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Children's Strategies in Producing Three-Dimensional Relationships on a Two-Dimensional Surface

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It is a common task to give children a picture containing implicit depth cues and to require them to extract depth information from it. The cues are always selected from the adult repertoire: little is known about children's production of their own cues. In this experiment, 5- to 10-year-old children were required to draw one object behind another in a situation in which adults invariably produce the further object partially occluded by the nearer. The results were an age-related decline in the tendency to segregate the objects and an increase in the tendency to group the objects using partial occlusion, with a cross-over at 8 years. At all ages some children drew one object inside the boundary of the other. It is argued that the results are composed of two tendencies, a gradual mastery of discrete scaling phenomena (e.g., "up" on the page means "further") within a given style, and a set of decisions to be made between incompatible styles.

Early accounts of children's drawings in English laid stress upon basic spatial skills. Sully (1896) gave his influential account the title *The Child as Draughtsman*. He noted the acquisition of "the usual stock in trade of the juvenile draughtsman" who "can draw a sort of straight line, curved lines, a roughish kind of circle or oval, as well as dots, and even fit lines together at angles" (pp. 334–5). Sully argued that these abilities make drawing possible; and Piaget and Inhelder (1969, p. 66) assert that drawing is associated with "the evolution of the spontaneous geometry of the child."

More recent research on spatial organization includes use of a baseline (Lark-Horovitz, Lewis, & Luca, 1967), the role of start and stop cues (Olson, 1970), and the influence of the sides of the page on localization (Berman, 1976). One can gain insight into children's production of apparently deviant forms in representational drawing by experimental examination of the spatial problems involved in mastering the design

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characteristics of the drawings (Freeman, 1975; Goodnow & Friedman, 1972; Ibbotson & Bryant, 1976). Thus, it is necessary to study the way in which children can combine very simple shapes to represent simple spatial relations before asking them to cope with the immensely complex task demands of the type imposed on them by Lewis (1963) or Piaget and Inhelder (1956). The latter may well be right when they say (p. 175) that it is not until about the age of 9 years that the child can *systematically* apply perspective to drawing, but their work sheds little light on the intermittent precursors of this "stage." Perspective is only one of three methods of conveying depth information, as will be detailed below, and it is unwise to use perspective as a paradigm depth cue in the way that much of the cross-cultural work does.

The present experiment is designed to see how children use their ability to relate shapes to represent a simple spatial array: the task involves drawing two circles to show one object behind another. The necessity for this sort of data is demonstrated forcibly by recent research in psycholinguistics. Faced with complex problems of the child's linguistic representation of the world, researchers conduct experiments in which adjectives such as "in front" and "behind" are isolated and studied (e.g., Clark, 1971). The present study is the graphic counterpart to linguistic studies of spatial adjectives. As there, the issues raised are the extent to which a model based on the acquisition of discrete features is useful, and the extent to which discrete stages are identifiable.

There is a particular problem in drawing in-depth relations. Consider the common depth illusion of two objects on a railway track, as represented by two converging lines. One of the objects is placed *above* the other on a page, but must be seen as *behind*. In so doing, the verticality must first be perceived and then be suppressed, or more strictly, used up, in translation from the 2-D (above) to the 3-D (behind) relationship; thus a drawing of "two people, one smaller than the other and higher up the page" must be read off as "two people, one *not* smaller than the other and *not* above it, but further away." Therefore one of the problems of pictorial representation is of an extreme case of ambiguity rather than of encoding unfamiliar symbols, and various strategies involving different depth cues may be employed to deal with the ambiguities. There are three types of depth convention, (a) within an object (e.g. foreshortening), (b) between two objects (e.g. partial occlusion), and (c) between objects and context (e.g., placement within perspective lines). Here we concentrate on the second sort, and ask how children attempt to draw a depth relationship between two discrete objects with no internal features or context. This restriction is a research necessity, but inevitably reduces the generality of the findings.

Figure 1 shows how one could draw one apple behind another. Even the partial occlusion representation is ambiguous, for it could conceivably show one apple beside a partial apple. Thus any of the drawings could be

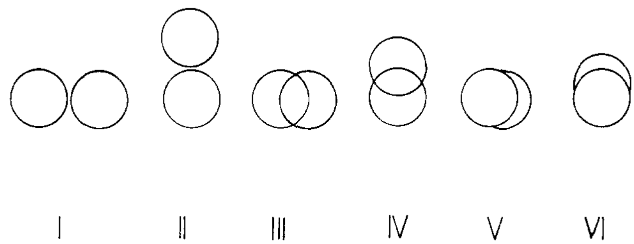

FIG. 1. Alternative Representations of One Apple Behind Another.

interpreted (i.e., scaled) in the 2-D terms of above/below/beside, and any of the drawings could, in principle, be converted into a relatively plausible 3-D representation by providing an appropriate context.

