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INFANTS HAND PREFERENCE IN A SELF-FEEDING CONTEXT

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XIAOMEI WANG

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INFANT HAND PREFERENCE IN A SELF-FEEDING CONTEXT

BY

XIAOMEI WANG

A THESIS

Submitted to

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ABSTRACT

INFANTS HAND PREFERENCE IN A SELF-FEEDING CONTEXT

BY

XIAOMEI WANG

The hand preference of thirteen infants was observed from 9 to 18 months of age in a self-feeding context. The infants' hand use in unimanual and bimanual grasp and unilateral and bilateral reach and bimanual manipulation was observed. Parents behaviors -- holding infants' hand and positioning food -- was also observed. The results indicated that familial-right-handed (FRH) infants generally had right-hand preference in a variety of manual activities. However, shifts and fluctuations occurred in the development of hand preference. Familial-left-handed (FLH) infants showed a diverse and unpredictable pattern of hand preference. For FRH infants, the development of hand preference for bimanual grasp and bilateral reach lagged behind that for unimanual grasp and unilateral reach respectively. The parents, regardless of their own handedness, exerted moderate right-hand use pressure on their infants. The parents of FRH infants exerted the stronger right biased pressure on male infants than on female infants. However, the parents' right biased behavior was inconsistently related to the direction of infants' hand preference. There was no relationship between newborns' head orientation and infants' hand preference. In sex differences, FRH female infants showed greater right-hand preference than their male counterparts. Lastly, the infants tended not to cross the body-midline to reach for objects. However, all infants showed more contralateral reaches when their non-reaching hand was occupied than when it was free.

TO MY PARENTS AND SISTER

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TABLE OF CONTENT

LIST OF TABLES	vi
LIST OF FIGURES	vii
INTRODUCTION	1
LITERATURE REVIEW	4
1. The developmental process of infant hand preference	4
A. Grasping	
B. Reaching	
C. Bimanual manipulation	
2. Task influences on handedness	6
3. Parental influence on infant hand preference	8
4. Relationship between head orientation and hand preference	9
5. Sex differences	10
6. The "Midline barrier" and the effectiveness of overcoming the "midline barrier" by having the non-reaching hand occupied	12
SUBJECTS	15
METHOD	16
Procedure	16
Hand preference during self-feeding period	
Head-orientation (HO) in neonatal period	
Definitions of variables and data coding	17
Reliability	19
Analysis	19
RESULTS	21
1. The developmental process of infant's hand preference ...	21
A. Unimanual grasping	
B. Bimanual grasping	
C. Unilateral reaching	
D. Bilateral reaching	
F. Bimanual manipulation	
G. The trend of changes in hand preference	
2. The effect of different types of activities	33
3. Parental influence on infant hand preference	35
4. The relation of newborn head orientation (HO) and hand preference	41
5. Sex differences	42
6. The effect of "midline barrier" and the effectiveness of overcoming the "midline barrier" by having the non-reaching handoccupied in unilateral reaching	43

DISCUSSION	46
1. The development of handedness in infancy	46
A. FRH subjects	
a. Grasping	
b. Reaching	
c. Bimanual manipulation	
B. FLH infants	
2. Task influence on handedness	52
3. Parental influence on infant hand preference	55
4. Relationship between head orientation and Hand Preference	56
5. Sex differences	57
6. The "midline barrier" and the effectiveness of overcoming	
the "midline barrier" by having the non-reaching hand	
occupied	58
 CONCLUSIONS	 59
 LISTS OF REFERENCE	 60

LIST OF TABLES

1. HAND PREFERENCE (Z SCORE) IN UNIMANUAL GRASP	23
2. HAND PREFERENCE (Z SCORE) IN BIMANUAL GRASP	25
3. HAND PREFERENCE (Z SCORE) IN UNILATERAL REACH	27
4. HAND PREFERENCE (Z SCORE) IN BILATERAL REACH	30
5. HAND PREFERENCE (Z SCORE) IN BIMANUAL MANIPULATION	32
6. THE AGE TREND IN HAND PREFERENCE (Z SCORE) FOR FRH INFANTS .	34
7. HAND PREFERENCE (Z SCORE) IN VARIOUS MANUAL ACTIVITIES	35
8. PARENTS' HOLDING AND POSITIONING BEHAVIORS (Z SCORE)	36
9. DIFFERENTIAL PARENTS' POSITIONING BEHAVIOR FOR FRH MALE AND FEMALE INFANTS	37
10. SPEARMAN RANK CORRELATIONS IN HAND PREFERENCE	38
11. SEX DIFFERENCE IN HAND PREFERENCE (Z SCORE) FOR FRH INFANTS	43
12. MIDLINE BARRIER - CONTRALATERAL VS. IPSILATERAL REACH (C SCORE)	45
13. CONTRALATERAL REACHES WHEN THE NON-REACHING HAND OCCUPIED VS WHEN IT WAS FREE (CO SCORE)	45

LIST OF FIGURES

1. HAND PREFERENCE (Z SCORE) IN UNIMANUAL GRASP	23
2. HAND PREFERENCE (Z SCORE) IN BIMANUAL GRASP	25
3. HAND PREFERENCE (Z SCORE) IN UNILATERAL REACH	27
4. HAND PREFERENCE (Z SCORE) IN BILATERAL REACH	30
5. HAND PREFERENCE (Z SCORE) IN BIMANUAL MANIPULATION	33

INTRODUCTION

Scientists have been interested in the development of cerebral lateral specialization and its main manifestation, handedness, for a very long time. Is it present at birth? How does it develop over age? Social training theory posits that handedness is absent at birth and then develops as a consequence of social reinforcement. In contrast, genetic theories hold the opposite point of view. They suggest that handedness, whether present or absent at birth, develops as the direct expression of cerebral lateral specialization regardless of social reinforcement. One of the best known genetic models is Annett's (1964, 1974) simple allele model for the inheritance of handedness and cerebral dominance. Her model postulates a single allele, which, when present, superimposes a dextral bias on individual variability in handedness. But when it is absent -- as in the offspring of two left-handed parents -- it permits individual handedness to assort in random proportions. Her model also implies that this allele may not affect handedness directly, but instead may produce asymmetries for other functions, which, in turn, produce the dextral bias. The controversy among genetic theorists is whether cerebral lateralization is variant or invariant over age. One group of investigators suggests that lateralization is age variant. It is absent or very minimal in the newborn, and develops gradually as a maturational unfolding process (Lenneberg, 1967). Lenneberg proposed that lateralization does not stabilize until adolescence, whereas Krashen (1972) placed the age of stabilization at about 5 years of age. Inasmuch

as handedness is a direct expression of lateralization, its development will parallel the development of cerebral lateralization. Lenneberg (1967) also suggested that the right hemisphere's capacity to assume language function of the left hemisphere decreased with age as the right hemisphere became more specialized.

However, there is other evidence to suggest that cerebral lateralization is present in the newborn and remains relatively unchanged over age (Dennis & Whitater, 1977; Harris & Witelson, 1977; Kinsbourne & Hiscock, 1977). EEG recordings of cortical activity suggest that hemispheric asymmetry in response to an auditory stimulus is present in 1-month-old newborns (Molfese 1977). Studies using evoked potential (EP) found that the EP asymmetry was present at birth and declined with age (Molfese, Freeman & Palermo, 1975). Anatomical studies discovered that asymmetries of size and direction in the temporal speech cortex in infants was similar to that found in the adult (Wada, Clark & Hamm, 1975; Witelson & Pallie 1973). Use of the dichotic listening technique -- a standard tool for assessment of hemispheric specialization in normal adults -- found a lateral cortical specialization with prelinguistic infants (Glansville, Best & Levenson, 1973). Berlin, Hughes, Lowe-Bell and Berlin (1973) reported that they found a strong right ear advantage at early age which did not show a constant increase over age. Turkewitz Gorden and Birch (1965) and Turkewitz (1977, 1983) observed that "the posture of the infant is asymmetrical, and the infant lies with its head turned out of the midline. This asymmetry is highly uniform, almost all of the infants lie with their heads turned to the right". Fitzgerald and Webster (1979) reported conflicting results. In their study, Mexican

newborns' predominate head position was to the left. However, the head-left position was attributed to an interaction between nursing practices and biobehavioral state (Harris & Fitzgerald, 1983), rather than to genetic influences. Clinical data obtained from left hemidecorticate patients suggests that the right hemisphere's regulatory control of language, which Lenneberg argues is easier in infancy than in adulthood, causes difficulties with language structure in childhood as well as in adulthood. All of these findings suggest that cerebral lateralization is an age-invariant event and is present in the newborn. Caplan and Kinsbourn (1976) proposed that differentiation of handedness over age was due to the increasing capacity of the left hemisphere's fine motor control, but not to lateralization itself.

Overall, the evidence looks stronger for the age-invariance model of cerebral lateralization. Since handedness is a main manifestation of cerebral lateralization, then handedness is age-invariant. Moreover, all the theories agree that the expression of handedness increases over age regardless of its underlying structure, e.g., social pressure, cerebral lateralization, or fine motor control.

