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The development of visually guided reaching

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This investigation measured the accuracy of reaching in infants wearing 30-diopter prisms. Infants varied in age from 4 to 10 months. Although accuracy was barely affected, the reach trajectories indicated that infants switched from a miss path to a hit path in midcourse. There was some evidence to support the view that visually directed reaching was operative in the youngest infants and that it improved with age.

This study proposes the use of prisms as a method of identifying reaching controlled by visual guidance. Hein, Gower, and Diamond (1970) and Hein, Held, and Gower (1970) have demonstrated the distinction between visually elicited or triggered behavior and visually guided behavior in young kittens. Development of the latter requires a certain amount of exposure to patterned stimulation under conditions of self-produced movement.

In spite of the several studies that have been done on reaching in human infants (Bower, 1974; Bruner & Koslowski, 1972; Halverson, 1931), none have clearly distinguished visually guided from visually triggered behavior. Although it is assumed that, developmentally, visually guided reaching would be preceded by visually triggered reaching, the lack of an operational distinction between these terms renders even this basic question lacking proof.

Accurate visual perception of radial direction could permit accurate reaching providing there was a one-to-one mapping of kinesthetic proprioceptive space onto visual space. Under these conditions, accurate reaching would not require sight of the hand or arm. Although elicited by visual cues, the trajectory could be altered only between reaches, and so it could be characterized as a ballistic reach. Alternatively, accurate reaching could also be achieved through periodic adjustment of hand trajectory as a consequence of visual feedback of hand and target position.

Conditions of pure ballistic reaching were approximated in an experiment by Bower and Wishart (1972) in which infants of 20 weeks, or so, were shown a toy and then reached as the lights were extinguished. They demonstrated accurate reaching, which indicates that nonguided ballistic-type reaching was certainly possible for this age group. Other studies by Bower (1974) have shown that reaching in very young infants (2 weeks) was around 40% accurate and increased to about 80% by 20 weeks. Bower, Broughton, and Moore (1970a) investigated accuracy of reaching in neonates of a few days of age and was able to show that the reaches were directed and should not be described as excited threshing.

This improvement in accuracy could reflect the increasing regulation or modulation of reaching by the visual guidance system, implying that the infants' first reaches were controlled by a primitive eye-hand coordination. There is evidence that specific visual properties of the reach target preprogram patterns of action directed at the target. For example, Bruner and Koslowski (1972) have found that the size of a ball shown to prereaching infants will elicit behavior appropriate to a graspable object (if small) or behavior appropriate to a palpable object (if large). Also Bower, Broughton, and Moore (1970b) found that infants under 5 months of age were distressed when unable to touch a virtual image of a solid object. A virtual image of an impalpable object produced no distress. Further, these infants showed anticipatory hand shaping, whereas older infants did not close their hands until tactile contact was made. This evidence suggests that a degree of eye-hand coordination was available to very young infants, but it does not show that the direction of reaching was under visual control in infants under 5 months of age. The situation is far from clear, however, as other facts seem to imply that early basslistic reaching is unlikely.

Bower (1974) has clarified the significance of bodily growth for perception. Rapid changes due to growth in the shape and position of the eyes and the size of the limbs and body must render useless any system for absolute spatial perception that cannot accommodate such changes. At a time when growth is most rapid (0-4 weeks), it would be surprising indeed if reaching was controlled by a system of eye-hand coordination requiring continual adjustment. Visual guidance, however, would be unaffected by growth and would provide a reliable method of reaching for objects. On the other hand, the difficulty with postulating visual guidance as the main mechanism of accurate reaching is that it implies a heavy load on the infant's attention.

Data for this study were collected in Dr. T. G. R. Bower's laboratory while the author was on sabbatical leave at the University of Edinburgh. The author gratefully acknowledges the generous assistance and advice of Dr. Bower, Jane Dunkeld, and Jennifer Wishart.

Monitoring hand and target positions requires a division of attention which must be achieved without a change in fixation. The infant must attend to the position of the object, the hand, and the difference between them. If the object is fixated, the hand moves through the periphery of the visual field. Changing fixation would result in the target's being temporarily lost and hence disrupting the continuity of the reach.

