes this is common in art from India (page 51). Horizontals stand for the right-to-left dimension and depth is shown by the vertical dimension. Oblique projection, he comments, uses parallel obliques for depth. Much in Tracy's drawings fits his definition, but the rows-of-glasses drawing adds polar-projection features.

Tracy varies the form of projection from one drawing to the next, and within sketches some features are projective and some are shown by similar shapes. Some use foreshortening in one dimension and some in two. Some scaffold on earlier decisions in the drawing process in order to complete a face. Evidently, her tools permit idiosyncratic combinations (Milbrath 1998, page 183). In drawing the house with the ridged roof, convergence is not applied by Tracy, though it would solve the problem of ambiguity. In drawing faces of objects, she preserves similarity of shape at the expense of slant and distance information that would be provided by convergence, though she shows she can apply convergence to space between objects.

4.8 *Tracy's skill and development's systems*

In drawing-development theory each person learns several systems. Each system can be retained as a more sophisticated one is adopted. We suggest each generates certain features on the page, given certain forms in the landscape, and does not operate comprehensively across the scene. The result is mixtures of features selected from different systems in a single drawing, or a set of drawings, in drawings from blind and sighted adults and children.

We speculate that Tracy may more readily apply projection to spaces between objects than to angles of parts of their faces. Space is depicted by an empty part of the drawing, and this may be sufficient to support recognition. Tracy may consider recognition would be impeded by changing the angles of a foreground form. Tracy may therefore readily use true form or foreshortening that preserves angles, consistent with parallel projection to a picture plane, orthogonal to the line joining the observer to the form to be depicted. This would allow her to foreshorten one dimension of a receding face (of a cube). Also it would allow her to foreshorten two dimensions of items parallel to the picture plane (glasses), for these preserve similarity of form. It would permit her to foreshorten the spaces horizontally and vertically on the picture surface since no angle defined by explicit lines meeting on the page differs from true form, although the alignment of the objects across space is depicted by two converging obliques.

In a drawing-development scheme from Milbrath (1998), a younger category includes a left-to-right ground line on which objects are placed in order of distance from the observer. Her most advanced principle for the use of the ground is the use of a plane, not a single line, which fits Tracy's drawings of the three mountains and the rows of glasses. Her scheme includes a middle-level category, using 'one perspective indicator', which fits Tracy's drawing of a cube balanced on a vertex, since a Y for a protruding vertex is 'a perspective indicator'. In her scheme [and related schemes in Kennedy (1993) and Willats (1997)], foreshortening left – right and vertically indicates Tracy's simple drawing of the glasses uses a principle at the highest level of projection drawings.

Tracy is more practiced with drawing than most early and congenitally blind subjects in the literature on haptic pictures. She shows a high level of interest in pictures. She tackles drawing tasks with zest, and offers lively comments. She is of special interest to research in haptic pictures as she may reveal a level of skill which many blind people can reach self-taught with a modicum of opportunity. Her drawings are akin to ones that emerge in normal drawing development of sighted children, and reveal some use of advanced principles. They support the hypothesis that early-blind people may proceed through a drawing-development trajectory much like sighted people, including features of projection. We suggest her drawings are based on comprehension of spatial relations that are important in everyday use of haptics, including directions of parts of a scene from a vantage point. For the sighted and blind alike, comprehension of these directions could allow projection to a picture surface orthogonal to the line joining a vantage point to the form.

Acknowledgment. We thank Patrick Cabe and an anonymous reviewer for helpful comments.

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© 2003 a Pion publication

ISSN 0301-0066 (print) ISSN 1468-4233 (electronic)

PERCEPTION
VOLUME 32 2003

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