Several questions related to hand preference development can be raised.

First, how does hand preference develop over age?

Second, is hand preference affected by task difficulty level?

Third, to what extent does social pressure influence the development of hand preference?

Fourth, is there a relationship between early behavioral lateralization and hand preference?

Fifth, are there any sex differences in hand preference?

LITERATURE REVIEW

1. The developmental process of infant hand preference

A. Grasping

There are relatively few studies focusing on the development of grasping, especially involving infants older than 6 months. Halverson's study (1937) on grasping showed that right hand preference emerged at age of 1 week. He found that the right hands of supine infants aging 1 to 20 weeks were more active when a rod was pressed against their palms. Caplan and Kinsbourne (1976) compared infants' (average age was 2.7 months) hand use bias as indexed by grasp duration (began when a rattle was placed in one or both hands and ended when it was dropped) during unimanual and bimanual tasks. On the unimanual task, the results showed that infants held a rattle significantly longer with the right hand than the with left hand (62 and 41 seconds respectively). On the bimanual task, they also held the rattle longer with the right hand than with the left (45 and 36 seconds respectively). Hawn and Harris (1979, 1983) used a similar procedure and found that unimanual grasp duration was significantly longer for 5-month-olds than for 2-month-olds. Grasp duration was longer with the right hand than with the left hand for both age groups (54 seconds with the right and 35 seconds with the left), but the difference between right and left hand preference groups was not significant between the two age groups. On the bimanual task, 5-month-olds grasped significantly longer than 2-month-olds,

but only 5-month-olds showed a significant difference in hand preference, in favor of the right hand.

Age comparisons in grasping duration are often confounded with total duration, since older infants also have longer grasp duration. Therefore Hawn and Harris (1979) reported a mean laterality index ($(R+L/R-L \times 100)$), which indicated a right hand preference when it was positive and a left hand preference when it was negative. In unimanual task, the index was 22 for 2-month-olds, and 23 for 5-month-olds. In bimanual task, the mean laterality index for the 2-month-olds was 20 and 39 for the 5-month-olds. Applying the same index to the Caplan and Kinsbourne's study (1976), the laterality index was 20 on unimanual grasp and 11 on bimanual grasp.

B. Reaching

More is known about the development of reaching than about grasp duration. Investigators suggest that there is no consistent preference in reaching before at least the middle of the first year (Waston, 1924; Grapin & Perpere, 1968, cited in Young, 1977; Cernacek & Podivinsky, 1971; Seth, 1973; Sherick, Greenman & Legg, 1976) or before the third or fourth year (Gesell & Ames, 1947). The time at which hand preference in reaching becomes stable varies from study to study depending on the nature of stimulation and response measurement. Gesell and Ames (1947) used a combined cross-sectional and longitudinal design to investigate hand preference in reaching from 2 months to 4 years of age with a 4-week observation interval. Objects were presented to the midline, and infants were scored for the hand used in reaching and contacting the objects. Infant subjects were tested in both the sitting

and supine positions. The result was a shifting, unstable pattern of hand preference, which Gesell and Ames traced through numerous, distinct stages as follows: no preference until 12 weeks; unilateral and largely left-hand preference between 16 and 20 weeks; a definite shift to bilaterality by 24 weeks; a shift to unilateral, most often right-hand preference by 28 weeks; another shift to bilaterality at 32 weeks; unilateral, and more often right-hand preference at 40 weeks and a more left-hand preference at 48 weeks; a clear change to right-hand preference at 80 weeks; relatively clear unilateral use of right hand at 2 years; another marked shift to bilaterality between 2.5 and 3.5 years, and finally an unilateral, right-handed preference predominating by 4 years.

C. Bimanual Manipulation

Bimanual manipulation is defined as holding an object in one hand and manipulating it with the other hand. Previous studies suggest that this ability does not occur until the end of first year of life (Bruner 1970). Ramsey, Campos and Fenson (1979) and Ramsay (1980) reported that bimanual manipulation first showed hand preference at about 12.8 months of age (range from 10-17 months) and achieved stability at 14.2 months of age.

2. Task Influences on handedness

The previous studies indicate that task difficulty level influences the degree of hand preference. The same degree of right-hand preference was found in a unimanual task at 2 months and 5 months. But right-hand preference only persisted for the 5-month-olds in a bimanual task (Caplan and Kinsbourne 1976, Hawn and Harris, 1979). Hawn and Harris (1979)

reported similar results in reaching by using a technique to overcome the "midline barrier".

An interpretation for task influence on handedness was offered by Caplan and Kinsbourne (1976) arguing that, on a bimanual task, what increases with age was the degree of fine motor control of the left hemisphere and a corresponding increase in its ability to inhibit activity of the right hemisphere when both were activated and competed for attention. In other words, the 2-month-olds had a tendency to put their hands together and the bimanual task brought out this tendency. Therefore they did not show a hand preference bias until the left hemisphere gained sufficient inhibitory control of the right hemisphere, estimated to be at least at 5 months of age. According to this view, although there are behavioral changes in hand preference bias, the underlying structure of lateralization is invariant. Furthermore, Hawn and Harris (1979) reported that the 5-month-olds were far more skillful and attentive than the 2-month-olds. For instance, on grasping tasks, the 2-month-olds seemed quite passive, as though unaware that anything was happening. They held objects quite loosely with little arm movement. In contrast, the 5-month-olds were much more active, moving their arms and grasping much more strongly. They often held the objects in front of their faces and looked at them. So, the greater hand difference of the 5-month-olds might relate to their greater skill level. There is some evidence that lateralized behavior is brought out more clearly on tasks requiring greater skill. For instance, the preschoolers were more likely to show lateralized hand use for eating with utensils than with their fingers (Cf. Harris and Fitzgerald 1980).

3. Parental Influence on Infant Hand Preference

We live in a right-hand dominant society. Social expectations and social norms will unavoidably affect the organization of behaviors. Even handedness, with its basis in the genotype, is influenced by social-cultural pressures. The genotype may structure the direction of hand preference, but social pressure may determine the degree to which hand preference is expressed in the phenotype. For instance, Teng et al (1976) found exclusive use of the right hand for eating and writing among a group of genotypically left-handed Chinese children. The proportion of children who used their right hands to eat and write but who were otherwise left handed was less among Chinese Americans and even lesser among the whites in the United States than in Chinese children in Taipei (Teng, 1976). There is undoubtedly societal pressure in favor of right-hand preference. This is exerted by means of handling practices during infancy, parental modeling of manual behaviors, provision of tools suited to right-hand use, and social disapproval of left handedness (Liederman, 1983). It is not possible to tell from Teng et al's data, however, whether the right hand preference for eating and writing reflects a generalized preference among presumably genotypic left-handed children, or if the observed right-hand preference is task-specific. One can not determine also from their study whether socialization factors exert their influence during infancy or at some later point in development.

4. Relationship between head orientation and hand preference

Some theorists who espouse a genetic explanation for the development of handedness believe that newborn head orientation is the precursor

of later hand preference via its facilitation of eye-hand coordination (Gesell & Ames 1950; White, Castle & Held, 1964; Coryell & Michel 1978; Michel, 1981; Coryell, 1985; Michel & Harkins, 1986). Gesell & Ames (1950) proposed that the newborn's spontaneous tonic-neck-reflex (TNR) position orientation (i.e., head turning bias when newborn is supine) indicated later hand preference. Right TNR predicted right hand preference and left TNR predicted left hand preference. White et al (1964) reported a positive relationship between gaze and later hand preference using a reaching task. Michel (1981) and Michel and Harkins (1986) reported a strong correlation between head orientation in newborns and hand preference in reaching in infancy (3 weeks to 18 months) regardless of the direction of head orientation. Infants who turned their head to right were likely to use their right hand to reach, whereas infants who turned their head to left were likely to use their left hand to reach. Coryell (1985) found slightly different results. Handedness of right-handed children was predicted by their right-head-turning in neonatal period, whereas non-hand-preference was related to non-preference in head-orientation. Michel (1981) and Michel and Harkins (1986) offered two alternative interpretations regarding the mechanism linking neonates' head orientation to infants' handedness. One of them is that when neonates turn their heads to the right, they see their right hand more often than their left hand. With more opportunity to observe their right hand, infants may develop better eye-hand coordination with the right hand, thereby giving it advantage over the left in visually guided reaching. Thus head-orientation preference could be associated with hand preference because of differences in visuomotor experience

of the hands. Alternatively, head orientation and handedness could be independently determined by the same underlying factor, namely, the right-bias allele proposed by Annett (1964, 1974). An association between head-orientation preference and handedness is compatible with Annett's genetic model if we assume that head orientation, as well as handedness, is directly affected by the right biasing factor. Actually, the two interpretations are not necessarily mutually exclusive. Annett's theory predicts a rightward bias in head orientation for familial-right-handed infants. Rightward head turning then facilitates eye-hand coordination, leading to the greater right hand use than the left hand use. The same holds true for left head turning and left hand preference.