These issues would be considerably clearer if a method could be found to distinguish visually guided reaching from purely ballistic reaching. Accurate reaching while wearing displacing prisms would necessitate direct visual control. It is clear that adults reaching slowly and with hands in view have no difficulty in locating prismatically displaced targets. The present study thus examined infant reaching under such prismatic conditions from 4½ to 10 months of age.

METHOD

Subjects

A total of 22 infants, ranging in age from 16 to 41 weeks, served as subjects. Of these, a total of 16 infants, 4 each at ages 21, 27, 34, and 41 weeks, completed all phases of the experiment.

Apparatus

Thirty-diopter Fresnel displacing prisms[1] were fitted to plano lenses mounted on National Health spectacle frames designed for 6-month-old infants. The Fresnel prisms consisted of a series of water thin plastic prisms (2 x 0.5 mm) lying in adjacent strips on a thin platform of plastic. The prisms were attached to the plano lens with simply water and atmospheric pressure. There was a very slight acuity decrement compared to conventional glass prisms. Base orientation was always right for both eyes. The main advantage of these prisms was their extremely light weight and small size regardless of power.

The infants seldom made attempts to remove the glasses, and they gave every appearance of contentment while wearing the prisms.

A set of small dolls and other toys were used as objects to be reached. The baby was seated on his mother's knee at the edge of a table. The surface of the table was covered with black cardboard marked off into 5-cm divisions with white lines. Each division was further calibrated in centimeters.

A closed-circuit TV camera was mounted directly above the table surface and aligned vertically to eliminate parallax. The infant reaching activity was then recorded on a ½-in. Sony videocorder.

Procedure

The infants were tested in a single session of about 15 min in duration. They were allowed to make up to six reaches while wearing spectacle frames with prisms and six reaches with frames without prisms. The six trials were divided randomly between two table positions, the midline or 7.5 cm to the right of the midline. The target was placed so that, when the infant was sitting erect, the eye was approximately 25 to 30 cm from the target location; given a 30 D prism, the expected deviation would be approximately 7.5 cm. The infants moved their heads quite considerably, so these figures are only a rough estimate of the true displacement. The infant usually sat erect while waiting for the next toy. The head typically inclined forward slightly as the reach was initiated. The experimenter attempted to adjust the infant's position each time by gently placing the hands at the sides of the body.

RESULTS

Trajectories of reaches were transcribed by hand from video tape onto a graphical representation of the tabletop drawn to a scale of 5 to 1. For each reach, the tape position at which one of the infant's fingers contacted the target was found. Next, the tape was rewound to the point where the infant's index finger was 25 cm distant from the target on the longitudinal axis. Then, by winding the tape forward by hand slowly, the position of the index finger was marked every 2.5 cm to the target.

The next step was to integrate individual trajectories to determine the average trajectory. The target was considered as the origin of a set of coordinates. Seven concentric circles were drawn

