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# Drawings from Gaia, a blind girl

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**Abstract.** Gaia, a totally blind girl, was asked to make raised-line drawings. Gaia's vision at best was peripheral. She draws out of interest, and has drawn since preschool with encouragement from her mother. She was asked to draw objects and scenes involving depth from a vantage point, eg a table from below, two cars (one behind the other), and two parallel rows of apples (receding from her, on a table top). Gaia represented space in her drawings using T-junctions for overlap, height in the picture plane, parallel projection, and inverse projection. That is, Gaia uses features of systems common in sighted children's drawings. The development of drawing in blind and sighted children may be similar in good measure because haptics provides access to many of the same spatial principles as vision.

## 1 Introduction

Remarkable drawings from a blind girl, Gaia, will be discussed here. They deserve close attention. She shows an appreciable level of skill and initiative, comparable to sighted children's. Because Gaia has drawn from an early age, steadily encouraged by her mother, her prowess may indicate what many blind children can achieve with opportunities like those of sighted children, perhaps underwritten by the hypothesis that their schemes for spatial representation in pictures can be akin to those used by sighted children. One reason for this expectation is that in several respects haptics provides information for a tactile space much like the space defined by visual information.

Gaia was asked to render 3-D objects and scenes in 2-D pictures. Projection from 3-D to raised-line pictures is a matter of controversy (Hopkins 2000), though Heller et al (1995, 2002) conclude that visual experience is not essential for comprehension of perspective drawings of geometrical objects. Strikingly, Gaia may use several systems, such as parallel and inverse perspective, and a 'foldout' system.

Haptic pictures are raised-line drawings of common objects, such as a car, a person, a cup, and a telephone. These pictures can be made with a raised-line kit, a board with a face coated with rubber on which a textured plastic sheet is placed. Raised lines are produced when an ordinary ballpoint pen is pressed on the sheet, writing on it. The surface puckers and forms a raised line that can be felt from the side from which the pressure is applied. Blind and blindfolded participants generally identify pictures in raised-line drawings after a longer exploration time than would be needed in visual inspection, and at a lower accuracy than vision would achieve (Kennedy 1974; Lederman et al 1990; Millar 1994). These studies leave open for debate in what ways a blind child might depict spatial arrays (for discussions see Arnheim 1990; Lopes 1997; Eriksson 1998; Holmes et al 1998; Millar 2000; Kennedy and Juricevic, in preparation).

D'Anguilli et al (1998) tested blind and sighted children and found the pictures most often identified by one group were the pictures most frequently identified by the other. Kennedy and Bai (2002) suggest major principles of form depiction are available readily to both vision and haptics. A solid or dotted line can depict boundaries of surfaces in outline, and the drawings can copy order and proportions of parts of objects, depict figure–ground depth, reveal occlusion by T-junctions, imply the observer's vantage

point, offer shapes similar to faces of objects ('true' shape) while changing scale, and make available some readily understood aspects of perspective projection (Eriksson 1998). Accordingly, Gaia was given tasks bearing on these principles, especially features of occlusion, vantage points, and projection. She was also asked to draw some objects moving, a task which might require novel postures and devices.

Occlusion can be indicated by a T-junction, the stem showing one surface border passing under a second, indicated by the crossbar. It may be simple to show one object lying on top of another, and more sophisticated developmentally to show two spatially separated objects overlapping from a vantage point. Certainly, one can readily feel one surface lying on top of another and partially obscuring it. Occlusion at a distance sets close restrictions on the direction of a distant vantage point. Occlusion at a distance implies projection, but any of several kinds of projection would suffice.

Vantage points can be shown by selecting fronts of objects (the parts facing the vantage point). The orientation of the object with respect to the vantage point can be copied, by using top-down and left-right on the page for vertical and horizontal in the scene (Kennedy and Mirabella 1998). Also, objects can be drawn in their proper top-down and left-right order for one vantage point, and then reordered to show their directions from a second (Heller and Kennedy 1990). The re-ordering of top-down and left-right, together, is not generally successful until after 10 years of age (Milbrath 1998). These directions are haptic (eg we reach out to objects in different directions) as well as visual.

Projection occurs when a flat picture shows objects at different depths and slants. The objects can be projected in parallel, polar, or inverse perspective. Also, depicting the base of the object at increasing heights in the picture plane can show the object's base at increasing distance from the observer on a ground plane, in 'vertical' projection (Willats 1997), replicating haptic as well as visual directions (Kennedy and Mirabella 1998).

Parallel projection presents objects without changing the relative sizes of far and near sides. Features produced by parallel projection appear frequently in drawings of cubes from sighted children aged 8 years and up, and are dominant from the age of 13 years (Nicholls and Kennedy 1992, 1995), though some foreshortening is evident at 6 years (Nicholls 1995). Parallel projection may influence drawing and picture interpretation by the blind child (Eriksson 1998). In parallel perspective, a receding side of a cube can be drawn foreshortened to a thin rectangle, with all angles preserved as right angles (Kennedy 1993, figure 5.17, a drawing by a blind adult). It can also result in the receding side being projected as a parallelogram.

In polar projection, parallels converge, modifying the angles at the corners of objects and foreshortening the extents of receding surfaces. Polar perspective governs the directions of haptic objects (Kennedy 1993; Lopes 1997). If we reach out to the corners of a long table while standing in the middle of one end, we find there is a small angle (say  $10^\circ$ ) between the directions of the two far corners compared to the directions of the two near corners (which may subtend close to  $180^\circ$ ).

When a door opens and closes, the directions to its near and far sides widen and narrow (foreshorten) in vision and touch. The door can be full-frontal or in profile (edge-on), or in an intermediate position (three-quarter view). Milbrath (1998, pages 136–137) writes that intermediate positions are rarely drawn by sighted children aged 7 and 8 years drawing the human figure. They use shapes similar to full-frontal or profile orientations of shapes parallel to the picture surface, projected by parallel rays orthogonal to the picture surface. However, the relation between haptic perception of directions and haptic pictures remains unsettled.

Polar projection in drawing is likely more sophisticated developmentally than parallel projection (Cox 1992). Parallel projection changes angles and extents, but polar

projection changes receding parallels as well. Sighted adults use both parallel and polar projection, depending on the task (Arnheim 1974; Golomb 2002). Polar perspective is rarely applied comprehensively throughout a drawing of an extended scene (Kennedy and Juricevic 2002). Mixtures of projective systems are common in a drawing from the sighted (Milbrath 1998, page 121). Accordingly, if her comprehension of drawing is like that of the sighted, Gaia would be expected to use features from several projections in a single drawing.

Inverse projection entails receding parallels diverging. Its status in drawing development and art history is frequently debated (Arnheim 1974; Landerer 2000). It may be used by relatively few sighted children (around the age of 10 years), and a few sighted adults (Nicholls and Kennedy 1992; Landerer 2000). It has no direct application in optics or haptics. As will become evident, its use by Gaia will require discussion.

Projection operates as if the picture is a window, with an object on one side of the window and the observer on the other side, out of the picture plane. In contrast, in non-projective pictures, objects can be lined-up in order of their distance from the observer, putting the observer's location in the picture plane at, say, one end of a left–right ground line. [Milbrath (1998) finds ground lines as common in 3- to 6-year-olds as in 7- to 10-year-olds.] A plan view, a non-projective picture that is a developmental advance on lining-up, entails objects placed in an area mapping not only their left-to-right order but also their direction from the observer, with the observer in the picture at, say, one edge of the area, or in the middle (Kennedy 1993). Milbrath (1998) finds “ground planes” of this kind common in drawings from 7- to 10-year-olds (as well as in drawings from 11- to 14-year-olds).