5. Sex Differences

Both clinical studies and studies on neurologically intact individuals suggest that females are more bilateral and males are more unilateral in brain organization (McGlone, 1977; McGlone & Davidson, 1973; McGlone & Kertesz, 1973; Inglis & Lawson, 1981; Kimura, 1969; Landell, 1962; Landell & Urbach, 1965; Lacoste-Utamsing & Holloway, 1982). The evidence that non-verbal functions are more lateralized in males than in females is convincing, whereas findings regarding verbal asymmetries are conflicting (McGlone, 1977; Maccoby & Jacklin, 1974). One study with children (Witelson, 1976) indicated that 6 to 14 year old boys had greater left hand advantage in a visual recognition task of non-sense shapes, whereas girls did not show asymmetries between hands during the same age period. This suggests that sex differences in the lateralization of function emerge at or before

the age of 6 with the possibility that males are more lateralized than females.

Nevertheless, the studies with infants indicate that lateralization emerges earlier in female infants than in male infants. For example, Shucard, Shucard and Thomas's (1984) study with 3- to 6-month-old infants found that a lateralized pattern of processing auditory stimuli established earlier in female than in male infants. Carlson and Harris (cited in Harris, 1983) found that female infants increased the use of their right hands for reaching between 4 and 9 months while males showed a consistent preference for the use of their left hands. Humphrey and Humphrey (1987) reported that 5- to 8-month-old female infants had right hand preference in reaching whereas male infants showed no hand preference. However, they found no sex difference in hand preference in 9 to 13-month-old infants. Both male and female infants showed right-hand preference. Michel, Ovrut & Harkins' (1986) study with 6- to 13-month-old infants found that females had more distinct hand-use preference than males for object manipulation.

The sex differences in infancy in lateralization and hand preference may be attributed to the fact that girls mature developmentally earlier than boys (NCHS, 1976; Hamill, Johnson & Lemeshow, 1973). Wolff (1977) believes that fine motor coordination, the underlying structure for the expression of handedness, follows a different developmental timetable in boys and girls. Therefore, girls may show stability for handedness earlier than boys.

6. The "midline barrier" and the effectiveness of overcoming the "midline barrier" by having the non-reaching hand occupied

"Midline barrier" refers to the infant's tendency not to cross body midline in order to reach for an object. Crossing the body midline appears to depend on the maturity of the corpus callosum (Liederman, 1983). For instance, Hurwitz (1971) reported that split-brain patients use their left hand to point to locations on their left side and their right hand for the right side rather than reaching across the body midline, which is the typical adult response. Hawn and Harris (1979) developed a procedure to facilitate the infant's ability to cross body midline. Their procedure was to put an object in one of the baby's hand and then to encourage the baby to reach for an object which was placed on the contralateral side of his unoccupied hand. The method was successful in that infants did increase their contralateral reaches. This method was used in a structured context and has not been replicated in other contexts such as in an unstructural or naturalistic setting like self-feeding.

It is the intent of this study to investigate issues raised above. A longitudinal study with a natural setting has been chosen since most of previous studies have used cross-sectional designs and have focused on structured situations. Infants' hand preference was observed during self-feed periods every three months from nine to eighteen months of age. The self-feeding situation not only provides an excellent opportunity to systematically examine the infant's hand use in a natural context, but also allows us to have a close

look at the parent's role in directing and shaping infant's hand preference. The same infants' head-orientation was also observed during the newborn period. Both familial right-handed (FRH) and familial left-handed (FLH) infants were included because little is known regarding the development of handedness of the latter. A detailed description of subjects and procedure can be found in the "method" section.

The first purpose of this study was to investigate the development of hand preference in a variety of tasks -- unilateral and bilateral reaching, unimanual and bimanual reaching, and bimanual manipulation. The hypotheses and predictions were:

A) For FRH infants:

i) In grasping, based on the results of Hawn & Harris' (1979) and Caplan & Kinsbourne's (1976) studies, the hand preference of FRH infants in unimanual grasping should show a stable right bias over age, but it should show increasing right hand bias in the bimanual grasping.

ii) In reaching, a shift in direction and degree of hand preference was expected with age (Gesell & Ames, 1947).

iii) Bimanual manipulation, according to Bruner (1970) and Ramsey (1980, 1982), was expected to make its first appearance sometime around 9-12 months of age and then become more mature and frequent. Hand preference, accordingly, should show a fluctuating pattern at earlier age and more right-hand preference at later age in bimanual manipulation.

B) FLH infants

Since they are qualitatively different from their FRH counterparts and are heterogeneous in handedness (Annett, 1964, 1974, 1981), FLH

infants were expected to show a more inconsistent and unpredictable pattern in hand preference with greater within group variance than FRH infants.

The second purpose of this study was to examine task influences on hand preference. It was expected that FRH infants' hand preference would be stronger in bimanual tasks than in unimanual tasks (Hawn & Harris, 1979; Caplan & Kinsbourne, 1976). Again, the pattern would be less predictable for FLH infants.

The third purpose was to examine parental influences on infants' hand preference. Since most parents should be right handed (Tent et al, 1976), the relationship between parental behavior and the parents' own handedness could be examined.

The fourth purpose of this study was to examine the relationship between head orientation in the newborn period and hand preference later in infancy. A correlation between head orientation and hand preference was expected to occur regardless of familial handedness (Michel, 1981; Michel & Harkins, 1986).

The fifth purpose was to examine the sex differences. The hypothesis was that female infants would show greater right hand preference than male infants (Carlson & Harris, cited in Harris, 1983; Humphrey & Humphrey, 1987; Michel et al, 1986).

The sixth and last purpose of this study was to examine the "midline barrier". It was expected that 9- to 18-month-olds rarely cross the body midline to reach an object. However, reaching across "midline" should be encouraged by having the infants' non-reaching hand occupied (Hawn & Harris, 1979).

SUBJECTS

The subjects were thirteen infants, ranging in age from 9 months to 18 months. Five infants (4 males and 1 female) were familial left-handed (at least one parent was left handed). Eight infants (4 males and 4 females) were familial right-handed (no left handed parents and grandparents). Note that although this is a commonly used criterion of familial handedness, it is a lax criterion because the effect of familial-left-handedness may be stronger if a parent is left-handed than if a grandparent is left-handed (McCormick & Maurer, 1988).

The subjects were selected from a total of 36 participants in a longitudinal study of the lateralization during the first 18 months of life (Harris & Fitzgerald 1980). The criterion of the selection was four completed self-feeding episodes at 9, 12, 15 and 18 months of age. All infants were clinically normal at birth as indexed by Apgar scores, Ponderal Index, and the Brazelton Neonatal Behavior Assessment Scale. Informed consent for continued research participation was obtained from the original investigators.

METHOD

Procedure

Hand preference during self-feeding period

In the longitudinal study, the subjects were tested, observed and video-taped in their homes with one or both parents present at 14 days and 1,2,3,4,5,6,9,12,15 and 18 months of age. The tests and observations included head orientation, grasp duration, preferential reach, etc. The present study is based on the natural observations of hand preference conducted during infants' self-feeding at 9, 12, 15 and 18 months of age. Parents were asked to feed their infants as in their normal fashion. Infants usually sat on a high-chair. A camera was used to record the whole feeding episode. The length of the self-feeding varied from time to time and from individual to individual, ranging from about 4 minutes to 30 minutes. Later, all the taped self-feeding episodes (a total of 36 subjects' self-feedings were videotaped) were viewed to determine the number of subjects for whom the data were available for the four test periods (9,12,15 and 18 months). This screening resulted in the identification of 13 subjects with complete data. Self-feeding episodes from the tapes were re-recorded onto new videotapes and scored second by second. Time indicators were placed on the tapes with a time-data generator. A total of 13 hours long tapes provided the data base for this study with approximately one hour for each subject.

Head-orientation (HO) in neonatal period

The procedure is as the follows: baby laid in supine position, the experimenter (positioned behind the baby) gently held baby's head at midline for 60 seconds and then released it for 60 seconds. An observer recorded the direction of the infant's HO every 6 seconds during the 60-second period after the release. The same procedure was used for successive right, left and a second midline hold. Babies were tested within three days of delivery in the hospital and at 2 weeks, 4 weeks, 8 weeks and 12 weeks of age at home (see Harris & Fitzgerald, 1983; Cornwell, Barnes, Fitzgerald & Harris, 1985).

Definitions of variables and Data coding

- 1) Unimanual grasp: one hand exclusively grasped the object (food or utensil). Duration of unimanual grasping with the right and the left hand was scored.
- 2). Bimanual grasp: both hands grasped the object (food or utensils) simultaneously. The leading hand was the hand that engaged in feeding and eating or showed greater effort in grasping (for example: grasping an object and waving it in the air showed greater effort than grasping an object and then resting on the table). Sometimes, there was no leading hand in a bimanual grasp. Both hands were used equally. Duration of bimanual grasping with the right and the left leading hand and no leading hand was scored.
- 3). Ipsilateral reach: one hand or arm was extended to reach the object (food or utensil) without crossing body midline. The actual touch on the object was not required for an ipsilateral reach to

occur. Frequency of ipsilateral reaching with the right and the left hand was scored.