Note that (III) and (IV) would not commonly be made by adults; they are examples of transparency representations which are so common in children's drawing (Luquet, 1927). It would be easy to construct a series of approximations to the adult style; thus a simple model which worked by the accretion of discrete rules would involve the following four steps. With regard to Fig. 1, the least informative would be (I), in which the two objects are placed side by side. Then addition of the rule "up on the page means behind" gives (II). Then a superimposition rule gives (IV). This could be turned into partial occlusion (VI), by specifying that the further object should start at the contours of the nearer, without crossing them, by inserting a restricted "delete" instruction into the program. If the model has psychological validity, then this stepwise conversion of 2-D relations into 3-D relations could be observable in children either via a discrete stage phenomenon or a gradual shift in the relative frequencies of styles. The only direct evidence upon which to base expectations comes from Clark (1897). He showed children aged between 6 and 16 years an apple stuck through with a hatpin, and asked them to draw it. All the 6-year-olds made a transparency drawing in which the pin was superimposed on the apple in one continuous line; then by age 9, half the drawings only showed the visible parts of the pin, and this tendency increased up to age 16. Clark's results show regular trends which are in perfect accord with a cumulative model: a linear decline in the relative frequency of transparencies and an equally gradual increase in the visually faithful mode of partial occlusion of the pin, with a cross-over between ages 8 and 9. Making due allowance for the less rigorous methods of Clark's time, and the different task used, it would be reasonable to expect a similar result in the present experiment, namely a gradual diminution in a tendency to overlap the apples, with a gradual increase in partial occlusion of the further apple. The alternative expectation based on Piaget and Inhelder (1969) is that the data curves will fall into two discrete peaks with a small overlap around age 8. Below that age, transparency drawings will give evidence of the "intellectual realism" stage whereby the child is supposed to draw "what he knows rather than what he could see;" above that age, partial occlusion will give evidence of the "visual realism" stage. We prefer the cumulative model; unlike Piaget we are not convinced that acquisition of simple graphic skills is necessarily tied to "the laws of thought", and following Bryant (1974) we do not believe that Piaget's tasks are free enough of extraneous task demands to permit assessment of ability.

The reason for using apples is that they are typically drawn as circles, thus capable of extension in any of the 2-D directions, whilst the stalk (which all subjects spontaneously draw) defines verticality by a single unambiguous feature. At the same time one can require that the further apple be drawn in red (green) after the nearer has been drawn in green (red), which provides a differentiation of the lines without violating children's sense of color realism. The tasks were to draw one apple and then to draw another *above, below, beside* or *behind* the first. An additional task was to draw one apple *in front* of the first. This is, formally, an insoluble puzzle, in that it becomes impossible to use the adult convention of partial occlusion of the further apple, since this has already been drawn. This merits separate treatment for the light that it can throw on the 4 soluble problems, and will be referred to at more length in the Discussion section.

METHOD

Subjects. 446 children from city schools, within the age range 5–10 years, inclusive, served as subjects. There were approximately equal numbers of boys and girls. There were 67, 70, 103, 87, 65, and 54 children from the 5-, 6-, 7-, 8-, 9-, and 10-year-old classes, respectively. Fifty-six undergraduates, median age 20 years, also served as subjects.

Procedure. Each subject was given a single trial. The instructions were to draw a red (green) apple in the middle of the A4 page, without coloring it in. Then the subject was given a green (red) pen and asked to draw another apple, either *above, below, beside, behind* or *in front* of the first. The 5–8-year-olds were divided into subgroups who were each given one of the five conditions. Each of the 9-, 10-, and 20-year-olds attempted only one of the two in-depth conditions.

RESULTS

All drawings fell into the types shown in Fig. 1 plus unexpected enclosure drawings in which one apple was placed inside the other; the 16 exceptions (mainly ones in which the further apple was both above and beside the nearer whilst being drawn quite separate from it) were too few to be considered further and accordingly were dropped from the analysis. Size differences were ignored; although they are potentially informative the present design is not optimal for their measurement. First consider the 2-D

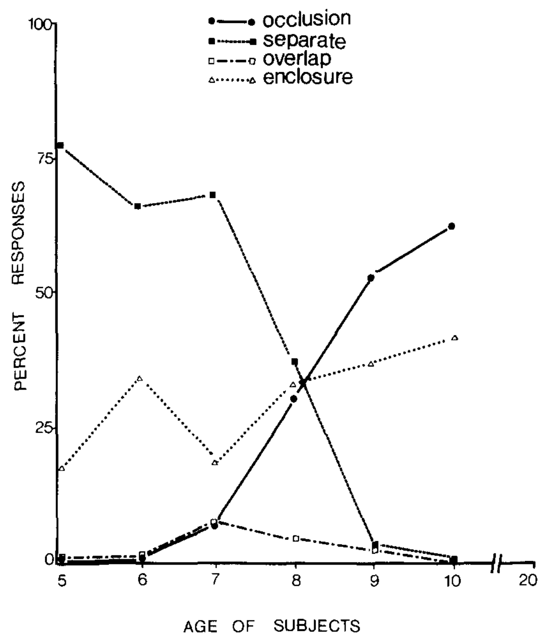

FIG. 2. Age-Related Shifts in Relative Frequency of Four Alternative Representations of One Apple Behind Another.