A copy of the shape of a single face—a ‘true’ form, or ‘similarity’, or ‘imprint’—could often be a cross section of an object. This need not be a projection. However, if the front face of the object is chosen explicitly, or shown by details of its surface, with details of the rear surface omitted, then the observer's vantage point is implied. Kennedy et al (1995) found a cube is usually drawn as a single square by sighted 4- and 5-year-olds and identified as a front face. In a developmental advance, multiple ‘true’ faces of the object can be drawn, as in depicting a cube ‘folded out’. In this, a central square has other squares attached, one on each of the sides of the central square. In drawing a cube, the age at which foldouts are most frequently used by sighted children is 8 years (Nicholls and Kennedy 1992; Willats 1997). ‘Foldouts’ may be non-projective or ‘object-centred’. However, if the central square is the front face of the cube, then a vantage point is implied.

Most drawing devices are used at many ages, even if they are especially frequent at particular ages, and their use depends on the task at hand (Nicholls 1995). With this as due caution, we may suggest that ground lines and single faces of objects characterise drawings from younger sighted children (about 5 years old), plan views and foldout are likely an advance (in common use by 6- to 10-year-olds), parallel projection's foreshortening of receding sides is strongly evident from the age of 8 years onwards (with some evidence at the age of 6 years), inverse projection is shown around the age of 10 years, left–right plus up–down indicators of vantage point changes are present from the age of 11 years, and simple versions of polar projection's convergence are typical of older sighted children (11 years old and up), though accurate polar projection is rare unless taught formally (Nicholls and Kennedy 1995; Milbrath 1998). Indeed, parallel projection is widely used by sighted adults.

The question at issue is: would Gaia use features of one or other or all of the drawing systems common to sighted children to depict space? Sighted children are exposed to realistic pictures but draw in ways that are developmentally appropriate, and Gaia may too: the question is what features does she call on when given spatial tasks.

## 2 Method

### 2.1 *Subject*

Gaia has been blind since birth. She could sense light on her visual periphery for her first years, and a cancerous condition required surgery at 7 years and loss of the one eye with sensitivity. Aged 12 years on her first interview (July), she was 13 on her second interview (October), her 13th birthday being in September. She never had enough vision to see the lines she uses in drawing. She likes to draw, using a raised-line drawing kit. Her mother (Lucia, a librarian) has drawn raised pictures and other graphics for her since Gaia was 2 years old. She drew floor plans of houses, street areas, and features of buildings, for example a façade of a cathedral. Gaia herself has drawn since soon after the age Lucia first made raised graphics for her. Now, much like sighted 12-year-olds, she draws novel pictures, made-up scenes, buildings, children's playgrounds, people on the beach or swimming in the ocean, people in intriguing clothing, horses, fish, etc. Her mother reports that Gaia regularly makes as many as 50 pictures in a space of 10 days. We can conclude that Gaia has been raised in a pictorial culture more like a sighted child's than any blind child yet studied.

Gaia often feels a line with a fingertip, one small section at a time. When questioned about the referents of some of her recent pictures she responded with comments to the effect "this line" shows "the leg of a person", evidently regarding the section of the line she was touching at a given moment as part of a long continuous line showing a continuous edge, much as sighted people use outline.

### 2.2 *Procedure*

Gaia, seated at a table, was given a raised-line drawing kit and asked to make a series of drawings. Questions were posed by the author, and translated by Paola Di Giulio, from the Hospital of the Infant Jesus, Rome. Di Giulio was responsible for instigating the present study, recognising the need to document Gaia's interest in pictures and her level of skill. Di Giulio helped formulate questions posed to Gaia. Further aid was provided by Vincenzo Bizzi, pedagogue, from the Italian association for education of the blind, who has encouraged Gaia and her family since Gaia was aged 6 years to continue fostering Gaia's drawing.

While spatial projection is the prime focus of the present report, the full set of tasks, with brief comments on their aims, is reported here, providing the context in which Gaia's responses occurred, and a broad sense of Gaia's ability, since the set includes tasks Gaia did not complete, or did not undertake at her behest, giving reasons.

The drawings requested included (in order):

1. A cube. After the first drawing of a cubic box was made, a second was requested by asking "Can you think of another way to show a cube, a better way?" Would a drawing she deemed better be a developmental advance?
2. A table from the side and above the level of the table-top. Gaia's hand was placed at a suitable vantage point, and she was asked to show the table on which she was drawing from there. This tested use of a projection system.
3. A hand, and a hand with its fingers crossed. Would she use T-junctions for overlap?
- 4 Two pencils lying on the table, crossing over each other, touching each other. This tested again for T-junctions showing overlap. Gaia was also asked to show one pencil behind the other, not touching. The pencils were held erect forming an X from Gaia's vantage point, with a separation between them of about 40 cm.
5. A wheel with 5 spokes, static, spinning, in wobbly motion, in jerky motion, too fast to make out, and with its brakes on (Kennedy and Merkas 2000). This tested for devices to show motion in a case where literal postures might not be adequate.
6. A glass, placed in her hand, first from its side, second with the brim facing her, and third in a position intermediate between these two. Then, a glass set on the table

and standing erect, a glass tilted back with its base towards Gaia and its top far, and then lying horizontally on the table with its base towards Gaia. How would her vantage point be related to features showing a single object with varied orientations?

7. A book (standing erect on the table, front towards Gaia) at a fixed distance from Gaia together with a cup at various distances from the observer (near, middle of table, far side of table). What features might she use to show relative depth—height in the picture plane or diminution of size with distance?

8. A man standing and walking. Would Gaia change posture to show motion?

9. A man lying down. How would the orientation of the figure in the picture plane show the orientation of the referent?

10. A rectangular card folded in half with one face toward Gaia, and the same card folded and placed like a convex corner with two faces toward Gaia, one face more frontal, one receding more. This tested for devices to show depth at a cubic corner.

11. An object Gaia “had not had as a toy”. A bath tub was suggested as an example. This was to test for change of scale, from the large object to the small picture. (Testing stopped for an interval at this point and recommenced with the next task.)

12. A person running. Would she use postures as before?

13. Tables. First, a table, orientation unspecified. Then, a table from above, from the side, and from below. What features of projection might show the vantage points?

14. Two rows of apples (three apples per row) receding into the distance along the table top. Again, what features might she use to show relative depth of separated objects?

15. Two cars at different distances along a street, one behind another. This tested use of a projection system again.

16. A person facing Gaia. A person in three-quarter view, which was explained as standing not facing Gaia, and not facing to the side, but in-between. This tested for devices such as overlap and foreshortening to show postures between profile and full-face.

17. A book standing erect on the table front towards Gaia, lying down on the table and tilted, half-way between standing up and lying down. The face of the book was towards Gaia. Would convergence be used to show the slant of a single surface?

18. A table with four chairs around it. This tested joint use of overlap and projection systems to show depth.

19. A peaked-roof house, with a rectangular front and rectangular roof. A model provided by Morton Heller was given to Gaia. This tested her use of convergence or other features of projection to show two surfaces at different slants.

20. Three objects sitting on a table from different vantage points (the Piagetian ‘three mountains’ task).

21. A car, action unspecified, and a car moving fast. This was to test for use of a suitable vantage point, and devices for motion.

22. An insect. This was to test for use of a suitable vantage point, revealing relevant features, such as above the insect.

23. A house, a road receding into the distance, and distant hills.

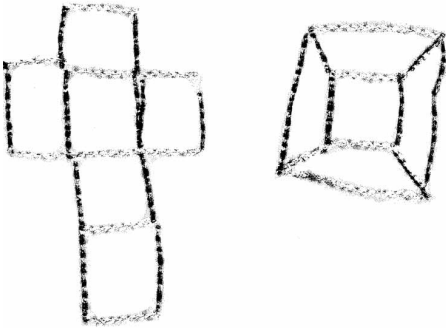
### 3 Results and discussion

The drawings are presented in the order in which they were made with a brief comment, and general discussion follows. The drawings were made with clear lines, with only two starts that Gaia regarded as errors to be disregarded (a hand and a glass, not shown here).