4). Contralateral reach: one hand or one arm was extended to cross body midline in an effort to reach the object (food or utensil).

The actual touch on the object was not required for a contralateral reach to occur. Frequency of the contralateral reach with the right and the left hand was scored.

5). Bilateral reach: two hands or arms were extended simultaneously to reach the object (food or utensils). The actual touch on the object was not required for a bilateral reach to occur. The leading hand was the hand which started the bilateral reaching movement or showed greater effort in bilateral reaching. Sometimes there was no leading hand in the reaching, both hands were used equally. Frequency of bilateral reaching with the right and the left leading hand and no leading hand was recorded.

6). Bimanual manipulation: two hands had qualitatively different functions in dealing with the object (food or utensil). One hand held it and another hand manipulated it. The manipulation hand was assumed to play the greater role in hand preference. Duration of bimanual manipulation was scored for holds where the right hand was the manipulating hand and where the left hand was the manipulating hand.

7). Parent holding: parent held infant's hand to feed the infant. Duration of the holding and the infant's hand that was held by the parent was scored.

8). Parent positioning: parent put food and/or utensils in the feeding table to facilitate one hand usage during feeding. Frequency of positioning and the side of the table (relative to the infant' body midline) to which the food and/or utensils were positioned was scored.

Reliability

A intercoder's reliability of 0.85 (percentage of agreement) was obtained by training coders before they began to code data using the self-feeding episodes which were excluded from the data base of the current study. The same level of reliability was maintained throughout the coding period by checking the intercoder's reliability on a randomly selected 20% of the data. Reliability was maintained at or above 0.85 (percentage of the agreement) throughout the coding procedure.

Analysis

The subjects were divided into two groups based on their familial handedness. The familial-right-handed group (FRH) consisted of infants from families where all the family members, including parents and grandparents, were right handed. The familial-left-handed (FLH) group consisted of infants from families where at least one of the family members, including parents and grandparents, was left handed. It was expected that FRH and FLH infants were different groups in terms of the pattern of hand preference.

The Walsh test was chosen to examine the difference between the right and the left hand use for FRH and FLH infants. The Fisher

exact probability test was chosen to examine the differences in hand preference between the FRH and FLH groups. Spearman rank test with correction for ties was selected to examine the relationship of hand preference across manual activities as well as the relationship between head orientation and hand preference. A $p < .5$ was adopted as the criterion for significance.

RESULTS

Initial scoring was done by dividing all the data into two groups based on the type of objects (food or utensils) the infants were exposed to in a variety of manual activities (reaching, grasping and manipulating). However, preliminary analyses failed to show that the type of object contributed significantly to infant hand preference. Therefore the scores were combined for further analysis.

1. The developmental process of infant's hand preference

In unimanual grasp and unilateral reach, the index of hand preference (Z) was computed as $Z = R-L / R+L \times 100$. In bimanual grasp and bilateral reach, the index of hand preference (Z) was computed as $Z = R-L / R+L+N \times 100$. R stands for duration or frequency of the right hand or the right leading hand used. L stands for duration or frequency of the left hand or the left leading hand used, and N stands for the duration or frequency of no leading hand used.

Therefore, a positive Z indicates a right hand preference (the greater the positive Z the greater the right preference), whereas a negative Z indicates a left hand preference (the greater the negative Z the greater the left preference), and $Z = 0$ indicates no hand preference (both hands used equally).

A. Unimanual Grasping

For all infants combined, there was a right hand preference ($Z = 22.9$) in unimanual grasping.

FRH infants:

The results (Table 1, Figure 1) indicated that FRH infants generally held food and/or utensils longer with their right hand than with their left hand. Infants showed right hand preference overall ($Z = 37.8$) and at 9, 12, 15 and 18 months of age ($Z = 36.4$, 17.8, 52.5 and 46.4 respectively). But the magnitude of right hand preference across ages fluctuated with a decline at 12 months. The Walsh test indicated that there was a significant difference in hand use favoring the right hand only at 15 months ($p = 0.01$). Furthermore, the individual data revealed that all FRH infants (except one at 9-months) grasped the food and/or utensil unimanually across age periods. Out of 8 FRH infants, 5 infants at 9-months, 5 at 12-months, 7 at 15-months and 7 at 18-months showed right bias, whereas 2, 3, 1 and 1 showed left bias at each of the 4 age periods respectively.

FLH infants:

FLH infants held objects an equal length of time with the right and the left hand (Table 1, Figure 1). They did not show an overall hand preference ($Z = -1$). However, hand preference for FLH infants shifted across age. For example, FLH infants showed a right hand preference at 9 and 18 months of age ($Z = 11.6$ and 22.0 respectively), but a left hand preference at 12 and 15 months of age ($Z = -27.4$ and -10.2 respectively). However, in no instance was any comparison of right and left hand preference statistically significant (Walsh test).

All FLH infants showed unimanual grasping during self-feeding.

TABLE 1. HAND PREFERENCE (Z SCORE) IN UNIMANUAL GRASP

	FRH Infants				FLH Infants				All Infants	
	M	SD	N	P	M	SD	N	P	M	N
9 Months	36.4	56.7	7	NS	11.6	54.4	5	NS	26.1	12
12 Months	17.8	45.8	8	NS	-27.4	60.9	5	NS	0.42	13
15 Months	52.2	41.2	8	0.01	-10.2	66.7	5	NS	28.2	13
18 Months	46.4	60.5	8	NS	22.0	64.0	5	NS	37.0	13
Average	37.8				-1.0				22.9	

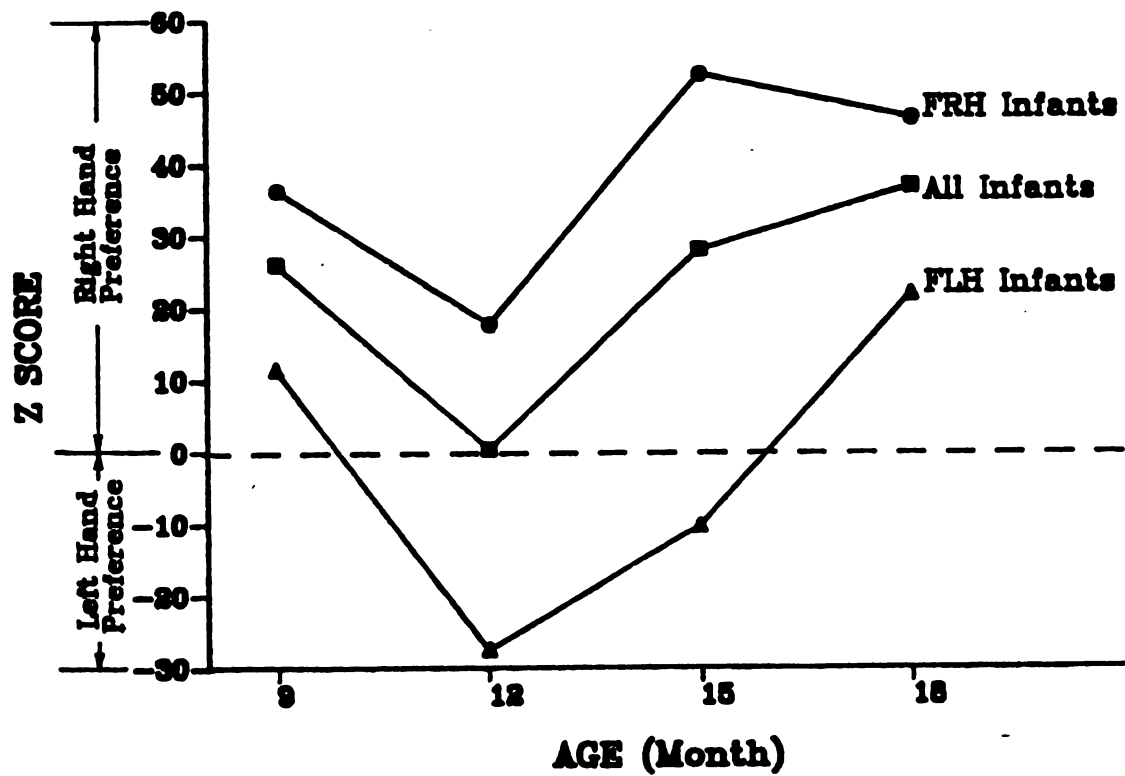


FIGURE 1. HAND PREFERENCE (Z SCORE) IN UNIMANUAL GRASP

Three FLH infants at 9-months, 1 at 12-months, 2 at 15-months and 3 at 18-months showed a right preference; whereas 2, 4, 3 and 2 showed a left preference at each age level respectively.

Difference between FRH and FLH infants:

Fisher exact probability tests did not reveal any significant differences between FRH and FLH infants at any age period.

B. Bimanual grasping

For all infants, there was a weak right hand preference ($Z = 5.3$) in bimanual grasping.

