The Ontogeny of Infant Bimanual Reaching During the First Year*

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Abstract:
Handedness and pattern of coordination during bimanual reaching were assessed separately for six groups of infants, 7 to 12 months old. Infants reached bimanually for a transparent toy-filled box. On some presentations of the box a low barrier was placed in the path of either the right or left hand, while on other presentations there was no barrier. The youngest and two oldest groups of infants were more likely thon the other age groups to perform simultaneous bimanual reaches with no barrier present, but when a barrier was present the 11.month-olds were most likely to continue to perform simultaneous reaches. This suggests that while infants as young as 7 months perform simultaneous reaches, the organization of these reaches may be different than for older infants. Hand-use preference contributed significantly to selection of a lead hand in non-simultaneous bimanual reaching. The 8-month group, which had the highest proportion of infants with a hand preference, was the only group likely to hit the barrier when it was placed on the nonpreferred side. Hand preference may, thus, bias the use of information about what the environment affords for action.

Article:
An ecological approach to studying infant sensorimotor activity (Goldfield, 1983; Goldfield & Shaw, 1984) asserts that the organization of action is a joint product of organismic properties of the infant (e.g., the size and form of the effectors and growth-related changes in the organization of the motor system) and what the environment affords for action (Gibson, 1982) given those organismic properties. Age-related individual differences such as age of onset of independent mobility, or the size and weight of the limbs (Thelen, 1984), in this view, may impose specific constraints on selection of information used to guide coordination of action. So, for example, as infants become independently mobile toward the end of the first year, their bodies no longer provide a stable frame of reference for locating objects and, as a consequence, during this period infants become more likely to attend to environmental rather than body- centered frames of reference to locate objects (Goldfield & Dickerson, 1981).

A growth-related organismic change which may also have an effect on the infant's use of information about what the environment affords for action is the occurrence of periods of predominant postural asymmetries. There are, for example, head orientation preferences (Goodwin & Michel, 1981; Turkewitz, 1977) and preferences for holding onto objects with one hand (Caplan & Kinsbourne, 1976) during the neonatal period, and unimanual preferences in reaching and object manipulation (Ramsay, 1980) and bimanual manipulation (Ramsay, Campos, & Fenson, 1979) in the first year. Other studies of infant unimanual reaching have examined the adjustment of motor activity to characteristics of visually perceived objects such as orientation (Lockman & Ash- mead, 1983) and size (Bruner & Koslowski, 1972), and to the presence of barriers. However, no research has examined how the coordinated activity of bimanual reaching by infants with specific hand-use preferences

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is adjusted to the location of a barrier to the right or left of midline which could potentially perturb the path of the reaching hand.

The present study took two steps not employed in other studies to examine how bimanual reaching is scaled to both interindividual differences in hand use and perturbations to the path of one of the hands. First, infants were tested with a "lure" object that required reaching out with both hands for grasp and retrieval (i.e., the lure was relatively large compared with the span of the infant's grasp). Previous studies of bimanual coordination have used objects that could be readily grasped and retrieved by one hand. Hence bimanual coordination often referred to the ability to change hand use when reaching by the nearest hand was blocked (Bruner, 1971).

Second, we used an independent measure of hand-use preference as a means of identifying interindividual differences in infants (Michel, 1983). In this way, we were able to group infants into those who had a right- or left-hand preference, and those who showed no preference. Perturbing the actions of the infant's preferred hand might affect bimanual coordination in ways that are different than if the actions of the nonpreferred hand are perturbed.

METHOD

Subjects

The 57 infants in this study were selected from 95 infants participating in a larger study of infant hand use. The sole criterion for selection was that each fall into one of six age groups ranging from 7 to 12 months. All infants were recruited from hospital birthlists in the Boston metropolitan area. Parents were initially contacted by letter and then with a follow-up telephone call. Participating parents were paid travelling expenses to the laboratory. The final sample consisted of six groups: 9 7-month-olds (M= 6.72, Range = 5.97-7.25), 10 8-month-olds (M= 7.88, Range = 7.57-8.39), 10 9-month-olds (M= 8.96, Range =8.76-9.31), 9 10-month-olds (M= 10.07, Range = 9.66-10.62), 10 11month-olds (M= 10.86, Range= 10.30-11.57), and 9 12-month-olds (M= 12.28, Range = 11.61-13.28).

Apparatus

Infant handedness was assessed by individual presentation of the following toys: a star, bracelet, red rattle, two yellow rattles, cube suspended on a stiff wire, two wire-suspended rings, two pop-it beads, ball in a cage, ball with clacker inside, two windup monkeys, plastic keys on a ring, small windmill, stacking rings, phone receiver, busy box, three nesting cups, xylophone, and windup bird in a transparent plastic box.