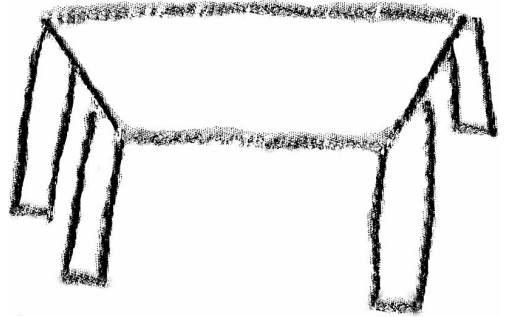
Figure 1 contains a drawing of a cubic box, and her response when asked for a better way to show the cube. The first is a foldout drawing, with all six sides of the cube shown as squares, attached to one another. The square is a ‘true’ shape, similar to each face. Gaia indicated that the square with four attached squares is the vertical front of the cube, the square attached above is the top of the cube, the left and right flanking squares are for the left and right sides of the cube, the square below is the

base on which the cube stands, and the lowest square is the vertical face of the rear of the cube. Gaia said the box has been opened up. The second drawing shows the cube by means of a central square (each line standing for two surfaces meeting at a convex corner), a square surrounding it (each line standing for an occluding edge), and diagonals joining the two (each line standing for a convex corner). Gaia identified the interior square as the front of the cube, the upper quadrilateral as the top of the cube, the flankers as the left and right sides of the cube, and the lowest quadrilateral as the base of the cube. This is a cube drawn in inverse perspective, and is her response when asked for a better drawing, so Gaia evidently judges this as superior to the foldout style. (Likely, it is indeed developmentally.) The square is a 'true' shape, and the other quadrilaterals sacrifice similarity but retain number of sides and angles, two parallels, and more attachments than foldout, although the rear face is omitted. The omission suggests a vantage point plays a role.

A rectangular table from one side and above the level of the table top was drawn by Gaia with lines diverging towards what Gaia indicated was the back edge of the table (figure 2). The feet of the table legs are squared-off, but the tops meet the table sides as obliques, with T-junctions, showing occlusion. The table top is another example of divergent projection. The legs use height in the picture plane to show depth.



**Figure 1.** Gaia's drawing of a cube, and her response when asked for a better way to show the cube.



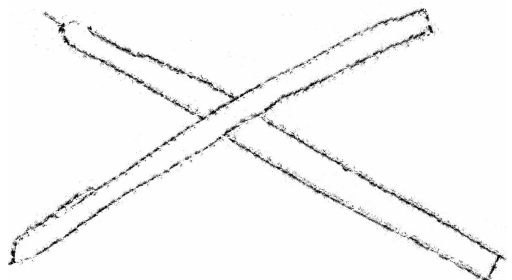
**Figure 2.** A table drawn with lines diverging towards the back edge of the table.

Figure 3 shows a hand and a hand with its fingers crossed, using shapes similar to the referent. No T-junctions were used, and when Gaia was asked what indicates which finger is on top, she indicated nothing did, and left it at that. This is likely a case of Gaia omitting a feature she could supply, as in other drawings she used T-junctions.

Figure 4 is Gaia's crossed-pencils drawing. In it Gaia used four T-junctions for overlap, consistently indicating which object is nearer the vantage point. The drawing uses similarity of shape, depiction of occluding foreground borders (with a surface



**Figure 3.** A hand and a hand with its fingers crossed, omitting T-junctions.

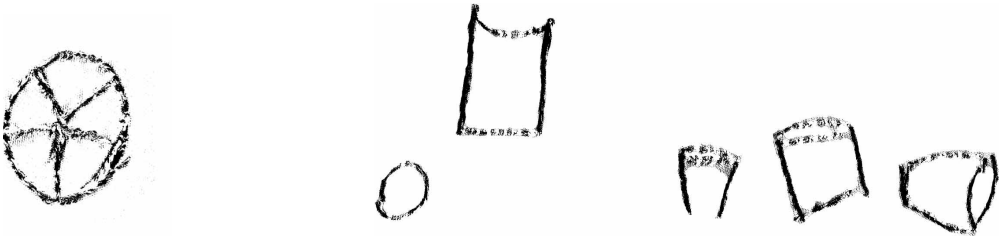


**Figure 4.** Crossed pencils drawn with T-junctions.

and its border behind), omission of occluded borders, and a short line at each pencil tip to stand for the wire-like pencil lead. Since objects at different depths are shown, the drawing suggests use of projection, eg parallel projection. When asked which pencil was behind the other, Gaia said the one that is interrupted. However, when asked if she could show one pencil near her and one behind it at some distance and not touching the near one, she said she did not know how to do this (possibly because it would not be different from figure 4).

Figure 5 is her drawing of a static wheel, a circle for the circumference, and 5 radiating lines for 5 wire-like spokes. Gaia said she did not know how to draw a wheel spinning, wobbling, moving too fast to make out, or in jerky motion. She said it is not possible. Pictures show objects and positions she said, not movement. Asked to draw a wheel with its brakes on, she said it would be like figure 5, and left it at that.

In figure 6, to show a glass with a side facing towards her, Gaia used a U shape (three parts of a rectangle) topped by a shallow arc for the brim of the glass. She said the arc shows half the top. Caron-Pargue (1985), who found similar drawings from sighted children aged 7–9 years, describes this as emphasising the sides and base of the glass, and only partially showing the brim. To show the glass from above, Gaia drew a circle, for the brim. The U shape and the circle are shapes similar to those in the referent. They suggest parallel projection to a picture plane between Gaia and the referent, with the sides of the glass in depth compared to the semicircle, or behind the circle.



**Figure 5.** A static wheel.

**Figure 6.** A glass from the side and from above (left). Also, a glass erect, tilted, and lying down on the table (right).

Showing the brim's arc together with the U suggests inconsistent projections. The U suggests the glass is vertical but the arc for the brim suggests it is tilted slightly, and the shallowness of the arc suggests it is foreshortened.

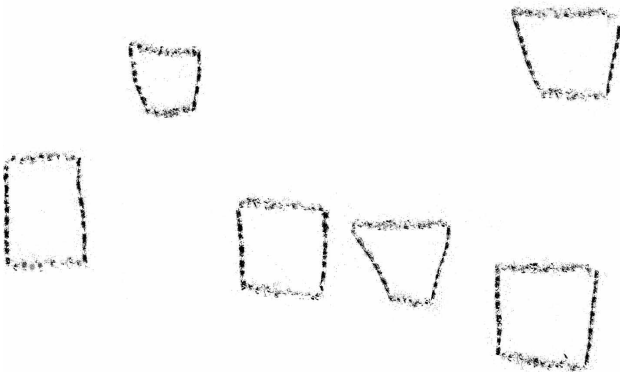
Gaia uses the observer's vantage point to select object features side-on and front-on. When asked to show the glass leaning and slanted towards her, Gaia said she did not know how to do this. She then suggested perhaps she could show three-quarters of the top (the brim), but she did not make a drawing. Sighted children also readily use features of objects parallel or orthogonal to the picture plane (Milbrath 1998). This accounts for the U and circle, but the brim as a shallow arc may be developmentally more sophisticated.

To show a glass erect on the table, leaning backwards away from her (top far from her) and lying flat on the table (top far from her), Gaia used a truncated cone (with an ellipse at the top, suggesting foreshortening) as shown in figure 6. The erect glass has the cone vertical and baseline omitted. The tilted glass is shown by a tilted rectangle (ellipse at the top). It lying down is shown by a cone with its axis horizontal (ellipse at the right, broader end of the cone). The dimension of depth is depicted by the horizontal (left-to-right). This finesses the problem of slant that Gaia initially said she did not know how to solve, but the cost is that the object is shown from the side. The solution is in keeping with parallel projection to a picture plane between Gaia and the target object, with the object largely orthogonal to the picture plane. The ellipse for the brim is a feature of projection, with strong foreshortening.