FRH infants:

FRH infants generally preferred to use their right hand as the leading hand in bimanual grasping (Table 2, Figure 2). They showed a right hand leading preference ($Z = 22.9$), with positive indexes at 9, 12 and 18 months of age ($Z = 20.7, 36.9$ and 36.3 respectively) and a slightly negative index at 15 months ($Z = -2.2$), indicating a shift to left bias at 15 months and a subsequent shift to right bias at 18 months. There was a significant difference (Walsh test) in hand use favoring the right hand at both 12 and 18 months ($P = 0.05$) of age.

Furthermore, individual data revealed an increase in the number of infants who demonstrated bimanual grasping behavior during self-feeding: 5 at 9 months, 8, 8, and 8 at 12, 15 and 18 months respectively. Among them, 4 babies at 9-months, 7 at 12-months, 4 at 15-months, and 7 at 18-months had a right-hand bias, whereas 1, 1, 2, 0 had a left-hand bias at each age respectively. Finally, two 15-month-olds and one 18-month-old showed no hand preference.

TABLE 2. HAND PREFERENCE (Z SCORE) IN BIMANUAL GRASP

	FRH Infants				FLH Infants				All Infants	
	M	SD	N	P	M	SD	N	P	M	P
9 Months	20.7	48.1	5	NS	-31.4	60.1	5	NS	-5.4	10
12 Months	36.9	29.0	8	0.05	-27.0	24.2	4	NS	15.6	12
15 Months	-2.2	37.6	8	NS	3.9	38.3	5	NS	0.2	13
18 Months	36.3	40.2	8	0.05	-27.2	38.6	4	NS	15.1	12
Average	22.9				-19.6				5.3	

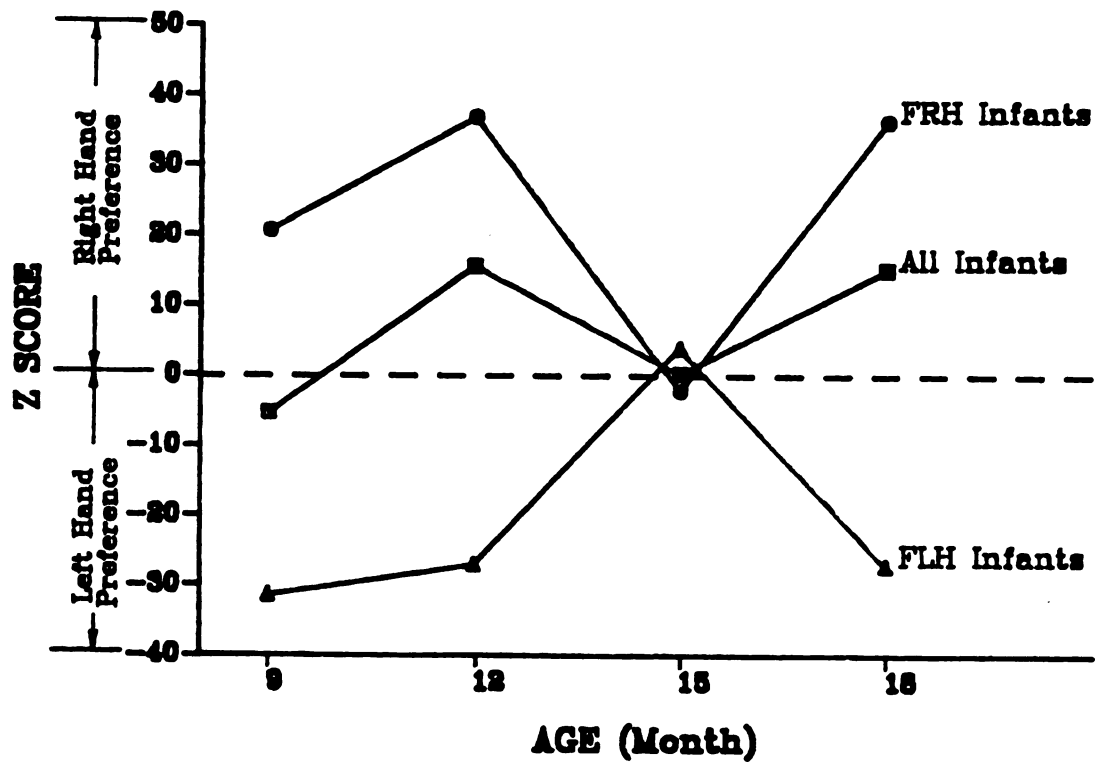


FIGURE 2. HAND PREFERENCE (Z SCORE) IN BIMANUAL GRASP

FLH infants:

FLH infants showed general left hand leading preference ($Z = -19.6$), meaning that they used the left hand as leading hand longer than the right one (Table 2, Figure 2). There were negative indexes at 9, 12, 18 months of age ($Z = -31.4, -27.0$ and -27.2 respectively) and a slightly positive index at 15 months ($Z = 3.9$). The Walsh test did not reveal any significant difference in hand use at any age level.

All FLH infants except one 12-month-old and one 18-month-old grasped objects bimanually. One, 0, 3 and 1 infants demonstrated right bias, whereas 3, 4, 1 and 3 were left biased, and 1, 0, 1 and 0 showed no preference at 9, 12, 15 and 18 months of age respectively.

Differences between FRH and FLH infants:

The Fisher exact probability test failed to reveal significant differences in hand preference between FRH and FLH groups at 9, 12 and 15 months. However, the difference was significant at 18 months ($P = 0.05$).

C. Unilateral reaching

For all infants, there was a right hand preference ($Z = 16.4$) in unilateral reaching.

FRH infants:

FRH infants used their right hand more than their left hand to reach for an object (Table 3, Figure 3). They showed general right hand bias in unilateral reach ($Z = 30.1$), with positive indexes at 9, 12, 15 and 18 months of age ($Z = 28.4, 33.0, 1.6, 57.2$ respectively),

TABLE 3. HAND PREFERENCE (Z SCORE) IN UNILATERAL REACH

	FRH Infants				FLH Infants				All Infants	
	M	SD	N	P	M	SD	N	P	M	N
9 Months	28.4	31.5	8	0.025	-15.8	51.1	5	NS	11.4	13
12 Months	33.0	35.7	8	0.043	13.4	41.5	5	NS	25.4	13
15 Months	1.6	52.8	8	NS	-2.4	47.2	5	NS	0.1	13
18 Months	57.2	34.9	8	0.008	-18.0	52.5	5	NS	28.6	13
Average	30.1				-5.5				16.4	

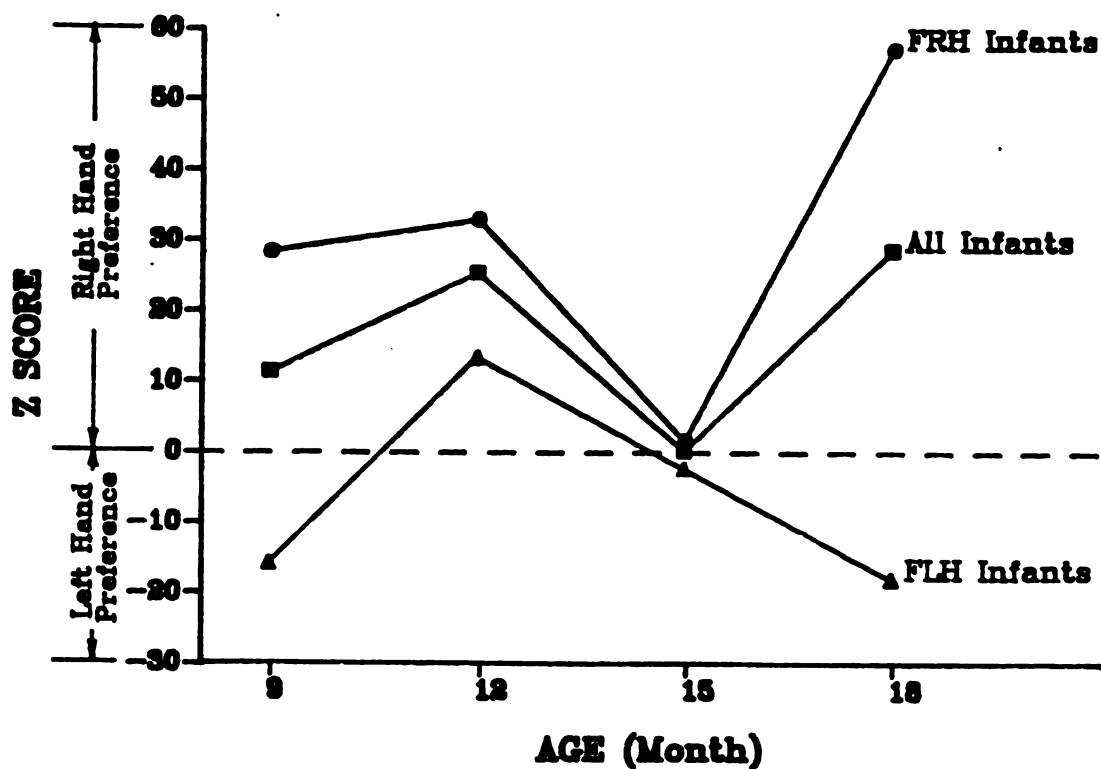


FIGURE 3. HAND PREFERENCE (Z SCORES) IN UNILATERAL REACH

although the right hand bias decreased sharply at 15 months. There were significant differences (Walsh test) in hand use favoring the right hand at 9 months ($P = 0.025$), 12 months ($P = 0.043$) and 18 months ($P = 0.008$).

