Bimanual Role-Differentiated Toy Play During Infancy*

By: MARLIESE KIMMERLE, LAURA A. MICK AND GEORGE F. MICHEL

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Abstract:

Role-differentiated bimanual manipulation requires each hand to perform different, but complementary, actions on one or more objects. It is usually considered to be a late-developing high- level motor and cognitive skill involving the coordination of the two hemispheres of the brain. The frequency of role-differentiated bimanual manipulations was recorded in a longitudinal sample of 24 infants tested at 7, 9, 11, and 13 months during play with 10 different toys. Role differentiation was observed as early as 7 months, and its frequency was unaffected by toy characteristics. Role-differentiated bimanual actions increased with age, and the type of toy did influence the likelihood of eliciting role differentiation between 9 and 13 months.

Article:

Role-differentiated hand use can be defined as a bimanual manipulation skill in which each hand performs a different action, but these actions coalesce in the manipulation of an object. The different actions of the two hands have complementary functions; one hand has a supporting, or stabilizing, role as the other manipulates or explores the object. Although Gesell (1939) found very little bimanual activity around 12 to 14 months when he presented children with blocks, role-differentiated bimanual actions have been observed during toy play as early as 1 year of age, and they have been labeled role differentiation (Ramsay & Weber, 1986), collaborative hand use (Bresson, Maury, Pieraut-Lebonniec, & de Schonen, 1977), complementary bimanual actions (Bruner, 1970; Fagard & Jacquet, 1989; Michel, Ovrut, & Harkins, 1985), and functional asymmetry (de Schonen, 1977).

Compared to the investigation of infant uni- manual skills, role-differentiated bimanual skills have received relatively little attention. Recent research indicates that role differentiation emerges by the end of the 1st year (Michel et al., 1985; Ramsay, 1985; Ramsay, Campos, & Fenson, 1979), after the infant has acquired some competency with unimanual grasping and manipulation skills and a variety of bimanual skills (Bruner, 1970; Piaget, 1952).

Several studies have reported data suggestive of a transition in the organization of the control of the two hands, starting between 10 and 12 months. Goldfield and Michel (1986) found that by 11 months, the spatial and temporal pattern of movement of both hands changed in ways that suggested that the movement of each hand was separately controlled and coordinated. Before infants show bimanual role differentiation, they engage in undifferentiated bimanual object exploration with both hands holding or moving symmetrically, or alternating, such as rolling or turning an object around. Symmetrical bimanual manipulations appear to precede asymmetrical ones (Fagard & Jacquet, 1989), and incomplete differentiation precedes role differentiation (Ramsay & Weber, 1986).

The ability to perform role-differentiated bimanual manipulations represents a major shift both in motor skill and cognitive demands from those required for unimanual reaching, grasping, and manipulation of toys (Bruner,

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1970; Connolly & Dalgleisch, 1989; Ramsay & Weber, 1986). Role differentiation requires integration and sequencing of separate motor acts between the limbs, and it has been presumed to reflect both hemispheric specialization and interhemispheric collaboration (Michel et al., 1985; Ramsay et al., 1979). Diamond (1991) has suggested that this type of bimanual coordination is dependent on the appropriate development of the supplementary motor area (SMA) of the left and right frontal cortices and their interconnection through the corpus callosum. Thus, the presence of the behavior may be a useful neurological marker of callosal functioning in infancy.

The exact age of emergence and its possible relationship to neural development is not known, however. Clear collaboration between the hands, with a distinct role differentiation between the hands, emerges by 1 year of age and is lateralized, with the preferred hand taking the manipulating role (Michel et al., 1985; Ramsay et al., 1979). Although such role differentiation is not reliably present in all infants until 13 months, it has been elicited as early as 9 to 10 months (Fagard & Jacquet, 1989; Michel et al., 1985). However, with certain objects, it may not appear until 17 to 24 months (Bruner, 1970; Fagard & Jacquet 1989; Ramsay & Weber, 1986). Variation in the characteristics of the toys used for assessment and/or measurement protocol may possibly account for differences in age at which the action has been observed.