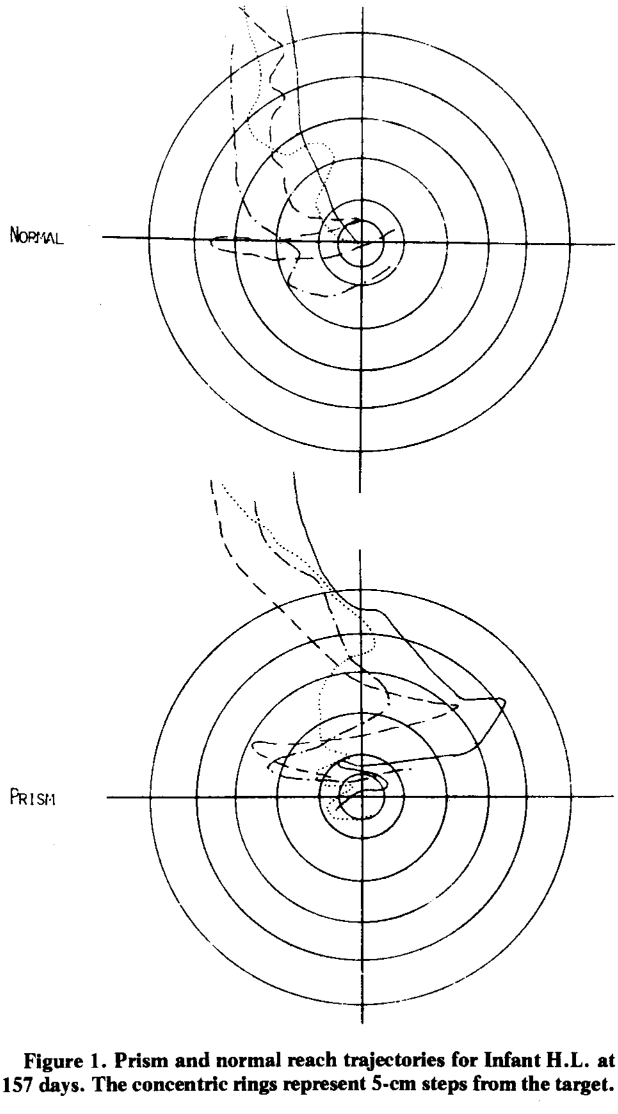

Figure 1. Prism and normal reach trajectories for Infant H.L. at 157 days. The concentric rings represent 5-cm steps from the target.

about the origin, with the largest having a radius of 35 cm. The set of trajectories for a particular condition for an individual provided a distribution of trajectory positions along the circumferences of the circles. From these, the median trajectory position could be easily determined. Further integration of trajectory data across individuals was achieved in the same manner. An example of the concentric circles superimposed upon coordinates and a sample of trajectories from a particular subject are given in Figure 1.

The performance of the subject in Figure 1 shows clearly the trajectory error induced by the prism and the subsequent abrupt alteration in direction of the reach. The median trajectories for this subject's control and prism trajectories are shown in Figure 2 and appear to represent the important differences in the conditions without exaggeration.

A very small percentage of reaches (3.8%) failed to contact the target altogether. Failure to contact was defined as retraction of the arm to the start position without contact or whenever the hand stopped short of the target, remaining stationary until the target was removed by the experimenter. It should be clear from trajectories that it would be inappropriate to describe the infant's reaching as excited threshing. Such behavior was never observed in our subject.

The number of successful grasps was also recorded. Halverson (1931) considers a successful grasp to mean lifting the object off the table on initial contact. The same criterion was employed in the present study. The results are presented in Table 1, and it is clear that they are comparable to Halverson's data for similar age groups. There is evidence of improvement in grasping with age.

Figure 3 shows the trajectory error for right-handed reaches induced by the prism, averaged over the 14 subjects for the two target positions. Two subjects made predominantly left reaches. The points are medians of individual trajectories and show the dispersion obtained for individual trajectories. Figures 4A, 4B, 4C, and 4D compare prism and normal trajectories directly. As expected, the prism trajectories tend to intersect the y-axis at a higher value than normal trajectories, consistent with reaching for a virtual target displaced to the left. In the rightside (RS) position, 11 subjects clearly showed higher prism trajectory, 1 subject showed a higher normal trajectory, and 4 subjects showed more or less equal trajectory positions. In the midline (ML) position, 13 of the subjects showed higher prism trajectory, 1 subject showed a reverse effect, and 2 subjects showed no difference. By the sign test, these differences were significant.

An attempt was made to examine the data for developmental trends. There appeared to be evidence of improved prism reaching in the RS position, and in both positions the prism trajectories deviate from normal most in the youngest age group. The fact that the median trajectories did not show strong developmental trends probably resulted from the between-subject design. Longitudinal studies might yield a clearer age trend.