The vantage point is inconsistent in these drawings. The glass tilted away from Gaia is tilted top to left, as if the imagined vantage point were to the left of the line joining the actual glass and Gaia's location. The glass with its base to Gaia has its base to the left, the reverse of the tilted glass, so the imagined vantage point is now to Gaia's right.

Foreshortening is applied by Gaia to the brim, but not to the sides of the cup (which would allow her to retain her true vantage point). It may be that the alignment of the near and far sides of the brim, on the line joining them to the vantage point, favours drawing the two sides of the brim with two lines close together. Sighted children often draw the brim as a complete circle (Caron-Pargue 1985). Gaia's solution is likely developmentally more sophisticated.

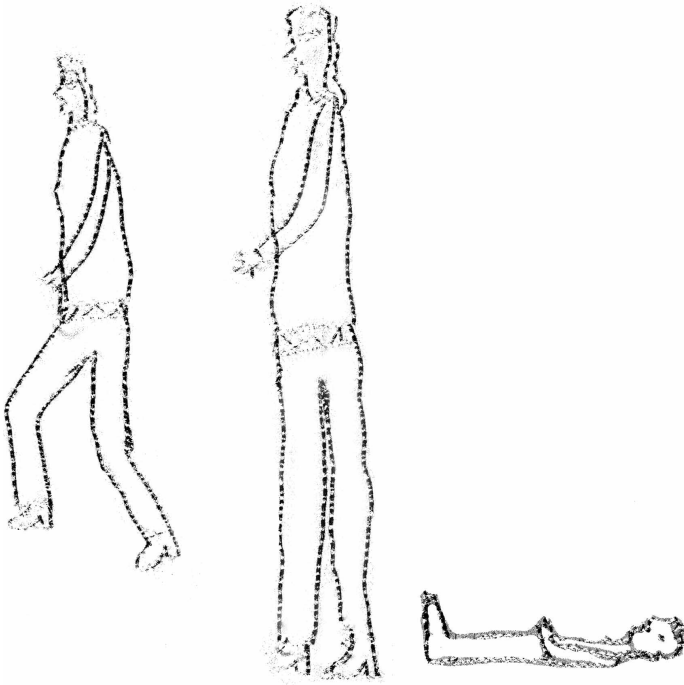
Figure 7 shows a book at a fixed distance (near the observer) and a cup more and more distant (near in the centre of the picture, far on the right, and mid-distance on the left). The cup is to the right of the book (as it was in the scene), except the far cup was drawn above the book. When asked about this, she said that now she thought it would be better "here" and she pointed to the right side. Relative depth is shown by means of height in the picture plane. There is no diminution of size with distance (the furthest cup is the biggest, without comment from Gaia).



**Figure 7.** A book, paired with a nearby cup (in the centre of the picture), a far cup (on the right), and mid-distance (on the left).

Figure 8 is Gaia's drawing of a man standing, a man walking, and a man lying down. They are largely in profile, including the legs. Sighted children aged 10–12 years commonly draw the human figure in this fashion (Cox 1993, pages 69 and 73; Milbrath 1998, page 138). The arm was drawn after the body in two cases, which may account for absence of hidden line elimination, since the raised line is not erasable. T-junctions are used for overlap at several places, such as the shoes and pant leg, and the arm of the man lying down. The legs are bent and apart to show the man walking. Only one arm is shown in each case, and only one leg of the man lying down, giving good information about the vantage point. The standing and walking man are vertical in the picture and the man lying down is horizontal, in keeping with projection onto a vertical picture surface between the referent and the vantage point. The arm of the man lying down may be foreshortened, since the extent of the arm after the elbow, receding from the observer, is short.

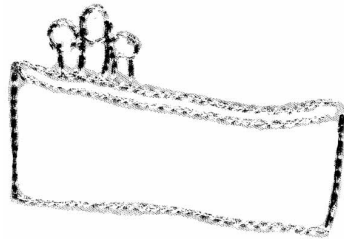
Gaia drew a card folded and placed on the table two ways. One had a single face towards Gaia, and the far side folded in behind. This can be drawn as a rectangle (front face) with the far face shown partially, poking up above the rectangle as a triangle. The other placement was with the corner projecting towards her (a convex corner). She drew the first as a square omitting all of the occluded rear face, and the second with obliques (figure 9)—parallel obliques for the more frontal side, divergent obliques for the more receding side, with the lower line close to horizontal.



**Figure 8.** A man walking, standing, and lying down.



**Figure 9.** A folded card, one face (lower), or both faces towards Gaia.

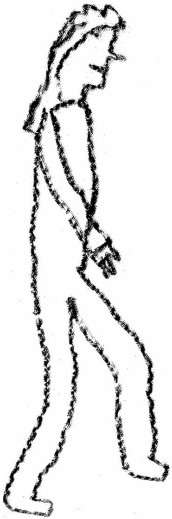


**Figure 10.** A wash tub with handles and a bath tub.

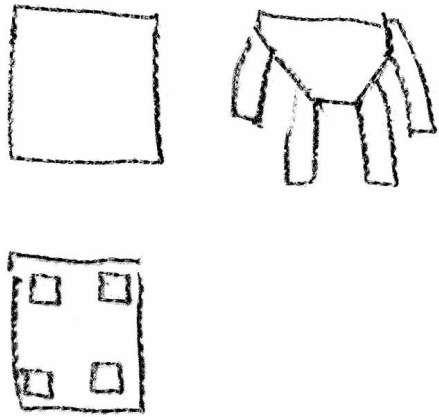
Asked to draw an object she had not had as a toy, such as a bath tub perhaps, Gaia drew a wash tub with handles and a bath tub (figure 10). Both were drawn as if from the side, with two parallel lines to suggest the near and far top edges of the brims. Above the bath are indications of the taps (two flanking circles, with pipes below shown by vertical lines) and the faucet (the central circle with lines for a pipe below). The wash tub is a shallow U shape, flanked by two handles, double C shapes close together. As a test of change of scale, from the large object to the small picture (8 cm long) of an object Gaia is unlikely to have had as a toy or drawn previously, the result indicates

scale-change is not difficult for Gaia. The projection of the brims at different depths as close arcs is a notable feature, in keeping with foreshortening, but the tub brim should be an ellipse to be consistent.

This was the end of Gaia's first test (23 July, Gallery of Contemporary Art, Rome). After a break, during which Gaia turned 13, testing began again on 26 October (in facilities supplied by Di Giulio). The interval is worth noting, since Gaia may have invented devices such as inverse perspective in July, but, if so, they were nevertheless retained stably and used in October.



**Figure 11.** Man running.

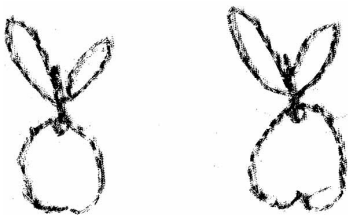


**Figure 12.** A table from above, from the side, and from underneath.

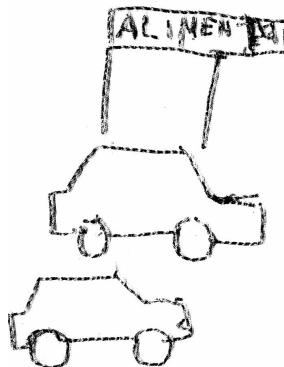
Figure 11 is another drawing of a man running. It is much as before, with less detail. Asked what shows the man is running, she said one leg is up.

Figure 12 shows a table from the side, from above, and from below. From above, Gaia drew a square. From the side, she used inverse perspective. From below, she drew a square with four small squares in the corners to show the legs, in keeping with parallel projection. Since the table was drawn three times, twice as a square, the relatively small vertical extent of the table drawn from the side suggests foreshortening.

For two rows of three apples, Gaia drew two apples (figure 13) explaining that the rest of the apples were behind (in accord with parallel projection). She added twigs and leaves (not in the model) to help make the apples recognisable.