Role-differentiated bimanual toy play may be demonstrated with both hands contacting one toy with movable parts or with one hand on each of two toys. The single-toy category generally consists of effect-producing toys in which manipulation produces motion or sound from a part of the toy (e.g., a squeaker). Effect-producing toys appear to facilitate the expression of role-differentiated responses around 12 to 14 months from all or nearly all infants studied (Kimmerle, 1991; Michel et al., 1985; Ramsay et al., 1979). The two-toy task involves the manipulation of two toys which are attached to, inserted into, or removed from each other (e.g., the stabilizing of a cup with one hand, while a smaller toy is inserted or removed with the other). Although two-part toys were included in the Michel et al. (1985) handedness assessment battery and the Ramsay et al. (1979) study, neither study provided separate data by toy type. Fagard and Jacquet (1989) presented toys in containers which varied in level of difficulty. Removing a tube from an open container occurred as early as 10 months, but unscrewing a cap was not successful until 24 months.

In order to understand and describe the early emergence and pattern of development of role differentiation, it is important not only to clarify which of several role-differentiated behaviors are being studied but also to describe what the infant has to do in order for the behavior to be identified. For example, Kimmerle (1991) and Michel et al. (1985) recorded any attempt at role-differentiated bimanual manipulation, whereas Fagard and Jacquet (1989) noted only those infants who demonstrated a specified level of proficiency. Moreover, infants must be provided with a range of toy characteristics which permit different patterns of role differentiation.

Children exhibit different types and complexities of exploratory behavior depending on the specific characteristic of the toys, for example, shape, size, function, and support surface (Bresson et al., 1977; Goldfield, 1983; Kopp, 1974; Palmer, 1989; Power, Chapieski, & McGrath, 1985). However, there are only a few studies dealing specifically with the influence of toy characteristics on the type of infant manual skills (e.g., Newell, Scully, McDonald, & Baillargeon, 1989). The importance of presenting infants with a broad variety of toys to adequately assess lateralized unimanual and bimanual hand use was emphasized by Michel et al.'s (1985) 21-item protocol, but hand use was not reported specifically per toy category. The effect of specific toys on the frequency of role-differentiated versus unimanual and undifferentiated hand use was reported by Kimmerle (1991) for a sample of preschoolers (3-5 years), but similar data are not available for infants.

Fagard and Jacquet (1989) examined the effect of motor characteristics of the tasks (symmetrical vs. asymmetrical, simultaneous vs. successive) on bimanual performance between 10 and 24 months. However, the scoring systems of success/failure did not provide data on all role-differentiated attempts. Also, three of the four toys used were too difficult for infants younger than 13 months to manipulate effectively; therefore, it is not surprising that the youngest children could not demonstrate role differentiation. Their study does point out the need to systematically examine toy properties in bimanual studies.

It would appear, therefore, that neither the earliest development of role-differentiated toy play nor the context of its emergence has been adequately described during infancy. Although the presence and lateralization of role differentiation have been studied between 9 and 24 months, the bulk of the data describes development between 1 and 2 years and emphasizes lateralization issues. Little data are available on the earliest expression of role differentiation, with longitudinal investigation of changes in the frequency and context of role-differentiated actions during the 1st year. There are no data evaluating the role of different toys in eliciting role differentiation in young infants.

This study initiates a program of research to examine the pattern of expression of role-differentiated bimanual manipulation during the period from 7 to 13 months after birth and the contribution of toy type to the manifestation of this behavior. We examine the frequency of occurrence of role-differentiated actions in relation to toy type and infants' age, sex, and pattern of handedness.