Reaching was assessed by presenting each infant with a transparent plastic cube with a hinged top, called the "toy box." The toy box was 14.6 cm on each side and was filled with an assortment of the toys used in the handedness task. The toy box was placed on a 20x 41 x 53 cm plexiglas platform positioned on a table top so that when the infant was seated on the table, his legs were under the platform and he could reach for the toybox at chest height. The platform top was covered with a sheet of white paper with a drawn grid of 2.5 cm squares to accurately position the toy box and barrier. A 9 x 18 cm piece of wood clamped to the top of the platform between the infant and the toybox served as a barrier. The barrier was positioned 9 cm from the infant on all barrier trials, and the distance from the toy box to the edge of the platform with or without the barrier present was 18 cm. A black and white television camera (Panasonic WV 3082) suspended from the ceiling at a distance of 170 cm above the platform provided an overhead view of the infant, toybox, and barrier. The video signal was recorded for later analysis on a videotape recorder (Panasonic NV3160).

Procedure

For the handedness test, each infant sat across from the experimenter on the carpeted floor with the parent seated nearby. The experimenter presented each of the individual toys to the infant's midline, and each of the pairs of identical toys at the shoulder line in the order listed above. A research assistant scored the hand used for initial contact with the toy and took notes on the characteristics of manipulation.

Following the handedness assessment, each infant was seated on the tabletop in front of the platform and toybox. The parent sat in a chair behind the infant and held the infant's hands at shoulder height until the experimenter asked the parent to simultaneously release the hands for each trial. A trial was begun when the infant was settled, a toy was lifted from the toybox by the experimenter and then replaced, and the parent was holding the infant's hands. Each infant was presented with a maximum of four trials in each of three conditions: no barrier, barrier to the left of midline, and barrier to the right of midline. No barrier trials were presented both before and after barrier trials. The order of left and right presentation of barrier trials was counterbalanced over infants. The infants reached for the toybox during each of the four trials 37% of the time, on 3 of 4 trials 42% of the time, and on 2 of 4 trials 19% of the time. All infants reached for the toy box at least one time during each set of four trials.

Scoring

Both the infant's hand preference on the handedness assessment and performance on the reaching task were scored after testing was complete. The infant's hand preference was determined by reviewing on the scoring sheet which hand was used to make initial contact with each of the presented toys on each trial. A handedness score based upon binomial probability was computed to quantify the degree of handedness. Infants with scores greater than 13/18 or less than 5/18 (where binomial probability equals .05) were classified as right and left handed, respectively. All other scores were classified as "no preference."

Reaching was scored by reviewing the videotapes for the type of reach by each hand per trial. The frequency of nine different reaching activities was initially scored: rest on platform, manipulate platform or barrier, hit barrier, extend and hover without reaching the toybox, extend arm to the side while rhythmically twitching the hand, extend and touch the toybox in advance of the other hand (nonsimultaneous reach), extend and touch the toybox after the other hand did so, extend both hands simultaneously and touch the toybox (simultaneous reach), and reach around the barrier to touch the toybox. Three patterns accounted for the majority of infant reaches: simultaneous reaches (.27), nonsimultaneous reaches (.51), and hitting the barrier with one hand while the other hand makes contact with the toybox (.10).

Interobserver Agreement

A second coder independently scored the videotapes for the reaching activity of a random sample of half of the infants in each age group. Based upon a sample of 310 observations, we first computed percentage agreement for each of the three types of reaching using the formula: agreements/agreements + disagreements. The results were: .92 for nonsimultaneous reaches, .85 for simultaneous reaches, and .90 for one hand hitting the barrier. We also computed Cohen's Kappa by fitting the three reaching categories and two coders into an agreement matrix. Kappa was found to be .79. The data analysis which follows is based upon the scores of the first coder.

RESULTS

Handedness Status

The distribution of infant handedness (right, left, no preference) by age and sex for the sample of 57 infants is presented in Table 1. There was no significant association of age group with hand-use preference, 05) = 4.70, p> .1, nor was the distribution of right-handedness associated with age, 05) = 9.4, p = .094.

TABLE 1
Distribution of Infants by Age, Handedness Status, and Sex

		Hand-Use Preference		
Age[a]	n	Right	Left	None
7	9	2	3	4
8	10	8	1	1
9	10	4	2	4
10	9	6	1	2
11	10	3	4	3
12	9	3	1	5
Total	57	26	12	19

[a] Age is in months.