**Figure 13.** Two rows of apples, showing only the apples to the fore.



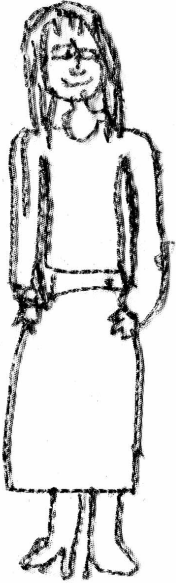
**Figure 14.** Two cars on a street, one further than the other, and a store.

For two cars on a street, one further than the other, Gaia drew two cars in profile (figure 14), the further car higher up the picture. Above the further car is a grocery shop (added at Gaia's behest), its lines interrupted by the car, as T-junctions. The occluded object is separated in space from the occluder.

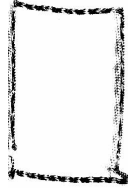
For a person standing and facing her, a pose Gaia had not used in July, Gaia drew a woman (figure 15), full face, arms to the side, with T-junctions where the body is overlapped and elsewhere, and put one foot pointing left and one right. She said she could not think of a way to show a person not standing facing her, or with the side towards her, but in-between.

Figure 16 shows a book standing on the table. Gaia said she did not know how to show the book lying down or inclined, and did not make a drawing.

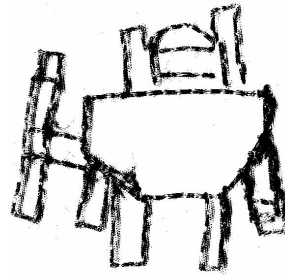
Figure 17 shows a table and chairs. Inverse projection is evident for the side of the table, until the back legs, at which point the sides become parallel. T-junctions show the table overlapping the chairs. The chair on the left has a notable projection. It has a high back, and its highest parts are shown by the near side (complete), with the far side as a small square atop the near side.



**Figure 15.** A woman facing Gaia.



**Figure 16.** A book standing on the table, front towards Gaia.

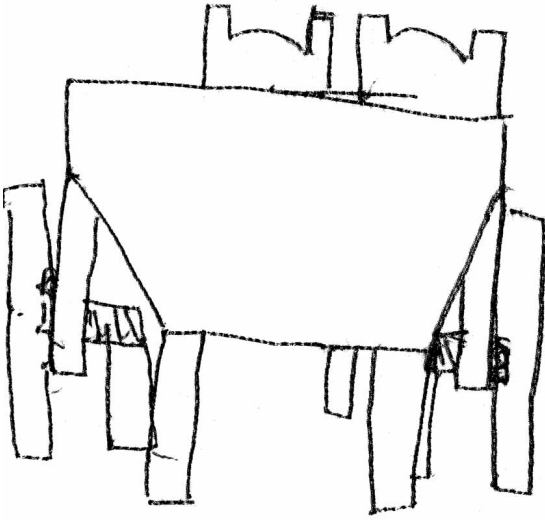


**Figure 17.** Table and chairs (4 cm wide drawing).

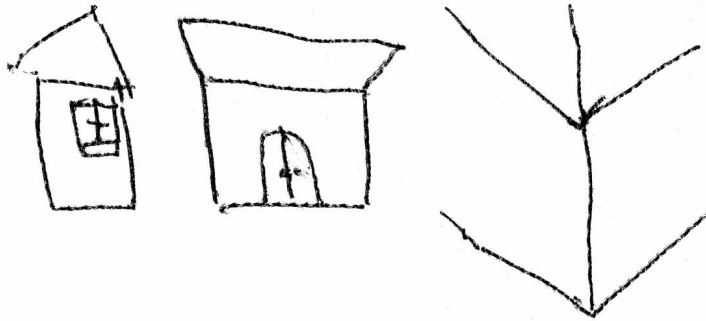
The drawing contains occlusion across a spatial separation, since the seat of the chair would be separated from the top of the table.

Since this was a small drawing (4 cm width) she was asked to make a larger drawing (figure 18, 12 cm wide in the original). The form is again inverse projection until the back legs are drawn. T-junctions indicate the table overlapping the chairs. Inconsistently, each of the side chairs (in profile) is overlapped by rear legs of the table, though the chair legs come down lower than the table leg.

For a house from the gable end, Gaia drew a rectangle with a triangle on top, and added a window, at her behest, since there was none in the model (figure 19). In this figure, her drawing of a house with a rectangular pitched roof from the front shows the roof in inverse perspective, and a double door (again at her own behest). She said the shape showed the roof was slanted. She was asked to draw the house from a position above the house and with a corner towards the vantage point. As figure 19 shows, she used obliques for the receding sides. The line for the convex



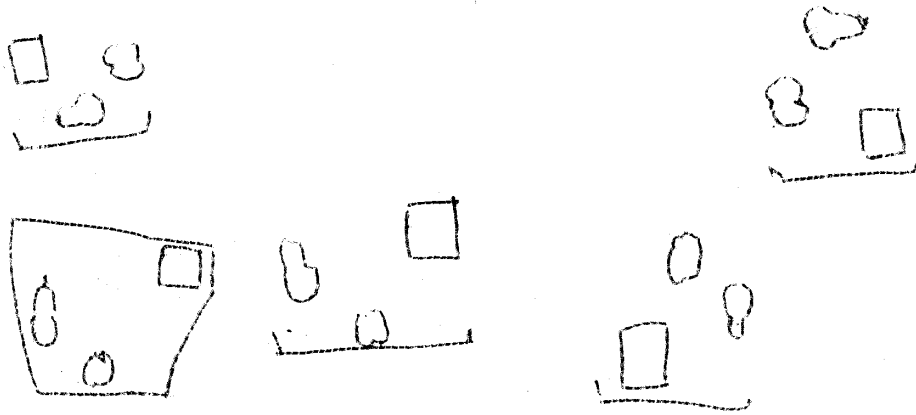
**Figure 18.** Table and chairs (12 cm wide drawing).



**Figure 19.** House from gable end, front, and corner-on (incomplete).

corner of the house is a direct extension of the line for the convex corner of the slanted roof. (This would only be true in parallel projection for a vantage point in front of the house.) Gaia said she did not know how to complete the drawing.

Piaget's three-mountains task involves drawing three objects set on a rectangular mat from five different vantage points. The three objects for Gaia to draw were an apple (in the middle of the front of the mat), a pear (middle of the left side of the mat), and a cube (at the rear right corner of the mat). Gaia was asked to draw these as if she was level with the objects, from her own position, from  $180^\circ$  opposite, at the left side of the mat, at the right side, and above the mat. From her own position (figure 20, centre) she drew a horizontal line for the mat (with small lines from the line termini, diverging upwards), and placed the apple, pear, and block, retaining left–right order, and using height in the picture plane for depth. The cube was drawn as a square—a single aspect. The pear was drawn thinner on top, and the top and bottom of the apple were indented to show its erect orientation. From  $180^\circ$  opposite, the order of the objects was reversed, correctly (figure 20, second from right). However, the pear was drawn inverted (as if the drawing was to be viewed from the top, her own location). For a vantage point  $90^\circ$  left of her true location, the order of the objects was pear in the near edge centre, block to the far left, and apple on the middle right (figure 20, top left). This is correct; however, the pear was turned on its side (base facing her true

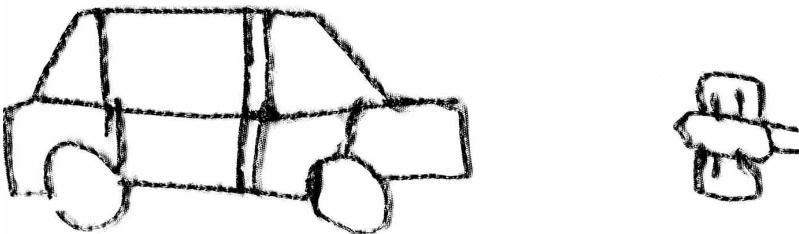


**Figure 20.** Pear, apple, and cube set on a rectangular mat from five different vantage points.

location to the right of this drawing, as if the drawing was to be viewed from the right edge of the drawing). For the  $90^\circ$  right location, the cube was bottom right, the apple middle left, and the pear far middle (figure 20, right). Again this is proper, but the pear base is towards the left, once again as if erect to her true vantage point (at the left edge of this drawing). Gaia finally drew the scene from above. In this case she completed the drawing of the mat (with sides diverging vertically, in inverse perspective). The orientation and placement of the objects were the same as in the drawing from her own position.