METHOD

Subjects

Data from 24 infants (12 males, 12 females), tested at 7, 9, 11, and 13 months (± 1 week), were selected for analysis from a larger sample of 65 infants who participated in a study of the development of manual skills at DePaul University. The infants were born at Columbus Hospital in Chicago and represent a mix of Central American Hispanic, African American, Eastern European, and Middle Eastern ethnic backgrounds. All infants had a normal gestation period and birthweight, with no diagnosed developmental abnormalities. All had two parents living at home, and their parents, occupations were blue-collar to white-collar representing upper-lower and lower-middle socioeconomic status. The 24 infants were selected to provide equal numbers of males and females for each of the four test periods. The infants, handedness was assessed for all four visits, and infants were divided into those who did and those who did not exhibit a stable hand-use preference throughout the four visits.

Procedure

When their infants were 5 months of age, parents were contacted by letter describing the research being conducted on the development of manual skills. Within 2 weeks of sending the letter, the parents were contacted by telephone to determine if they would like their infants to participate in at least three different "playlike" activities. If the parents agreed, the first appointment was scheduled for within 1 week of the infant’s 7-month birthday.

At each visit, the infant’s handedness was assessed using an adaptation of the procedure described in Michel et al. (1985). The infant sat on the caregiver,s lap at a stomach-high table which allowed free arm movement. The infants were videotaped (Panasonic 2000 VCR) simultaneously from two camera (Panasonic wv-cd 130) angles providing both an overhead and left-side view.

For this study, 10 toys (see Figure 1) representing different categories of manipulation were selected for coding from a handedness battery of 24 toys. Only single toys were selected from the battery on the assumption that single-toy manipulations were motorically and cognitively less complex than those involving two-toy manipulations and would facilitate the earliest demonstration of role differentiation. Each toy was presented at midline on or above a table in front of the infant. Presentations lasted 10 to 15 s or were terminated by the infant. The toys were presented in a variable order. The selection of toys included different- shaped toys, a variety of different types of effect-producing toys, as well as toys that produced no movement or sound.

Certain of the physical characteristics of the toys are summarized in Table 1 and include movable parts, grasp-ability, and finger control. The movable parts characteristic distinguishes single, solid-piece toys from those that have movable pieces. Graspability refers to the ease with which the object can be retained in the hand of the infant. All of the toys match the size of an infant’s hand at even the youngest age and are capable of being grasped by one hand. However, some toys are more difficult to hold (in part based on shape and weight).

Finally, finger control identifies those toys which require a single finger or pincer action for manipulation. Based on these three physical characteristics, the 10 toys were grouped into 5 categories: Category A (no moving parts, easy grasp, no finger control); Category B (movable parts, easy grasp, no finger control); Category C (movable parts, easy grasp, finger control

TABLE 1
Physical Characteristics of the 10 Toys

		Characteristics		
Toy	**Category**	**Movable Parts**	**Grasp**	**Finger Control**
Star	A	no	easy	no
Barbell Rattle	A	no	easy	no
Rings	A	no	easy	no
Rattle & Bracelets	B	yes	easy	no
Disc Chain	B	yes	easy	no
Ring Ball	C	yes	easy	yes
Flipper	D	yes	difficult	yes
Ball Within Ball	D	yes	difficult	yes
Cage & Ball	D	yes	difficult	yes
Activity Barbell	E	yes	difficult	yes