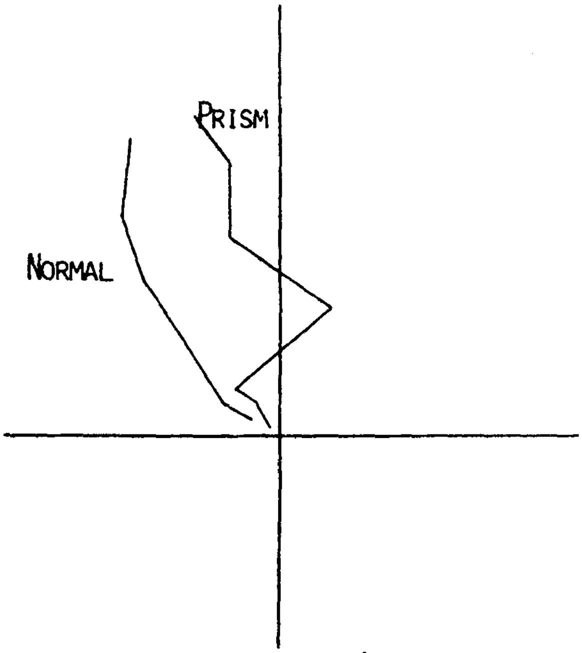

Figure 2. Plot of median trajectories for Infant H.L. at 157 days for both normal and prism conditions.

The frequency of left-handed reaches was minimal and constituted only 17% of all reaches. The majority of these were contributed by four infants (ages, 153, 177, 220, and 253 days), who used their left hands predominantly. The trajectories of prism reaches cut the x.axis further to the left than normal reaches, but the differences were smaller than with right-handed reaches.

The number of symmetrical two-handed reaches was a surprisingly small 6% of the total number of reaches, and generally the right-hand component was averaged with other right-hand reaches. It was noted that many of the infants appeared to lean on the left (or right) hand while reaching, which could account for their infrequency.

Table 1
Percentage of Successful Grasps of 22 Infants Between Ages of 110 Days to 300 Days Compared to Data Provided by Halverson (1933)

Age Group (Days)	N	Normal	Prism	Halverson (1933)
110-160	6	26	25	16
160-210	6	27	23	44
210-250	6	54	45*	66
250-300	4	61	41*	72

*$p < .05$

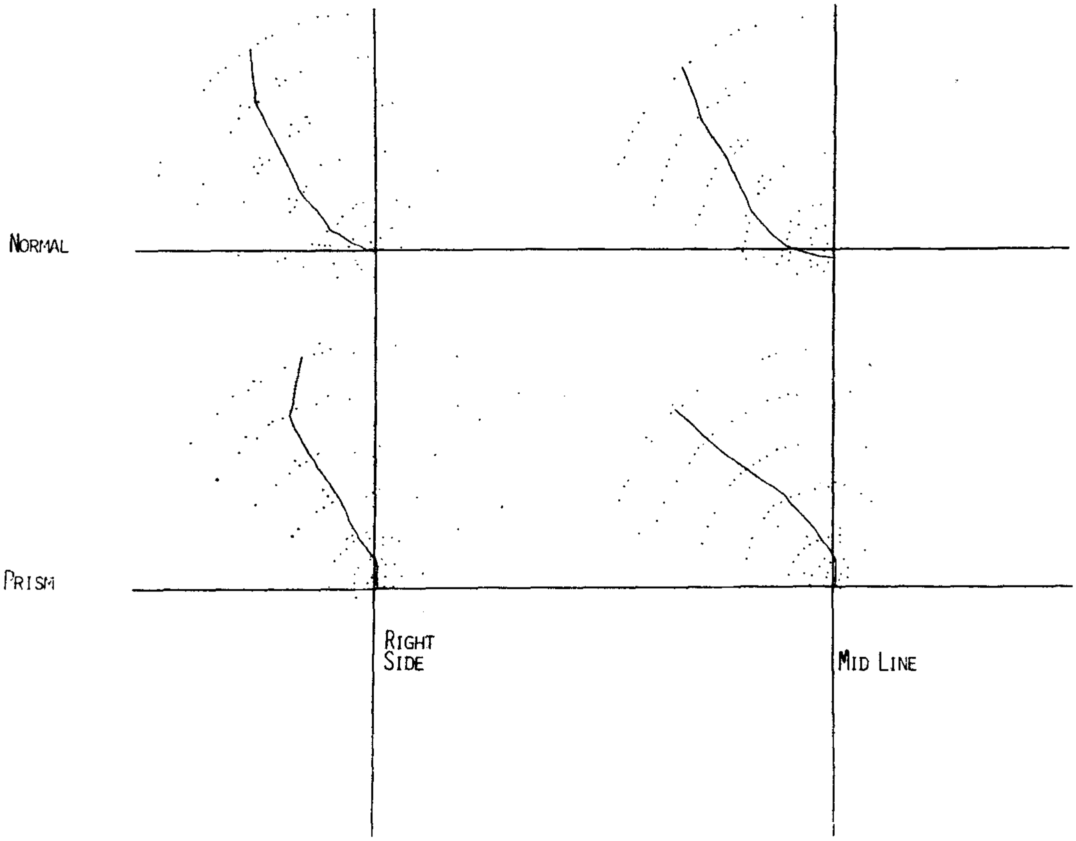

Figure 3. Distributions of median trajectory positions for target on right and target on midline. Solid line represents group median trajectory (14 subjects).