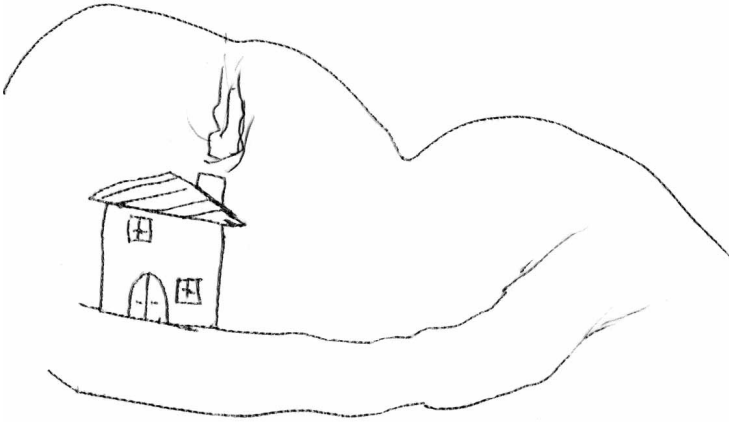
To check on the invariance of the orientation of the pear, it is useful to consider the corner of the cube nearest the pear. It always points to the indentation in the side of the pear drawing. The thin top of the pear is towards the square in all five drawings. Alternatively, turn each figure so the square is in the top right corner, and note the orientation of the pear is invariant.

Gaia was asked to draw a car and an insect. She drew the car from the side and the insect she described as from above (figure 21). The result is in keeping with a referent orthogonal to the line from the vantage point (parallel to the picture plane). This produces the 'object schemas' often drawn by sighted children. Asked if she could draw a car moving fast, she said she did not think anything would change, and did not draw further. (The drawing of the insect is likely highly influenced by models and other instructional materials for the blind. 3-D models are common in schools for the blind. The car is likely more influenced by real-life examples.)



**Figure 21.** Car and insect.

Gaia's final drawing was her response to being asked to draw a scene with a house, a road going into the distance, and hills in the distance (figure 22). The road, depicted by parallel lines oriented left–right, is in keeping with parallel projection. The hills are in profile, and high in the picture plane. The house is in front view, with its roof as a triangle (gable end).



**Figure 22.** House, a road going into the distance, and hills.

#### 4 General discussion

Gaia used outline to stand for edges of flat surfaces, boundaries of rounded surfaces, and wires. Figure-ground with a background surface is shown, for example in drawings of the two brims of a tub, one the border of a foreground surface and the other the border of a background surface. She used line for corners where two surfaces meet. These are the uses of outline by the sighted.

Gaia used T-junctions to show depth. Occasionally she omitted T-junctions where they would be apt. In one case this resulted in no lines for either of the two surfaces (the superior and inferior crossed fingers) and in some cases all the lines were present (lines for the inferior body as well as the superior arm). These appear to be matters of convenience, eg she drew the body before drawing the arm (Cox 1993). She used four T-junctions, in consistent fashion, for crossed pencils. She used T-junctions for occlusion with a space between occluder and occluded, eg a table top and the seat of a chair.

She used height in the picture plane to show depth, eg in drawing two cars. Since she had two systems which may be relatively independent for showing depth, she had the opportunity to be inconsistent. Indeed, a table-and-chairs drawing has the T-junctions telling one story and the height in the picture plane of the legs another. Similar inconsistencies between overlap and a possible projective scheme are evident in pictures from sighted adults noted by Willats (1997) and Landerer (2000). Gaia may not have noticed the inconsistency.

Cautions are in order here. The idea that a picture should be entirely consistent may be developmentally advanced, and in any case is an option many adults adopt or finesse at will, for example in caricatures. Also, “a substantial proportion [of sighted adults] are unable to match the apparent directions of objects in a perspective picture of a scene, even in a simple copying task” (Willats 1997, page 186). Inconsistency between different kinds of devices showing depth is the norm in drawings by naïve artists, adults, or children (Milbrath 1998). Further, the inconsistency was not pointed out to Gaia, and this might prove helpful in examining drawing development from accidental inconsistency to deliberate consistency (and possibly deliberate use of error, see below).

Another inconsistency is found in the three-mountains drawings. These show objects in accord with imagined vantage points, but orient objects with reference to Gaia’s own actual location in each of the drawings. (This is a subtle result, since Gaia placed all the objects in the correct locations for imagined vantage points, but then had to work out where she would be in each scheme and decide on an orientation for the pear for her imagined location. Two spatial transformations are required, not one, in this instance.)

Gaia makes use of lining up left-to-right to show slant (in cup drawings). This is likely a non-projective technique, though details in each picture suggest foreshortening. She used a plan view for objects only when drawing from above. Height in the picture plane may also be projective, since it is a kind of lining-up vertically, and matches the directions of objects on a ground plane, in which bases are higher in direction the further their distance.

The drawing of the apples combines parallel projection and hidden-line elimination. Only the front apples are shown. Likewise, the table from below is in parallel projection and only shows the feet of the table legs.

Foreshortening is suggested by ellipses for circular brims, close parallel lines for foreground and background edges of tubs, and in a drawing of a table. Surprisingly, Gaia clearly used inverse projection for several objects—table top, mat, and slanted roof. She used it in the first test (July) and later (October). There is no evidence of inverse projection in any of the drawings retained by her family and inspected by the investigator. She may have invented it on the spot and generalised its use cleverly. It is evident around the age of 10 years in a minority of sighted children of that age tested by Nicholls and Kennedy (1992). However, it may be closely related to a drawing described by Willats (1997) as “near oblique”, in which a cube is drawn as a square, and the top and a side are shown in addition. The quadrilateral for a side has a horizontal line at the base, a continuation (say towards the right) of the line showing the base of the frontal square. The horizontal line shows the receding base of the cube. The top has an oblique line (on the left, say), a continuation in the vertical direction of the line for the vertical corner of the front face. The oblique line shows a receding edge of the top. The horizontal line for the side and the oblique line for the top obviously diverge on the page, perforce. If this “near-oblique” cube drawing is a kind of inverse projection, then inverse projection is much more common in sighted children than previously suspected. Nicholls and Kennedy (1992) found near-oblique used by 15% of their 10-year-olds, 18% of their 11-year-olds, 17% of their 12-year-olds, and 16% of their 13-year-olds. Gaia used inverse projection across several tasks. This coherent use of the system does seem relatively advanced, perhaps strengthening the case for seeking inverse projection in allied forms of drawing that are persistent in sighted children.

Inverse projection uses obliques for depth, but the obliques do not remain parallel on the page. In cube drawing, Nicholls and Kennedy (1992) found parallel obliques attached to a frontal square were first used by a majority of sighted children at the age of 13 years (30% of their children at age of 10 years, 44% at age of 11 years, 46% at age of 12 years, and 52% at age of 13 years). The key property of inverse projection for Gaia may be the obliques stand for depth. The divergence may be secondary. (Alternatively, the obliques for table sides may be used in an attempt to avoid some partial occlusions with chair backs. But then their use for a roof would have to be deemed an import into a context where occlusion was not an issue.) She used both parallel and divergent obliques in depicting a convex corner, with all the lines for the receding sides being obliques. Divergence may be a way of emphasising obliques, producing symmetry, providing opportunities for closure, etc (Freeman 1986). If Gaia’s obliques mean recession, with parallelism or divergence secondary, this would be in keeping with increasing use of obliques by the sighted. Parallels may be features that she readily sacrifices at present.