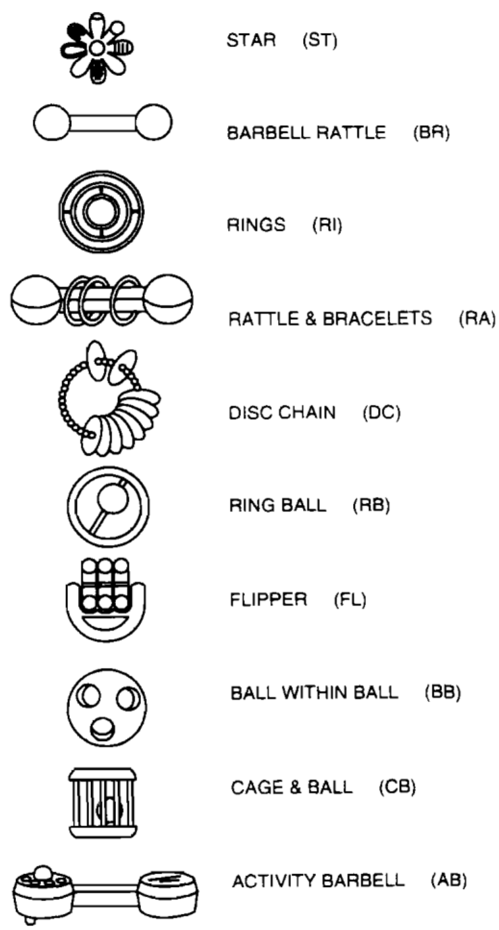

Figure 1. Schematic representation, verbal label, and abbreviation for each of the 10 toys used in this study.

required); Category D (movable parts, difficult grasp, fingering required); and Category E (added weight component making holding even more difficult).

Data Coding

Two observers independently coded the videotapes as they were played back at normal speed. The primary observer coded all 96 (24 x 4 age periods) tapes. The second coder coded 24 tapes (25%) for reliability calculations. In addition, 12 tapes (12.5%) were recoded by the primary observer to provide a measure of intracoder reliability. Reliability was determined by frequency of hits divided by frequency of hits plus misses for each subject. Mean intracoder percent agreement on frequency of role-differentiated actions was 90.2% (range = 79-100%), and mean intercoder reliability was 89.4% (range = 75-100%).

The coders recorded the frequency of role-differentiated bimanual toy play with each of the 10 toys. Role differentiation was defined as two hands having different but com plementary actions on the toy. That is, one hand engaged in facilitating actions: It supported (held up), stabilized (hung onto), pushed down on, or oriented (turned around) an object. The other hand manipulated: It stroked, poked, twirled, pulled, pushed the object or movable parts of the object.

In order to further operationalize the behavior, the following additional criteria were required:

1. There must be manual movement; object contact alone by finger(s) or hand was not considered manip-ulation.
2. The manipulation must be apparent at normal tape speed, even if it was just a very brief occurrence.
3. Manipulation could involve one or two fingers; this was coded regardless of how brief the action.
4. Manipulation could also involve the whole hand, the palm, or all the fingers (e.g., a sliding or stroking motion along the surface of the object). Typically, however, whole-hand actions were a "grab" (i.e., a hold or support action but not a manipulation). To be considered as a manipulation, the whole-hand action had to include at least I s of object exploration.
5. Role differentiation could involve a brief single action or a continuous series of actions. However, the series was only counted once, irrespective of its duration. Bouts of role differentiation were separated by either unimanual actions, other bimanual actions, or 1-s pauses in action.

RESULTS

Role-differentiated toy manipulations were observed in 79% of infants at 7 months and in all infants by 11 months (Table 2). Table 2 shows that the total number of role-differentiated actions increased with age, with the most striking increase occurring at the 13-month visit. Analysis of variance, with age as the within-subject factor and sex as the between-subjects factor, showed no significant main effect for sex, $F(1, 22) = 0.35$, $p = .55$, nor an age by gender interaction, $F(3, 66) = 0.23$, $p = .87$, on the frequency of role-differentiated actions.

However, there was a significant, $F(3, 66) = 3.45$, $p = .02$, difference in the frequency of role-differentiated actions with age. The mean frequency of role-differentiated actions doubled between the 7- and 13-month age periods (Table 2). A Tukey HSD post hoc test revealed that only the 7- and 13-month means are significantly different, $p < .05$. Trend analyses revealed a significant linear, $F(1, 94) = 11.13$, $p < .001$, increase with age in frequency of role-differentiated actions.