DISCUSSION

The most impressive aspect of the infants' reaching behavior was the fact that the prism condition appeared to disturb their accuracy to little. In fact,

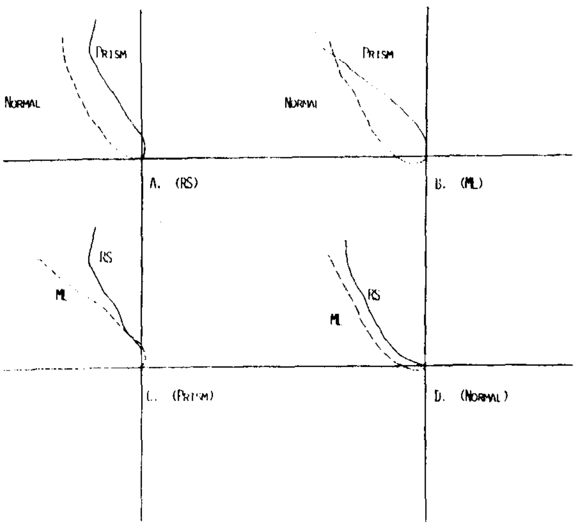

Figure 4. Group median trajectories (RS, target on right side; ML, target on midline).

with very few exceptions, the infants' parents could not recognize any error whatsoever, even on the first reach with prisms. The abrupt change in trajectory direction noted in some of the infant protocols made it clear that they had made a deliberate correction of the trajectory from a miss path to a hit path, typically after the hand had crossed the midline. In other cases, although the trajectory angle of a prism reach differed from a normal reach, the trajectory was monotonic. There were also some cases, especially among the youngest infants, of highly circuitous trajectories, which ultimately led to the target.

The evidence, then, strongly supports the view that reaching was at least partly visually guided. In instances where the trajectory path was abruptly altered, it may be that the initial path of the hand was determined by a ballistic arm movement directed at the virtual target position. In cases where no abrupt change in trajectory path occurred, it may be that the entire reach was under direct visual control.

In the youngest infants tested (4 to 5 months), accuracy of their reaches was greater than 90% even with prisms. By comparison, neonates show a hit rate of close to 40% (Bower, 1974). The improvements in grasping accuracy and the decline in prism trajectory errors between 5 and 9 months reflect the increasing precision of visual control of reaching. The youngest infants also showed a distinct tendency to alter the direction of the hand as it crossed the line of fixation to the target. This pattern may reflect the operation of ballistic reaching which, when the impending error is discovered, is switched to visual control. However, there remains an alternative explanation which excludes a role for ballistic reaching.

Visually guided reaching in 20-week-old infants must place considerable load on information processing systems. To begin with, the infant must note the radial position and depth of the target, the radial position and depth of his hand, and the space between them. The infant's task would be made more difficult by the necessity of maintaining fixation on the target while processing peripheral retinal information. To simplify the task, infants may be employing a strategy. Positioning the hand along the line of fixation before reaching forward to the target could reduce the attentional load. Since both hand and target would stimulate the central field of vision, the need to change fixation would be eliminated. Egocentric hand positioning would have the further advantage that depth estimation could be accomplished with motion parallax, which Bower (1966) has shown to be the most potent of depth cues for infants. As development proceeds, a process of decentering occurs between the ages of 4 months and 1 year. It may be that experience in reaching coupled with maturation of attention span permits increasing control of the hand in the visual periphery, resulting in smoother continuously adjusted trajectories, which characterize adult reaching behavior.

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NOTE

1. Fresnel Press On lenses and prisms can be obtained from Optical Sciences Group, Inc., 24 Tiburan Street, San Rafael, California 94901.

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