Nicholls and Kennedy (1992) found no drawing scheme used by more than 50% of children aged 7 to 12 years drawing cubes. At this age, children are likely exploring several ways to relate direction and depth in the scene to obliques on the page. Gaia’s use of inverse projection at the age of 12 and 13 years fits this description.

What tools in Gaia’s kitbag might lead her on developmentally? Some variables on the picture plane match variables in the haptic scene, and could provide a coherent

developmental order. Frequent copying of parallels in the scene might be a straightforward addition to the use of obliques, phasing out divergence. It requires changing just one feature (divergence) that does not copy a feature of the object to just one other (parallels) that does, and it fits with the practice of copying features. Thereafter, the copying of parallels could prepare the ground for questions about the lengths of the parallels. Indeed, copying intermediate postures (slant and three-quarter views) of parallels in the scene might pose questions about the possible lengths of parallels on the page which can be answered by foreshortening. If so, she may have little trouble realising foreshortening on the page can be intermediate between full-frontal similarity ('true forms') with no foreshortening and profiles ('edge-on') foreshortening to zero. She occasionally foreshortens currently, but this may be only for objects orthogonal to the picture plane (brims, tabletops).

At the moment, she may not realise that intermediate poses can be portrayed by intermediate lengths. If she does come to this realisation, at first this might be a formal and rather arbitrary correlation of properties on the page with properties in the scene. But she would likely realise foreshortening's application to the scene—that it can be to do with directions of objects from her. It could eventually be given a full rationale to do with four variables: first, kind of projection; second, the vantage point; third, the picture plane's orientation; and, fourth, the slant of a target surface. These specify the proper intermediate lengths. But each of these variables is likely understood only in special cases at present by Gaia, even if each is likely developing in generality. One can say the same about the sighted. In short, considerations of variables on the picture plane matching variables in the haptic scene suggest Gaia's probable next modest steps developmentally. To grasp the full extent of the issues into which these lead would require tutoring, surely.

What Gaia did not draw and why, according to her, is as significant as what she did. She did not scribble, draw vague circular forms, or use line in ways absent in sighted children of her age. She did not draw erect objects as horizontals, or vice versa. She did not choose vantage points to the rear of objects, or inside, or underneath, until asked to, and did not reject the notion of a vantage point, or demur from novel vantage points. She did not know how to draw figures in intermediate postures. She may be foreshortening on occasion, but not often, despite frequently depicting objects full-frontal, in profile, or totally hidden. Further, she did not draw crossed pencils that were spatially separate, or a wheel with its brakes on, or a speeding car, likely because the result would be no different from a drawing she had just made. What is striking here is her novel response to requests to draw a wheel in motion. She said moving objects such as a wheel with spokes could not be drawn. She offered a theory of representation (Perner 1991).

For Gaia, drawings show shapes not motion. That is, she does not merely copy, she represents, she knows she represents (metarepresents), she offers examples of more and less advanced drawings, and she has general principles about pictorial representation and general schemes fitting those principles. She is not just a repository of a vocabulary of individual object schemas. Hence, she can generalise spatial transformations (eg inverse projection and parallel projection). Hence, too, she deemed some targets relevant to depiction even though she explicitly said she does not know how to draw them (objects at three-quarter orientations).

Gaia has a 'common-sense' theory of representation, in which pictures are about a few things, though they depend on principles of representation which apply to an open set of objects. Expansion beyond the present limits would occur by acquiring new general schemes (eg for intermediate poses) in keeping with her principles. Pictures show objects as having certain characteristics (Perner 1991), such as direction

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or proportion or shape. Misrepresentation of any of these is not useful, so foldout is said by Gaia to mean the box has been folded out.

Drawings with motion devices are produced by older blind subjects (Kennedy and Merkas 2000). Therefore, Gaia may realise shortly, in her teenage years, say, that once the rules of picture-making are well-understood, and understood to be shared by others, they can be deliberately broken, to convey what lies outside the rules. This would give her a relatively sophisticated common-sense theory of representation. Its additional feature is that what can lead to false belief is used to convey another belief, understanding that the audience has the capacity to recognise what prominent but unrealistic feature in the drawing might lead to error and what other feature in the drawing might be intended to be relevant. Language does this in metaphor. “Juliet is the sun” is false literally (she is not inanimate) but helpful metaphorically (they both are attractive, wonderful, the centres for their worlds). Pictures do this in caricature (Charles has big ears, but not *that* big) and motion representation (Spiderman spins lines as he swooshes through the air but he does not actually leave speed lines, for example).

Gaia omitted a scheme. She did not use polar projection in the sense that parallels were never shown converging. At her age, many sighted children are beginning to use polar projection. However, it is a challenging form of projection, hardly ever used consistently throughout a panoramic picture by the sighted. It has perceptual effects that are still far from understood (Kennedy and Juricevic 2002). Gaia’s use of inverse projection for slant and depth of rectangular shapes may be but a small developmental step away from a beginning with polar projection (Kennedy and Juricevic, in preparation). It needs only to be reversed. Everyday haptic experience with pointing and reaching from different distances favours this close connection. Alternatively, she may need to pass through a phase where she favours preserving parallels (when using obliques for receding surfaces) over diverging lines, before moving on to convergence.

It must be stressed that Gaia’s pictures cannot tell us how tactile graphics are experienced (Lederman et al 1990). It is surely important to realise that Gaia does not say she is copying how things feel (or how they look to the sighted). Her statements are about copying features of objects and scenes. Many blind people asked to draw may be tempted to try to put on paper something controlled by their beliefs about perceptual experience, specifically the sighted person’s visual experience. This may be a red herring. Copying aspects of the scene, its objects and their directions, is sufficient for most purposes.

This is not to deny that visual pictures can create impressions of a real scene, but rather to bring up another issue. The fact must be faced that tactile graphics may be more limited than visual pictures (Lederman et al 1990; Hopkins 2000). They may generate illusory impressions of length (Millar and Al-Attar 2002; Heller et al, in press), and changeable impressions of orientation and grouping, but not many depth impressions besides figure–ground (Kennedy 1993). The information they provide may give clear perceptual impressions of length, grouping of parts, proportions and direction, but only cognition of depth, possibly.

Little is open and shut in this connection, so let us press on with the debate. When a line of dots is grouped as a Gestalt form, connections are made across the empty space between dots. With wide spacing, only one dot might be being touched at a time. What dimensions can be employed by the connections across space from this contacted dot to ones not currently being touched? Must they be 2-D? Can apparent connections be simultaneously 2-D (picture surface) and 3-D (pictured world)? Via haptics we often explore extended objects sequentially, using limited fingertip contact with the object, and yet obtain 3-D impressions, stretching from the contact to other parts of the object. Can some of the 3-D stretch be pertinent to pictures?

The skin gives us information about direct contact. Deployment of the muscles, joints, and tendons in haptics is a major source of 3-D information. Could the haptic information continue to provide impressions of lines on a flat tactile 2-D picture, and some further perceptual function allow these to be freely distributed in an apparent 3-D space? If not entirely freely, then perhaps to some extent? Could the observer using haptics set aside information for the display's 2-D surface, discounting some aspects of the skin, muscle, joint, and tendon signals and emphasising others? Reaching up in the picture plane might be taken to be reaching out in depth, for example. Notice that Gaia combines two systems inconsistently in drawing table and chairs, or three-mountain arrays. Conceivably, two systems dealing with depth might be treated somewhat independently in haptic exploration of a picture. By analogy, visual observers set aside the information for the surface of a visible picture to some degree. Therefore we cannot rule out the, admittedly speculative, possibility that sequential exploration of haptic pictures can generate some pictorial depth percepts allied with direction impressions. This long shot remains to be investigated. Indeed, it needs to be defined (Lopes 1996, 1997; Hopkins 1998, 2000).