Although the mean frequency of role differentiation was 3 at 7 months, 25% of the infants produced their highest frequency (peak frequency) of role-differentiated (RD) events at

TABLE 2
Frequency of Role-Differentiated Bimanual Toy Manipulations Across the Four Age Periods

	Age (Months)			
Role-Differentiated Actions	**7**	**9**	**11**	**13**
Total *N*	72	107	117	145
M Frequency	3.00	4.45	4.87	6.04
SD	3.05	2.95	3.57	3.40
Infants Showing RD	19	22	24	23
Maximum RD Actions	11	10	13	14
N of Infants with a Peak Frequency	6	2	6	10

Note. RD = role-differentiated manipulations.

this age (Table 2). In contrast, 42% of the infants did not produce their highest frequency until their 13-month visit. For 8 infants, the frequency of their RD actions peaked during the 7- and 9-month visits (early peak); whereas for 10 infants, the peak frequency of role-differentiated actions occurred during their 13-month visit (late peak). Subsequent analyses of these two groups of infants revealed no systematic differences between early and late peak groups in relation to sex, early hand preference, or stable hand preference, nor did the early peak infants respond differently to particular toys.

The effect of toys on role-differentiated hand use was studied in several ways. A toy by age contingency table was constructed using the frequency of role-differentiated events for each of the five toy categories. These frequencies were converted into percentages of the total number of role-differentiated events recorded at each age. These percentages were placed in an age (4) x toy type (5) contingency table. Chi-square analysis revealed a significant relationship between type of toy and age, $x^2(12) = 24.68$, $p < .025$. Subsequent analysis for goodness of fit for each separate age revealed that the difference between toys was significant at all ages except 7 months (Table 3). Expected values for each toy-type category were determined as 10% multiplied by the number of toys that constituted that category.

TABLE 3
Chi-Square Values for the Relation of the Relative Proportion of Role-Differentiated Actions Per Five Toy Categories for Each Age Period

	Age (Months)			
	7	**9**	**11**	**13**
χ^2	9.28	12.37	36.42	28.58
df	4	4	4	4
p values	> .05	< .025	< .001	< .001

Figure 2 shows that although some toy types (e.g., Category A: star, barbell rattle, rings) received few role-differentiated manipulations at each age, other toy types were differentially effective at different ages in eliciting role-differentiated actions. Table 4 shows the exact proportion of the chi square that was contributed by each of the five toy categories at each age. At each age, toy-type Category A elicited distinctly less role-differentiated actions than expected. In contrast, toy-type Category E elicited distinctly more role-differentiated actions than expected at all ages except 7 months.

Another way to identify toy effects is to examine the number of infants that produced at least one role-differentiated action for each toy. The percentage of infants demonstrating role differentiation for each toy category at each age is shown in Figure 3. There was a significant association between age and toy-type category, $x^2(12) = 25.34$, $p < .025$. Chi-square analyses of

TABLE 4
Proportion of the Chi-Square Value Attributed to Each of the Five Toy Categories at Each Age

	Toy Category				
Age (Months)	**A**	**B**	**C**	**D**	**E**
7	.29*	.67	.003	.0002	.03
9	.51*	.04	.05	.002	.40
11	.29*	.03	.01	.11	.56
13	.29*	.08	.004	.09	.52

*The proportion represents a frequency less than expected.