relationships: there were few errors, only 9 out of 127 subjects: 1 on *beside*, 3 on *above*, and 5 on *below*. Thus, even the youngest children discriminate between, and portray, 2-D relationships to an acceptable degree. Interestingly, 8 out of 9 of the errors were to draw a *beside* relationship in response to a request to draw *above* or *below*.

(1) Behind

The 37 20-year-olds who were in this subgroup all used partial occlusion, except for one who precisely superimposed the two apples: 26 put the occluded apple beside the other, 10 put it above, and none put it below. The results from the 198 children are shown in Fig. 2. The tendency to draw the apples as separated declined at the same time as the number of partial occlusions increased, with a crossover at age 8. Enclosure fluctuated between 18 and 39% with no reliable trend. Overlap never rose above 7%, and so is rather negligible. The next step is to consider trends *within* each of the categories: (a) separate, (b) enclosure and (c) occlusion. These are broken down into proportions in Table 1.

(a) Separate. Table 1 shows a gradual shift from drawing the apples beside one another to drawing them vertically. Thus verticality is mastered as a convention by age 7. All the vertical arrangements were with the

TABLE 1

DRAWING ONE OBJECT BEHIND ANOTHER: THE PROPORTION OF EACH SUBGROUP USING EACH OF THE THREE MODES OF REPRESENTATION—SEPARATE, ENCLOSURE AND OCCLUSION

	Mode of representation						
	Separate		Enclosure		Occlusion		
Age	V	H	2	1	A	S	B
5	.33	.67	1.00	0	–	–	–
6	.46	.54	.79	.21	–	–	–
7	.74	.26	.89	.11	0	1.00	0
8	.69	.31	.27	.73	.07	.93	0
9	–	–	0	1.00	.18	.74	.08
10	–	–	.10	.90	.54	.46	0
20	–	–	–	–	.27	.78	0

Note. V = vertically arranged, H = horizontally arranged; 1 = first apple inside second, 2 = second apple inside first; A = occluded apple above whole, S = occluded apple beside whole, B = occluded apple below whole.

further apple above the nearer, except for the youngest group in which 15 cases were above, and 11 below.

(b) Enclosure. Table 1 shows a gradual shift from drawing the further apple inside the nearer to drawing it outside. This shift occurs by age 8.

(c) Occlusion. There are very few cases indeed of the occluded apple being below the nearer. This is to be expected since occlusion was not used until age 7, by which time, as analysis (a) showed, the convention of verticality had been mastered. Thus one might have expected that there would be a tendency to draw the occluded apple above the nearer one, but Table 1 shows that the initial use of occlusion is with a beside relationship, and the shift to above is not completed by age 10. Interestingly, it is not completed at age 20 either, but the intermediate ages are necessary to see how the trend develops. It seems clear that the use of verticality which was seen under (a) does not carry over into the occlusion condition (with the proviso that verticality is not misused by putting the occluded one below).

(2) In Front

This condition differs from the others in that occlusion is removed as a potential option, and reference to the data from 124 subjects (shown in Fig. 3) shows that the adults' responses are very variable, with overlap, enclosure and separate, though in that order of frequency, not differing from a chance distribution. The children show a declining trend in the tendency to draw the apples separate which strikingly resembles the trend

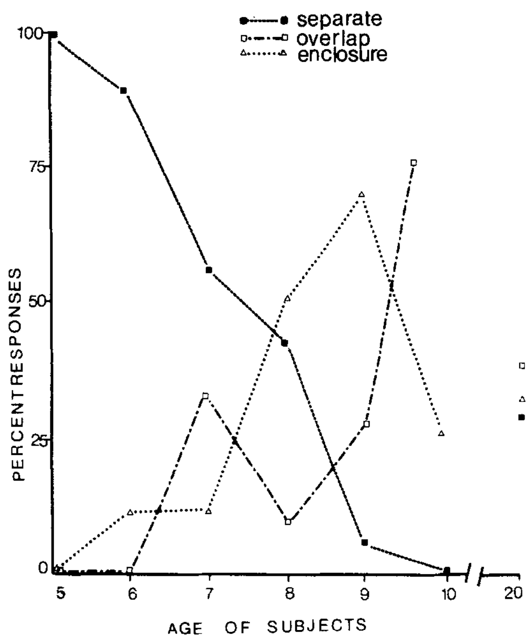

FIG. 3. Age-Related Shifts in Relative Frequency of Three Alternative Representations of One Apple in Front of Another.

for *behind*. In general, the other trends, enclosure and overlap, seem to increase gradually but with two kinks which make interpretation rather difficult, namely a sharp dip in overlap at age 8 and in enclosure at age 10. Nonetheless, two points are clear from the graph. First, the insoluble problem has not led to random or disorganized behaviour; second, overlap is not simply substituted for the occlusion of the *behind* condition.