Furthermore, individual data revealed that all the FRH infants reached for objects unilaterally during self-feeding. Six, 7, 4 and 7 infants had right bias, whereas 1, 1, 3 and 0 had left bias, and 1, 0, 1 and 1 showed no bias at 9, 12, 15 and 18 months of age respectively.

FLH infants

FLH infants generally preferred to use their left hand to reach for an object ($Z = -5.5$), with left bias at 9, 15 and 18 months ($Z = -15.8$, -2.4 and -18.0) and a right bias at 12 months ($Z = 13.4$) (Table 3, Figure 3). However, there was no significant difference between the right- and the left-hand use at any age (Walsh test).

All of the infants in FLH group demonstrated unilateral reaching during self-feeding. Two, 2, 2 and 2 showed right bias, whereas 2, 3, 3 and 3 had left bias, and 1, 0, 0 and 0 had no bias at 9, 12, 15 and 18 months respectively.

The difference between FRH and FLH infants:

Fisher exact probability tests were computed at each age level and no significant difference between FRH and FLH infants was revealed in hand preference at 9, 12 and 15 months. FRH and FLH infants were significantly different in hand preference at 18 months ($P = 0.05$).

D. Bilateral reaching

For all infants, there is a right hand preference ($Z = 13.2$) in bilateral reaching.

FRH infants:

FRH infants preferred to use the right hand as the leading hand more often than the left hand in bilateral reaching (Table 4, Figure 4). They demonstrated general right hand leading bias ($Z = 17.3$) with a shift at 12 months to the left bias and a subsequent shift back to right bias again at 15 months of age ($Z = 21.5, -3.2, 34.8$ and 16.0 respectively at 9, 12, 15 and 18 months). There was no significant difference (Walsh test) in hand preference at any age period (it was not applied in some cases due to the small sample sizes).

Examination of individual data indicated that the number of FRH infants who showed spontaneous bilateral reaching increased with age. Among eight FRH subjects, there were only 3 infants who reached for the food and/or utensils at 9-months of age, but 7, 8, and 6 reached at 12-, 15- and 18-months of age respectively. Moreover, among FRH subjects who demonstrated bilateral reaching, 1, 1, 6 and 3 showed right bias, whereas 1, 4, 1 and 1 showed left bias, and 1, 2, 1 and 2 had no bias at 9, 12, 15 and 18 months of age respectively.

FLH infants:

FLH infants showed generally weaker right leading hand bias ($Z = 6.7$ overall, and $Z = 13.5, 8.3, 2.8$ and 6.7 at 9, 12, 15 and 18 months respectively) (Table 4, Figure 4). There was no significant difference (Walsh test) in hand preference at any age. There was

TABLE 4. HAND PREFERENCE (Z SCORE) IN BILATERAL REACH

	FRH Infants				FLH Infants				All Infants	
	M	SD	N	P	M	SD	N	P	M	N
9 Months	21.5	21.0	3		13.5	66.0	3		17.4	6
12 Months	-3.2	45.6	7	NS	8.3	72.2	4	NS	1.0	11
15 Months	34.8	63.7	8	NS	2.8	20.8	5	NS	22.5	13
18 Months	16.0	33.7	6	NS	6.7	13.3	5	NS	11.8	11
Average	17.3				6.7				13.2	

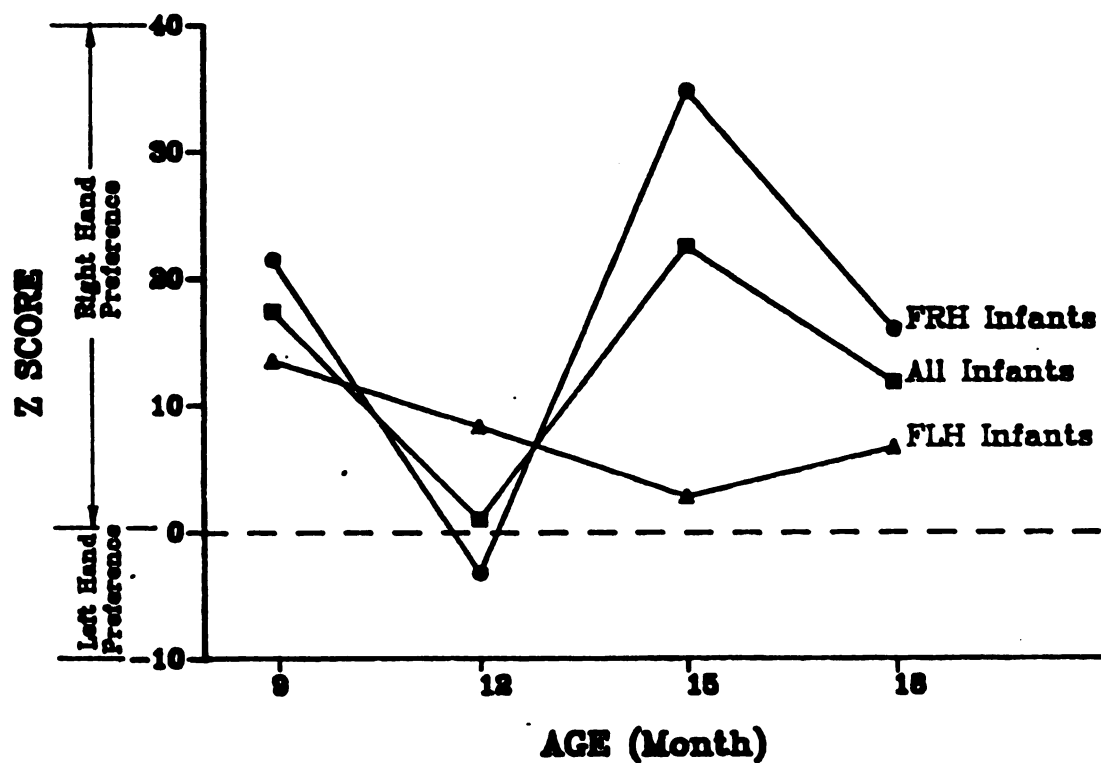


FIGURE 4. HAND PREFERENCE (Z SCORE) IN BILATERAL REACH

also an age trend in the increase in number of FLH infants who spontaneously reached for the food and/or the utensils during self-feeding (3 of 5, 4 of 5, 5 of 5, and 5 of 5 at each age respectively). Moreover, among FLH infants who reached for objects bilaterally, 1, 2, 2 and 1 showed right bias, whereas 1, 1, 2 and 0 showed left bias and 1, 1, 1 and 4 had no bias at 9, 12, 15 and 18 months of age respectively.

Differences between FRH and FLH infants:

The Fisher exact probability test did not demonstrate significant differences in hand preference between FRH and FLH subjects at 12 and 15 and 18 months. It was not applied for the 9-month-olds due to the small number of the subjects.

E. Bimanual manipulation

For all infants, there was a right hand preference ($Z = 37.0$) in bimanual manipulation.

FRH infants:

FRH infants preferred to use their right hand to manipulate while the left hand held food or an utensil (Table 5, Figure 5). They showed general right hand manipulating preference ($Z = 18.7$). However, there was a dramatic shift in the hand preference for manipulating hand, from completely left at 9 months ($Z = -100$) to right oriented at 12, 15 and 18 months ($Z = 34.6, 81.8$ and 44.4 respectively). There were only 3, 4, 3 and 4 infants at 9, 12, 15 and 18 months respectively who demonstrated spontaneous bimanual manipulation. The Walsh test was not applied due to the small sample sizes. Among those who showed bimanual manipulation, 0, 3, 3 and 3 showed right bias, whereas 3, 1, 0 and 1 showed left bias at 9, 12, 15 and 18 months of age respectively.