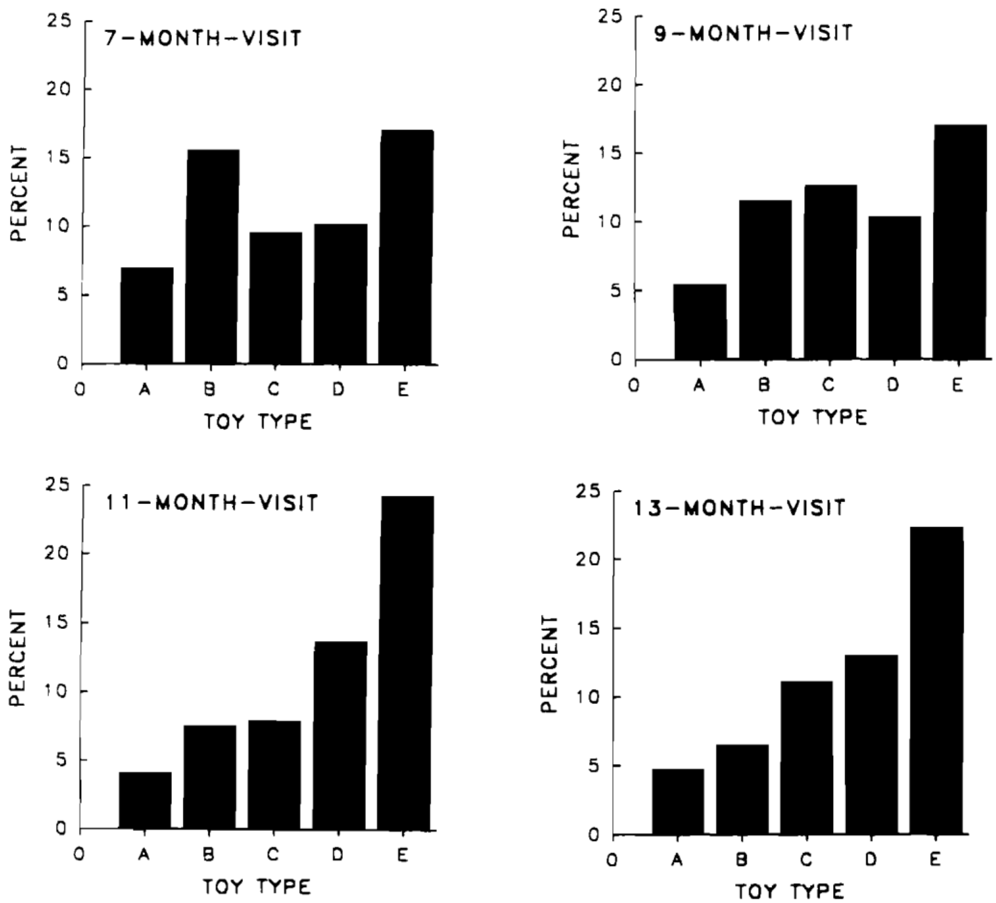

Figure 2. Mean percentage of total role-differentiated bimanual manipulations associated with each of the five toy-type categories at 7, 9, 11, and 13 months of age.

TABLE 5
Toys That Elicited Role-Differentiated Manipulations From the Most and From the Least Number of Infants at Each Age

	Age (Months)							
	7		9		11		13	
Most:								
	Disc Chain	33%	Disc Chain	52%				
			Activity Barbell	54%	Activity Barbell	64%	Activity Barbell	74%
					Cage & Ball	55%	Cage & Ball	58%
							Flipper	74%
Least:								
	Ring	13%						
	Rattle	13%	Rattle	13%	Rattle	9%	Rattle	21%
			Star	17%	Star	23%	Star	13%