In all, 46% of the sample had significant right hand-use preferences, 21 To had left hand-use preferences, and 33% showed no preference.

Bimanual Reaching

All analyses of bimanual reaching were based upon the general linear models procedure for ANOVA and were computed on individual proportions. Because there were no significant differences in proportion of any of the reaches for the first and second set of no-barrier trials, these trials were combined for all the analyses. All post hoc analyses are based on Duncan's test.

Simultaneous Reaches. Assessment of the proportion of simultaneous reaches on no-barrier trials provides a measure of the relative coordination of the hands when there is no environmental perturbation. Table 2A presents the proportion of simultaneous reaches as a function of age and barrier position. A 6 (age: 7, 8, 9, 10, 11, and 12 months) x 3 (hand preference: right, left, none) x 2 (sex: male, female) ANOVA was performed to examine the relative contributions of age, hand preference, and sex to the likelihood of simultaneous reaching.

There was a significant interaction between age and hand preference, $F(9,56) = 4.13$, $p = .0013$. Post hoc tests revealed that the significant effect was due primarily to the youngest and two oldest groups performing significantly more simultaneous reaches than the intermediate age groups. Inspection of Table 1 suggests that the distribution of hand preference in these groups may explain the difference. The 7-, 11-, and 12-month groups have the highest proportions of non-right-handed infants of the six age groups.

To further examine the interaction between hand-use preference and simultaneous reaching, analyses were conducted on the effects of the barrier to the right or left of the infant's midline. When the barrier was on the right side, there was a significant main effect of hand preference, $F(2,56) = 4.66$, $p = .016$, and a significant age x hand preference interaction, $F(9,56) = 4.64$, $p = .0006$, and when the barrier was on the left side, there was a significant main effect of age, $F(5,56) = 3.59$, $p= .01$. Post hoc analyses revealed that both when the

TABLE 2
Effect of Age, Barrier Position, and Hand-Use Preference on Simultaneous and Nonsimultaneous Reaching

	Barrier Position								
	No Barrier			*Right Barrier*			*Left Barrier*		
	Hand-Use Preference								
Age[a]	*R*	*L*	*None*	*R*	*L*	*None*	*R*	*L*	*None*
A. Simultaneous Reaching									
7	.81	.39	.29	.42	.07	.00	.00	.32	.00
8	.22	.25	.17	.00	.25	.99	.03	.25	.33
9	.71	.00	.24	.00	.00	.18	.08	.00	.04
10	.09	.75	.36	.00	.00	.38	.00	.00	.00
11	.72	.20	.17	.64	.06	.17	.55	.13	.41
12	.13	.13	.51	.00	.00	.25	.00	.00	.10

	Lead Hand					
	R	*L*	*R*	*L*	*R*	*L*
B. Nonsimultaneous Reaching						
7	.10	.44	.00	.56	.64	.12
8	.41	.35	.28	.46	.56	.18
9	.37	.27	.10	.47	.70	.22
10	.51	.29	.18	.38	.54	.31
11	.39	.23	.08	.57	.35	.16
12	.42	.12	.47	.35	.54	.31

[a] Age is in months.

barrier was on the left and right sides, respectively, the 11-month group differed significantly from the other age groups. No other group differences were statistically significant.

Nonsimultaneous Reaches. On no-barrier trials, 66% of bimanual reaches were characterized by one hand leading the other (i.e., nonsimultaneous reaches). This raises the question of whether the infant's hand-use preference contributed to the selection of a lead hand in reaching, and whether the presence of a barrier has a differential effect on that selection as a function of age and sex. Table 2B presents the proportion of nonsimultaneous reaches with the right or left hand leading as a function of age and barrier position. With no barrier present, there was a significant age main effect, $F(5,56) = 2.83$, $p= .031$, for the likelihood that the right hand was the leading one, and a hand preference main effect, $F(2,56) = 5.40$, $p = .0095$, for the likelihood that the left hand was the leading one. In both cases, post hoc analyses indicated that the effect was due to the 7-month group, who had only 22o of infants with a right hand-use preference, being less likely to lead with the right hand than the other groups.

With the barrier on the right side, there was a significant age effect, $F(5,56) = 4.55$, $p = .003$. The 8- and 12-month groups were less likely to have a right-hand lead disrupted by the presence of a barrier on the right side than the other age groups. There were no significant differences between the groups with a barrier on the left side.