There were no such obvious trends within each of the types of response as there had been for *behind*. However, overall, two consistencies were apparent. One was that the nearer object was more often drawn below the futher as opposed to above it by a factor of 8, taking separate and overlap combined; and that when enclosure was used, the nearer object was drawn inside the further as opposed to outside it, by a factor of 3.7. These tendencies are the opposite of those obtained in the *behind* task, and reinforce the view that the insoluble task did not lead to random behavior, but a consistent use of verticality and enclosure. Further work is necessary before this can be more than a tentative conclusion.

DISCUSSION

The data from drawing *above, below,* and *beside* relationships show that the children are capable of scaling the page in these 2-D directions at all the ages studied here. The data from drawing *behind* may conveniently be divided into three components. First, the primitive tendency to draw the two objects separate, with no common boundary, declines regularly with age. At the same time a growing number of children at each age use partial occlusion to represent behind. The cross-over obtained with these two trends resembles a conventional gradual process of development, certainly between the ages of 7 and 10 inclusive. To this limited extent, the results support the suggestion of Brown (1969) that depth cues are used reliably only after the age of 6.

The second point concerns enclosure and overlap, both achieved by superimposition of the apples. It had been expected that superimposition would form an intermediate stage between separate and occlusion, with particular emphasis on overlap since this is an obvious transparency representation. There was no evidence for this. Enclosure seems to be a stable competitor to the other modes at all ages, with overlap surprisingly rare. When occlusion is prevented, in *in front*, this potentiates both enclosure and overlap, the interesting point thus being that enclosure is not simply substituted for occlusion. This is further evidence against considering enclosure to be a more primitive variant, or substage, of occlusion; and the growth of overlap may be an indication that *in front* acts as a design puzzle rather than as a simple "functional deletion" of the preferred occlusion mode. The variable behaviour of the adults seems to bear this out. In other words, the most obvious equivalent of a transparency style, overlap, only appears when the subjects are puzzled. If enclosure really represents transparency, it does not seem to be a distinct stage of development.

Thirdly, consider the changes that occurred within the modes separate and enclosure. These showed regular shifts such that when the apples were drawn as separate, the further was reliably put above the nearer by age 7; when enclosure was used, the further reliably included the nearer by age 8. Thus improvement was occurring within each mode up to the crossover when occlusion became predominant. The interesting contrast is with occlusion in which there was no lawful tendency to use above on the page to mean further, either for adults or children. It is as though the use of occlusion renders verticality redundant as an indicator of depth, though there is no a priori reason why this should be so.

We have argued that the results indicate a gradual mastery of a number of discrete features (as in Clark's 1971 model for the acquisition of rules governing the verbal use of *in front* and *behind*). Verticality is mastered by age 7 whereby above is used to mean *behind*, and below means *in front*. Enclosure is mastered by age 8 whereby inside is used to mean *in front* and outside to mean *behind*. By age 9, occlusion is used. However, any such account would differ from that used in basic psycholinguistics, in that here the features are not simply additive; and this holds both on conceptual grounds (enclosure is an alternative to verticality) and on empirical grounds (occlusion seems to supersede verticality). In other words, these initial results cannot be fully accounted for either by a stage or feature account, although they cannot by themselves be used *decisively* to reject either.

This situation should not surprise us. To return to the introduction, it is characteristic of 3-D drawings that there is no correct, unambiguous solution to the problem. Instead there are a variety of answers; some of which are mutually exclusive (like enclosure and verticality) others of which are, in principle at least, open to additivity of features (e.g. partial occlusion and verticality). Alternative drawing strategies are possible, and rules must exist which determine the child's decisions between and within strategies (Goodnow, 1972). The use of such production tasks may help us reexamine the types of potential depth cue that experiments use as stimuli in pictorial depth-perception tasks (see Jahoda & McGurk, 1974; Newman, 1969): it may be necessary to include relations of enclosure for certain age groups. Conversely, this type of result may help us decide what depth information we read into a child's drawing when interpreting it, for data of this type can, in principle, be used to answer the question, if a 6-year-old draws one discrete object above another on the page, what is the probability that he intends to represent it as further away?

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