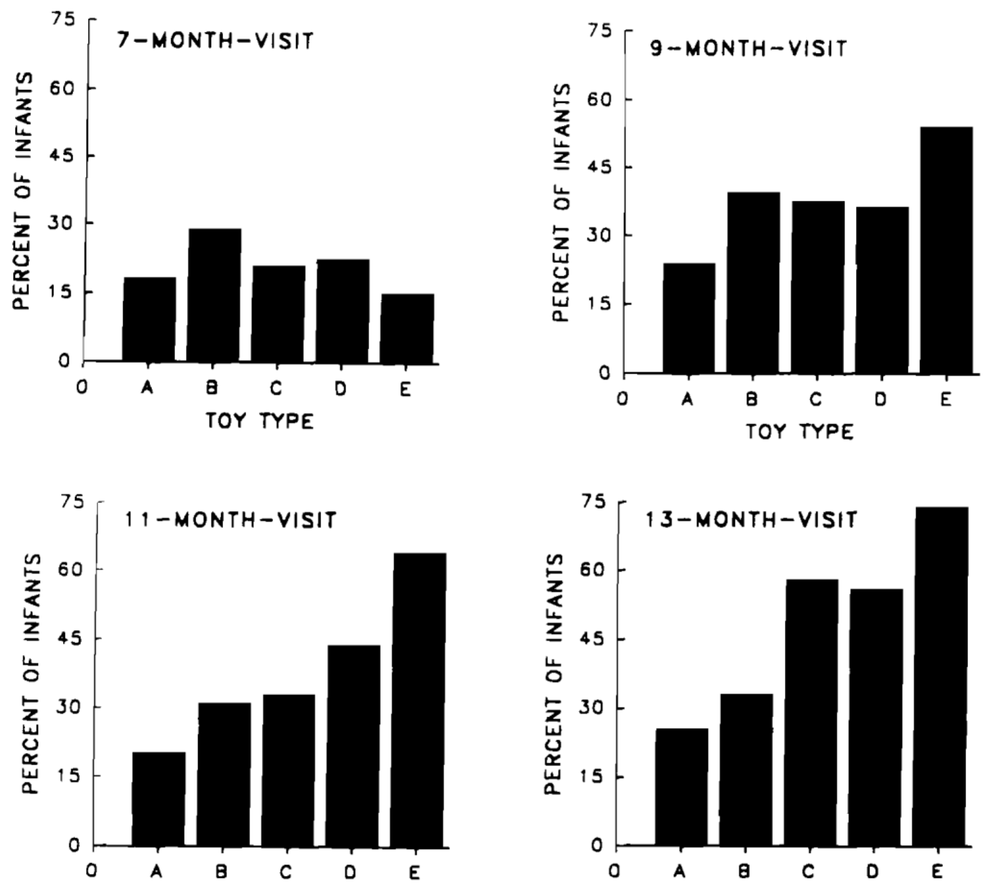

Figure 3. Mean percentage of infants who performed role-differentiated bimanual manipulations relative to each of the five toy-type categories at 7, 9, 11, and 13 months of age.

mean percent of infants who did or did not exhibit role-differentiated actions for each of the five toy-type categories were conducted for each age period. There were no significant differences according to toy type for the 7-month age period, $x^2(4) = 6.52$, $p > .25$. However, there were significant toy effects at 9 months, $x^2(4)$ _ 19.36, $p < .001$, 11 months, $x^2(4) = 46.32$, $p < .001$, and 13 months, $x^2(4) = 62.52$,$p < .001$.

Table 5 shows those toys which elicited a response from the most and the least number of infants for each age. The barbell rattle was least likely to elicit a response at all ages. The disc chain was successful in eliciting role-differentiated actions in the early ages, whereas the activity barbell, cage & ball, and flipper were most successful for the older infants. Note that at 7 months, even the most "attractive" toy elicited a role-differentiated action from only a third of the infants. However, at 9, 11, and 13 months, at least two toys received a response from over half of the infants, with the activity barbell being very effective at all three ages.

Although hand-use preference for role-differentiated actions was recorded, the number of those actions was insufficient to allow statistical comparison of the frequency of right and left role-differentiated bimanual manipulations for 7-, 9-, and 11-month visits.

DISCUSSION

The results demonstrate that role-differentiated bimanual manipulation can be observed as early as 7 months, exhibits linear increases with age, and that the frequency of its expression is influenced by the type of toy used in the assessment procedure. Also, the pattern of development of role-differentiated bimanual manipulation does not vary with the infant's sex.

Role-differentiated bimanual manipulations require the ability to grasp an object and exert some stabilizing, orienting, or resisting force with one hand, as the other hand explores the object surface with the fingers or whole hand. By 6 months, infants exhibit all of these actions as separate unimanual skills. Therefore, it is not surprising that some evidence of role differentiation might be found earlier than the 9 to 10 months reported to date (Fagard & Jacquet, 1989; Michel et al., 1985), and at least 5 months before, it is robustly present in all children. As Siegler and Munakata (1993) pointed out, new and more complex strategies do not emerge by "immaculate transition" but are more likely to make a gradual appearance sprinkled in a child’s repertoire long before they become a dominant or key feature.