TABLE 5. HAND PREFERENCE (Z SCORE) IN BIMANUAL MANIPULATION

	FRH Infants			FLH Infants			All Infants	
	M	SD	N	M	SD	N	M	N
9 Months	-100.0	0.0	3	100.0	0.0	2	-20.0	5
12 Months	34.6	81.7	4	100.0	0.0	2	56.4	6
15 Months	81.8	25.7	3	14.4	0.0	1	70.0	4
18 Months	44.4	83.9	4	50.0	100.0	2	46.3	6
Average	18.7			73.5			37.0	

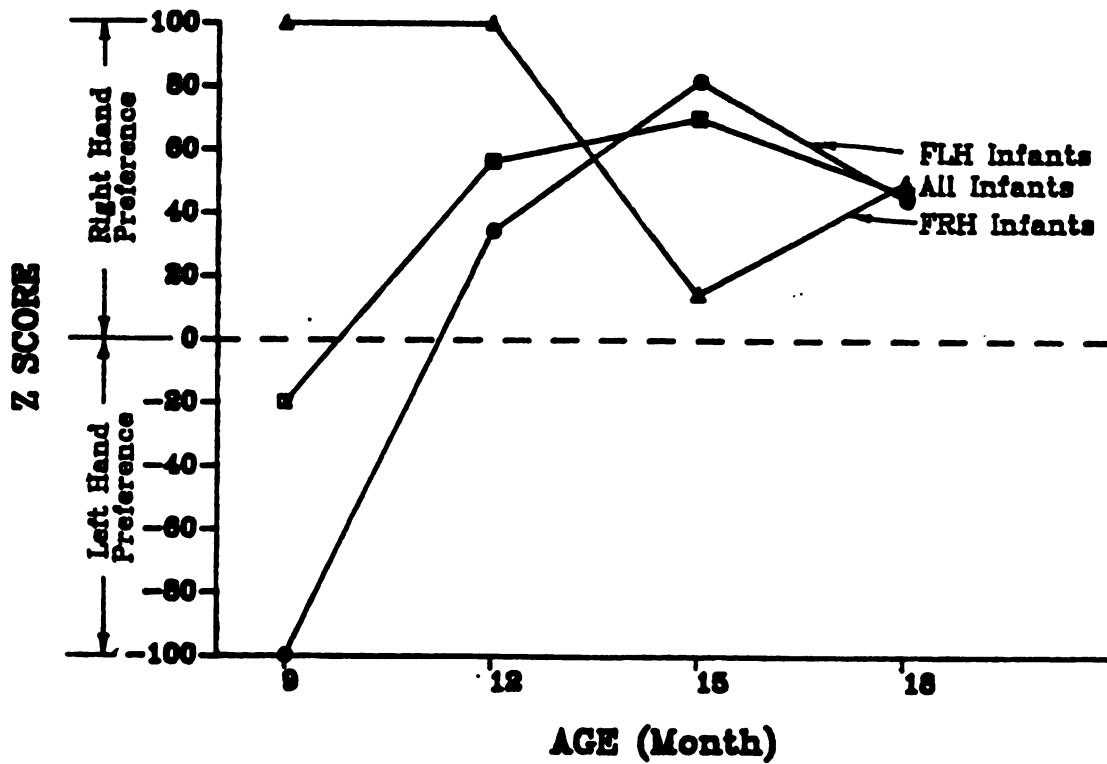


FIGURE 5. HAND PREFERENCE (Z SCORE) IN BIMANUAL MANIPULATION

FLH infant:

FLH infants showed stronger preference to manipulate with the right hand than FRH infants ($Z = 73.5$ overall, $Z = 100, 100, 14.4$ and 50.0 at 9-, 12-, 15- and 18-months of age respectively, Table 5, Figure 5). However, only 2, 2, 1 and 2 infants bimanually manipulated the objects spontaneously. The Walsh test was not applied due to the small number of subjects. Among those who demonstrated bimanual manipulation, all but one 18-month-old showed right hand bias.

Differences between FRH and FLH infants:

The Fisher exact probability test was not conducted at any age since the sample sizes were too small.

F. The trend of changes in hand preference

Table 6 shows that for FRH infants the patterns of hand use preference across age were completely opposite for the unimanual and bimanual grasping, and for unilateral and bilateral reaching. Moreover, for both reaching and grasping, the amount of increasing changes was greater at older ages than at earlier ages, whereas the amount of decreasing changes was greater at earlier ages than at older ages.

2. Task influences on hand preference

Table 7 shows us that FRH infants demonstrated stronger right hand preference in "uni" activities than in "bi" activities in most cases. The average hand preference indexes in unimanual grasp and unilateral reach were 38.7 and 30.1, whereas they were 22.9 and 17.3

TABLE 6. AGE TREND IN HAND PREFERENCE (Z SCORE) FOR FRH INFANTS

	UG	BG	UR	BR
9 Months	36.4	20.7	28.4	21.5
12 Months	17.8	36.9	33.0	-3.2
Difference	-18.6	16.2	4.6	-24.7
Trend	Decrease	Increase	Increase	Decrease
12 Months	17.8	36.9	33.0	-3.2
15 Months	52.5	-2.2	1.6	34.8
Difference	34.7	-39.1	-31.4	38.0
Trend	Increase	Decrease	Decrease	Increase
15 Months	52.5	-2.2	1.6	34.8
18 Months	46.4	36.3	57.2	16.0
Difference	-6.1	38.5	55.6	-18.8
Trend	Decrease	Increase	Increase	Decrease

* UG: Unimanual Grasp, BG: Bimanual Grasp, UR: Unilateral Reach,
BR: Bilateral Reach

TABLE 7 - HAND PREFERENCE (Z SCORE) IN VARIOUS MANUAL ACTIVITIES

	FRH Infants					FLH Infants				
	UG	BG	UR	BR	BM	UG	BG	UR	BR	BM
9 Months	36.4	20.7	28.4	21.5	-100	11.6	-31.4	-15.8	13.5	100
12 Months	17.8	36.9	33.0	-3.2	34.6	-27.4	-27.0	13.4	8.3	100
15 Months	52.5	-2.2	1.6	34.8	81.8	-10.2	3.9	-2.4	2.8	14.4
18 Months	46.4	36.3	57.2	16.0	44.4	22.0	-27.2	-17.0	6.7	50.0
Average	37.8	22.9	30.1	17.3	18.7	-1.0	-19.6	-5.5	6.7	73.5

* UG: Unimanual Grasp, BG: Bimanual Grasp, UR: Unilateral Reach, BR: Bilateral Reach, BM: Bimanual Manipulation

in bimanual grasp and bilateral reach. The same trend was not found among FLH infants who again showed a more diverse pattern. The average hand preference indexes for them were -1.0 and -5.5 for unimanual grasp and unilateral reach, and -19.6 and 6.7 for bimanual grasp and bilateral reach.

Bimanual manipulation is an exception where all subjects had relatively strong right-hand bias, with the FLH infants being stronger in the right bias.

3. Parental influence on infant hand preference

The index of parental influence in holding and positioning was computed as: $Z = \frac{R-L}{R+L} \times 100$. R and L stand for duration in which the parent held the infant's right and left hand respectively, or frequency in which parents positioned the food and/or utensils on

the right and the left side (relative to the infant) of the feeding table respectively.

Table 8 reveals that all the parents preferred to hold their

TABLE 8 - PARENTS' HOLDING AND POSITIONING BEHAVIORS (Z SCORE)

	Holding				Positioning			
	For FRH Infants		For FLH Infants		For FRH Infants		For FLH Infants	
	Z	N of Parents	Z	N of Parents	Z	N of Parents	Z	N of Parents
9 Months	71.4	1	100	1	21.3	6	3.9	5
12 Months	33.9	3	100	1	27.2	8	31.7	5
15 Months	66.7	3	10.0	1	25.2	8	27.7	5
18 Months		0		0	7.1	7	27.1	4

babies' right hand to help them to feed themselves when needed regardless of the familial handedness of their infants. In addition, relatively few parents did try to hold their babies' hand. Only 1, 3 and 3 parents of FRH infants tried so at 9, 12 and 15 months, and none at 18 months. Only 1 parent of FLH infants held the infant's hand at each 9, 12 and 15 months period respectively, and none at 18 months.

Table 8 also shows that parents preferred to position the food and/or utensils on the right side of the table regardless of their infants' familial handedness. However, the degree of the right bias in the parental positioning was weaker than that in parental holding behavior.

An analysis of parental positioning behavior based on the sex of FRH infants was also computed. Table 9 indicates that parents of

TABLE 9
DIFFERENTIAL PARENTS' POSITIONING FOR FRH MALE AND FEMALE INFANTS

	For Male Infants	For Female Infants
9 Months	21.4	21.3
12 Months	24.9	29.7
15 Months	40.0	2.1
18 Months	16.7	0.0

male infants showed more rightward bias than parents of female infants, except for a slightly opposite pattern at 12 months.