Gaia described a drawing of a cube as showing it unfolded. The drawing is by no means an illusory drawing of a cube. It is neither *trompe l'oeil* nor *trompe la main*. If so, drawing systems may be more or less lifelike for the blind, just as they are for the sighted. Front faces shown as 'true' shapes, and both parallel and polar projection convey lifelike impressions for the sighted (Nicholls and Kennedy 1995), and they may seem much more lifelike than foldout (or inverse perspective) to the blind too. Further, on the one hand some panoramic pictures in absolutely perfect parallel or polar projection seem highly distorted in shape to the sighted observer, and on the other hand in visual constancy some projective changes are of no consequence for our impressions of slant or shape (Kubovy 1986; Kennedy and Juricevic 2002). One wonders if there are similar effects and limits for haptic observers, in kind if not in degree. Eriksson (1998) suggests parallel projection is readily understood by blind children. Its results in a picture may seem 'realistic', even if there is no illusory effect. Raised lines in outline drawings readily stand for boundaries of curved and flat surfaces, with or without illusory impressions. Evidently it is necessary to distinguish devices that work readily as realistic representations and devices that convey vivid impressions. They may or may not be one and the same. Again, there is much here to investigate, in both vision and touch.

With the exception of polar projection's convergence, Gaia used all the devices commonly used by sighted children for depicting depth. The age range of the invention and frequent use of her spatial devices is likely 5 years (for single aspects) to 11 years (for the three-mountains task) in sighted children, and possibly more, since her use of divergent perspective is consistent across objects, and may be allied to a kind of drawing commonly used by sighted 10- to 13-year-olds. Her human figure drawings are similar to drawings by sighted 10- to 12-year-olds. She is age-appropriate for a sighted child in many respects, and her drawings are well executed, with clear lines, and precise control of intended form, rather than many false starts.

This is impressive support for the hypothesis that haptic pictures can be understood by blind children and adults much as they are understood by the sighted. We should seek to test other blind children who may have had the rare experience of being encouraged to draw throughout their childhood. It will be instructive to find out whether the results remain standard despite a variety of kinds of encouragement. Sighted children are exposed to many kinds of pictures, realistic polar-projected pictures included, but often draw in age-appropriate ways. So, too, the blind may be given a variety of examples but often find their own ways to draw, following a developmental trajectory like one in the sighted. The rationale may be pictures reproduce properties of objects and scenes available through vision and touch.

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## References

- Arnheim R, 1974 *Art and Visual Perception* (Berkeley, CA: University of California)
- Arnheim R, 1990 "Perceptual aspects of art for the blind" *Journal of Aesthetic Education* **24** 57–65
- Caron-Pargue J, 1985 *Le Dessin du Cube chez l'Enfant* (Bern: Peter-Lang)
- Cox M V, 1992 *Children's Drawings* (Harmondsworth: Penguin)
- Cox M V, 1993 *Children's Drawings of the Human Figure* (Hove, Sussex: Lawrence Erlbaum Associates)
- D'Anguilli A, Kennedy J M, Heller M A, 1998 "Blind children recognizing tactile pictures respond like sighted children given guidance in exploration" *Scandinavian Journal of Psychology* **39** 187–190
- Eriksson Y, 1998 *Tactile Pictures: Pictorial Representations for the Blind 1784–1940* (Gothenburg: Gothenburg University Press)
- Freeman N H, 1986 "How should a cube be drawn?" *British Journal of Developmental Psychology* **4** 317–322
- Golomb C, 2002 *Child Art in Context: A Cultural and Comparative Perspective* (Washington, DC: American Psychological Association)
- Heller M A, Brackett D D, Salik S S, Scroggs E, in press, "Objects, raised lines and the haptic horizontal-vertical illusion" *Quarterly Journal of Psychology*
- Heller M A, Brackett D D, Scroggs E, Steffen H, Heatherly K, Salik S, 2002 "Tangible pictures: Viewpoint effects and linear perspective in visually impaired people" *Perception* **31** 747–769
- Heller M A, Kennedy J M, 1990 "Perspective-taking, pictures and the blind" *Perception & Psychophysics* **48** 459–466
- Heller M A, Kennedy J M, Joyner T D, 1995 "Production and interpretation of pictures of houses by blind people" *Perception* **24** 1049–1058
- Holmes E, Hughes B, Jansson G, 1998 "Haptic perception of texture gradients" *Perception* **27** 993–1008
- Hopkins R, 1998 *Picture, Image and Experience* (Cambridge: Cambridge University Press)
- Hopkins R, 2000 "Touching pictures" *British Journal of Aesthetics* **40** 149–167
- Kennedy J M, 1974 *A Psychology of Picture Perception* (San Francisco, CA: Jossey-Bass)
- Kennedy J M, 1993 *Drawing and the Blind* (New Haven, CT: Yale University Press)
- Kennedy J M, Bai J, 2002 "Haptic pictures: Fit judgments predict identification, recognition memory, and confidence" *Perception* **31** 1013–1026
- Kennedy J M, Juricevic I, 2002 "Foreshortening gives way to forelengthening" *Perception* **31** 893–894
- Kennedy J M, Juricevic I, in preparation, "Haptic drawings by Tracy, a blind adult"
- Kennedy J M, Merkas C E, 2000 "Depictions of motion devised by a blind person" *Psychonomic Bulletin and Review* **7** 700–706
- Kennedy J M, Mirabella J, 1998 "Which way is upright and normal? Haptic perception of letters above head level" *Perception & Psychophysics* **61** 909–918
- Kennedy J M, Nicholls A, Desrochers M, 1995 "From line to outline", in *Drawing and Looking* Eds C Lange-Kuettner, G V Thomas (London: Harvester-Wheatseaf) pp 62–74
- Kubovy M, 1986 *The Psychology of Perspective and Renaissance Art* (Cambridge: Cambridge University Press)
- Landerer C, 2000 *Kunstgeschichte als Kognitionsgeschichte: Ein Beitrag zur genetischen Kulturpsychologie* Doctoral dissertation, University of Salzburg, Salzburg, Austria
- Lederman S J, Klatzky R L, Chataway C, Summers C, 1990 "Visual mediation and the haptic recognition of two-dimensional pictures of common objects" *Perception & Psychophysics* **47** 54–64
- Lopes D M M, 1996 *Understanding Pictures* (Oxford: Clarendon Press)
- Lopes D M M, 1997 "Art media and the sense modalities: Tactile pictures" *Philosophical Quarterly* **47** 425–440
- Milbrath C, 1998 *Patterns of Artistic Development in Children: Comparative Studies of Talent* (Cambridge: Cambridge University Press)
- Millar S, 1994 *Understanding and Representing Space* (Oxford: Oxford University Press)

- 
- Millar S, 2000 "Modality and mind: convergent active processing in interrelated networks as a model of development and perception by touch", in *Touch, Representation and Blindness* Ed. M A Heller (Oxford: Oxford University Press) pp 99–141
- Millar S, Al-Attar Z, 2002 "The Mueller-Lyer illusion in touch and vision: Implications for multi-sensory processes" *Perception & Psychophysics* **64** 353–365
- Mitchelmore M C, 1978 "Developmental stages in children's representations of regular solid figures" *Journal of Genetic Psychology* **133** 229–239
- Nicholls A L, 1995 "Influences of visual projection on young children's depictions of object proportions" *Journal of Experimental Child Psychology* **60** 304–326
- Nicholls A, Kennedy J M, 1992 "Drawing development: from similarity of features to direction" *Child Development* **63** 227–241
- Nicholls A, Kennedy J M, 1995 "Foreshortening in cube drawings by children and adults" *Perception* **24** 1443–1456
- Perner J, 1991 *Understanding the Representational Mind* (Cambridge, MA: MIT Press)
- Willats J, 1997 *Art and Representation* (Princeton: Princeton University Press)

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