Although role differentiation was clearly distinguishable as a behavior in these 7-month-old infants, its presence does not necessarily suggest a high level of skill. Any instance of role- differentiated behavior was recorded in this study regardless of its proficiency. Examination of the pattern of expression according to toy type indicates that early expressions of role differentiation do not appear to involve the independent control of the fingers that is associated with toy-type Categories D and E. Perhaps the collection of 10 toys provided a particularly enticing array which prompted unusually early bimanual explorations. These explorations in turn may have provided the conditions in which "precocious" (Fisher & Biddell, 1991) role differentiation could appear.

The earliest manifestations of role differentiation occurred, however, regardless of the toy properties. The star, for example, with no movable parts and no sound production elicited as many role-differentiated manipulations from as many infants at 7 months as the flipper with small movable parts. Therefore, role-differentiated bimanual manipulations at this early age may have occurred with little in the way of specific contextual support.

The presence of role differentiation as early as 7 and 9 months requires reexamination of notions about the relationship of bimanual coordination to the maturation of the supple mentary motor areas (SMA) and the callosal connections between the right and left hemispheres. Little is know about either the timeline of SMA development or the number and type of functional callosal fibers required for the appearance of bimanual collaboration. It is potentially possible that the earliest role-differentiated bimanual manipulations may occur without callosal involvement. Toy manipulations of the type described do not demand either great speed, precision, or strength, so it is perhaps not surprising that some role differentiation is present as early as 7 months. It is possible that these early, fairly simple, role-differentiated bimanual actions contribute to, as much as reflect, the functional development of the corpus callosum and the SMA.

The more smoothly coordinated, temporally sequenced bimanual manipulation such as box opening for object retrieval, which appears in the 2nd year, likely involves a more extensive neural network. Although some neural development must occur before any role differentiation can appear, its first appearance may occur incidentally during bimanual exploration. Consequently, it would be equally likely to occur with any object. This may account for the lack of toy effect at 7 months. Sound or movement toys were not necessarily more effective than nonmoving or silent toys. Often role-differentiated actions occurred as the child tried to grab and turn the object. A finger would slip into the cage & ball or, in passing, the hand made the flipper move. Only as the infant develops, would toy characteristics begin to exert an influence.

We propose that several factors contribute to the development of role-differentiated bimanual manipulation. One is the size, shape, and configuration of the object itself. The object must be such that the infant can readily hold, retain possession, and manipulate it, and the movable parts must be accessible and compatible with the infant's finger control. It is noteworthy that the activity barbell (a 20-cm plastic toy with a noisemaker at one end and a rotary knob at the other) was a highly effective toy at all ages except at 7 months. At 7 months, infants may have had more difficulty handling the heavy object and maneuvering the small knob. The cage & ball and flipper required one- or two-finger isolation to capture the small moving part, which may have been beyond the capability of the 7- and 9-month-old infants. On the other hand, the thin plastic disks on a chain could easily be stroked with the whole hand or several fingers and was effective at both 7 and 9 months.

Role differentiation also requires a match of the toy task with the level of the infant's cognitive understanding of the functional and effect-generating characteristics of an object. That is, the infant must comprehend that the object has movable pieces which can be activated if it is stabilized with one hand and poked at with the other. Such comprehension requires concepts such as causality, containment, stability, and so forth which are still developing during this period (Mandler, 1992). At 7 months, infants were as likely to use bimanual exploration on the rattle and the star as any other toy, even though these were single solid pieces with no movable parts. Both of these toys elicited few responses after 7 months, perhaps because of a change in the infant's comprehension of their properties.

It would appear then that development in perceptual-motor skill, comprehension of object function, and the object's physical characteristics collaborate, to enable the expression of role-differentiated toy play. Consequently, it may be inappropriate to use the presence of role-differentiated bimanual manipulations as a simple marker of either neural or cognitive development. The bimanual manipulations observed in this study at 7 to 9 months represent the earliest emergence of role differentiation reported. These actions clearly become more "skilled" in the following months in terms of precision, timing, and force control. However, our results demonstrate that a broad variety of toys both in terms of physical characteristics and cognitive demands are necessary to maximize the likelihood of eliciting the most complex manual skills from a sample of infants.

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