Hit Barrier. Infants hit the barrier with one hand while reaching out with both hands on 20% of trials. ANOVA revealed no significant differences between groups. With so few trials of hitting the barrier, it seemed possible that a measure which examined the effect of a barrier only for those infants who showed a hand preference might reveal age group differences. Table 3 presents the distribution by age group of infants who had either a right- or left- hand preference and hit the barrier. There was a significant association between age group and hitting the barrier with the preferred hand, $x^2(5) = 11.9$, $p < .05$, with the 7-month group hitting the barrier more frequently with the preferred hand than the 12-month group, $Z = 3.01$, $k = 6$, $p < .05$ (Silverstein, 1978). There was also a significant association between age group and hitting the barrier when it was on the side of the nonpreferred hand, $x^2(5) =17.7$, $p< .005$. Hitting the barrier occurred on a significantly greater proportion of trials in the 8-month group (who had the highest proportion of infants with a hand preference of any age group) then the 10-month group, Z= 3.74, k = 6, p< .01, and the 11-month group, Z = 3.74, k = 6, p < .01.

TABLE 3
Relation of Age Group to Proportion of "Hit Barrier" Trials For Infants With a Hand Preference

	Barrier Side	
Age Group[a]	*Preferred Hand*[b]	*Nonpreferred Hand*[b]
7	.35 (17)	.22 (18)
8	.21 (29)	.41 (34)
9	.13 (23)	.14 (22)
10	.29 (24)	.05 (22)
11	.10 (21)	.09 (23)
12	.00 (18)	.36 (14)

[a] Age is in months.
[b] Number in parentheses is sample size from which proportion is derived.

DISCUSSION

The major finding of this study is that the organization of bimanual reaching during the first year is a joint function of infant age, hand-use preference, and position relative to the midline of a barrier in the path of one of the hands. This is apparent in the pattern of results on simultaneous, nonsimultaneous, and "hit barrier" bimanual reaches.

The youngest and two oldest groups were significantly more likely than the intermediate age groups to reach out simultaneously with both hands when there was no barrier in the path of one hand. However, when a barrier was placed on either the right or left side, the 11-month-olds were the least likely to have their simultaneous reaches disrupted by the presence of a barrier. For the other groups, an impediment to the trajectory of one hand disrupted coordination between the two hands. This suggests that while infants as young as 7 months are capable of coordinating simultaneous reaches, the organization of these reaches may be different from that of the 11-month-olds. Since the simultaneous reaches of the 12-month-olds were more likely than those of the 11-month-olds to be disrupted by the presence of a barrier, the organization of bimanual reaching may undergo a reorganization between 11 and 12 months, a finding supported by the studies of Ramsay (e.g., 1985). The nature of such an organizational change is unclear from the present data, but its defining characteristic is that it permits a linkage between the two hands to resist disruption by a source of perturbation to either one of the hands.

The results for non-simultaneous reaching suggest a possible role for hand-use preference in resisting a perturbation to the path of one of the hands during bimanual reaching. With no barrier present and in age groups in which right-handedness predominates, most infants lead with the right hand. In the 7-month-old group, which is characterized by a high proportion of non-righthanded infants, right-hand leads are not evident. For 8-month-olds, who had the highest proportion of right-handedness, a barrier placed to the infant's right side was less likely than in other groups to disrupt right-hand leads. Thus, hand-use preference appears to assist the infant in maintaining a coordinated bimanual reach despite obstacles placed in the path of the preferred hand.

The results from trials on which the infant hit the barrier with one hand are also suggestive of a relationship between hand-use preference and the use of information to the left or right of the midline. The 8-month-olds, a group consisting of 9 of 10 infants with a hand-use preference, were more likely than any other age group to hit the barrier with their nonpreferred hand when the barrier was on their nonpreferred side, but were unlikely to hit the barrier when it was on their preferred side. Moreover, infants in the older age groups, who did not exhibit as high a proportion of infants with a hand preference, were also unlikely to hit the barrier when it was on their preferred side. The recent work of Bullinger (1984) indicating that postural asymmetries may bias the perceptual field to the right or left suggests a possible interpretation of the performance of the 8-month-olds. These infants, because of strong lateral preferences, may have had a head-orientation bias to one side of the midline so that they, effectively, may not have noticed the barrier on the nonpreferred side. We are currently following up on this possibility by examining head orientation during bimanual reaching.

In sum, the suggestion from three types of bimanual reaching is that during the first year, infants have at their disposal a set of potential solutions to the problem of using both hands to reach for an object. The actual solution appears to result from the imposition of postural and perceptual constraints on potentially available solutions.

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