The Spearman rank test with ties correction was used to compute correlations of hand preference among various manual activities and parental behaviors. Table 10 shows that only a few correlations were significant. For instance, for FRH infants at 9 months, the rightward bias in parental positioning was significantly negatively correlated with the tendency to reach across body midline. That is when parents put the food and/or utensils on the right side (relative to the infant) of the feeding table, infants were likely to reach with the right hand; when parents positioned objects on the left side, infants were also likely to reach with their right hand by crossing body midline. The whole picture looks as if infants insisted on using their right hand

TABLE 10

SPEARMAN RANK CORRELATIONS IN HAND PREFERENCE FOR FRH INFANTS

For FRH Infants	UR	BG	MI	UG	BG	BM	PH
9 Months	-.500 (3)						
BR 12 Months	.108 (7)						
15 Months	*.659 (8)						
18 Months	-.812 (6)						
9 Months	-.548 (8)	/					
MI 12 Months	.464 (8)	-.637 (6)					
15 Months	.095 (8)	.439 (8)					
18 Months	-.520 (8)	.400 (8)					
9 Months	.054 (7)	1.000 (3)	.559 (7)				
UG 12 Months	.238 (8)	.198 (7)	-.245 (8)				
15 Months	-.310 (8)	-.195 (8)	.333 (8)				
18 Months	-.167 (8)	.377 (6)	.304 (8)				
9 Months	.400 (5)	-.500 (3)	-.600 (5)	-.100 (5)			
BG 12 Months	-.238 (8)	.036 (8)	-.382 (8)	-.071 (8)			
15 Months	.611 (8)	-.319 (8)	-.299 (8)	-.371 (8)			
18 Months	.635 (8)	-.464 (6)	-.444 (8)	-.443 (8)			
9 Months	/	/	/	/	/		
BM 12 Months	-.211 (4)	-.949 (4)	.389 (4)	-.381 (4)	-.738 (4)		
15 Months	-.866 (3)	-.866 (3)	/	-.000 (3)	0.000 (3)		
18 Months	-.632 (4)	.632 (4)	/	.632 (4)	.211 (4)		
9 Months	/	/	/	/	/	/	
PH 12 Months	.500 (3)	/	/	.500 (3)	-1.000 (3)	/	(1)
		(2)	(3)			(0)	

TABLE 10 (Cont'd)

	UR	BR	MI	UG	BG	BM	PH
PH 15 Months	.000 (3)	-.5 (3)	/ (3)	.866 (3)	.866 (3)	/ (1)	
18 Months	/ (0)	/ (0)	/ (0)	/ (0)	/ (0)	/ (0)	
9 Months	.657 (6)	-.500 (3)	*-.886 (6)	-.314 (6)	.400 (5)	/ (3)	/ (1)
PP 12 Months	.431 (8)	/ (2)	.446 (8)	.299 (8)	-.084 (8)	.316 (4)	-1.000 (3)
15 Months	-.544 (8)	-.222 (8)	-.386 (8)	.374 (8)	-.200 (8)	.866 (3)	.000 (8)
18 Months	.527 (7)	.000 (5)	.264 (7)	*.800 (7)	.147 (7)	.866 (3)	/ (0)
For FLH Infants							
9 Months	.500 (3)						
BR 12 Months	.400 (4)						
15 Months	.200 (5)						
18 Months	-.707 (5)						
9 Months	-.224 (3)	/ (3)					
MI 12 Months	-.872 (5)	.316 (4)					
15 Months	-.000 (5)	-.000 (5)					
18 Months	-.205 (5)	-.544 (3)					
9 Months	.700 (5)	-.500 (3)	.447 (5)				
UG 12 Months	*-1.00 (5)	-.400 (4)	.872 (5)				
15 Months	.400 (5)	-.100 (5)	-.866 (5)				
18 Months	.600 (5)	-.354 (5)	-.205 (5)				
9 Months	*.900 (5)	.500 (3)	-.244 (5)	.600 (5)			
BG 12 Months	.800 (4)	-.500 (3)	*-1.00 (4)	-.800 (4)			
15 Months	.300 (5)	-.500 (5)	.289 (5)	-.400 (5)			
18 Months	.800 (4)	.000 (4)	-.800 (4)	-.200 (4)			
9 Months	/ (2)	/ (2)	/ (2)	/ (2)	/ (2)		

TABLE 10 (Cont'd)

	UR	BR	MI	UG	BG	BM	PH
BM 12 Months	/	/	/	/	/		
	(2)	(2)	(2)	(2)	(2)		
15 Months	/	/	/	/	/		
	(1)	(1)	(1)	(1)	(1)		
18 Months	/	/	/	/	/		
	(2)	(2)	(2)	(2)	(2)		
9 Months	/	/	/	/	/	/	
	(1)	(1)	(1)	(1)	(1)	(1)	
PH 12 Months	/	/	/	/	/	/	
	(1)	(1)	(1)	(1)	(1)	(1)	
15 Months	/	/	/	/	/	/	
	(1)	(1)	(1)	(1)	(1)	(1)	
18 Months	/	/	/	/	/	/	
	(0)	(0)	(0)	(0)	(0)	(0)	
9 Months	.500	-.500	-.335	.300	/	/	/
	(5)	(3)	(5)	(5)	(1)	(2)	(1)
PP 12 Months	-.410	-.155	-.237	-.410	-.400	/	/
	(5)	(4)	(5)	(5)	(4)	(2)	(1)
15 Months	.300	.300	-.866	*.900	-.300	/	/
	(5)	(5)	(5)	(5)	(5)	(1)	(1)
18 Months	.400	.258	.211	.200	.500	/	/
	(4)	(4)	(4)	(4)	(3)	(2)	(1)

* $p < .05$

/ Spearman Correlation not Conducted

Numbers in Parentheses Indicate the Number of Infants

UR: Unilateral Reach, BR: Bilateral Reach, MI: Cross-body-midline

Reach, UG: Unimanual Grasp, BG: Bimanual Grasp, BM: Bimanual

Manipulation, PH: Parents' Holding, PP: Parents' Positioning.

to reach regardless of the side of positioning by the parents. At 18 months, the FRH infants' hand preference in unimanual grasping was positively related to the parental positioning. At 15 months, there was a positive correlation in hand preference between unilateral and bilateral reaching. That is the more right biased the infants were in unilateral reaching, the more right biased they were in bilateral reaching.

For FLH infants, there was a positive correlation in hand preference between unilateral reaching and bimanual grasping at 9 months. However, there was a negative correlation between unilateral reaching and unimanual grasping at 12 months. Also at 12 months, the tendency to reach contralaterally was negatively related to the rightward bias in hand use in bimanual grasping. At 15 months, the right hand preference in unimanual grasping was positively correlated with rightward bias of parental positioning. That means that the more parental positioning was biased to the right, the less infants' hand preference was biased to the left. It is noteworthy that at 15 months, parental positioning was generally toward the right side, whereas the hand preference of FLH infants was generally toward the left. Therefore, parental positioning did not reverse the direction of infants' hand preference, but only influenced the degree of the hand preference.

4. The relation of newborn head orientation (HO) and hand preference.

An index of HO was computed as follows: $HO = (R-L) \times 100$. R refers to duration of head turning to the right across the four holding positions,

whereas L refers to the duration of head turning to the left across the four holding positions.

Given the small sample sizes and the fluctuating nature of hand preference across tasks, it is not surprising to find out that the majority of correlations were not significant (Spearman rand test). Among a few significant correlations for FRH infants, hand preference in unimanual grasping at 9 months was negatively related to HO at the in-hospital period; At 12 months, the hand preference in bilateral reaching was negatively related to in-hospital HO, and unilateral reaching was positively related to HO at 4 weeks. At 18 months, unilateral reaching was positively related to in-hospital HO. For FLH infants, only the hand preference in unilateral reaching at 18 months was positively related to the preference of HO at 8 weeks.

Fisher exact probability test also failed to show any significant relation between HO and hand preference.

An interesting finding was that at 12 and 15 months, the preference of parental positioning behavior was positively correlated with direction of HO at 8 and 12 weeks for FRH and FLH infants.

5. Sex differences

Since there was only one female infant in the FLH group, it was decided only to examine FRH subjects' data for sex differences.

Table 11 shows that female infants had greater right hand preference than male infants generally across the manual activities. Statistical tests were not conducted due to small subject samples.

TABLE 11. SEX DIFFERENCE IN HAND PREFERENCE (Z SCORE) FOR FRH INFANT

		Unimanual Grasp	Bimanual Grasp	Unilateral Reach	Bilateral Reach	Average
9 Months	M	21.8 (4)	25.0 (2)	2.7 (3)	-8.2 (3)	10.1
	F	35.0 (4)	14.3 (1)	61.5 (4)	63.9 (2)	48.0
12 Months	M	25.7 (4)	-.63 (4)	20.0 (4)	12.9 (4)	14.5
	F	40.3 (4)	-6.67 (3)	15.5 (4)	60.1 (4)	29.8
15 Months	M	28.6 (4)	11.7 (4)	56.2 (4)	-19.7 (4)	19.2
	F	31.8 (4)	57.8 (3)	48.2 (4)	15.5 (4)	37.0
18 Months	M	60.6 (4)	-6.9 (3)	34.6 (4)	40.8 (4)	34.9
	F	53.5 (4)	38.9 (3)	58.0 (4)	31.8 (4)	50.0

Numbers in the Parentheses Indicate the Number of Infants.

6. The effect of "midline barrier" and the effectiveness of overcoming "midline barrier" by having the non-reaching hand occupied in unilateral reach

The "midline barrier" refers to the infants' tendency not to cross the body midline in order to reach for an object. The effect of "midline barrier" in unilateral reaching was indexed by C. $C = (C-I)/(C+I) \times 100$. The index of the effect of overcoming the "midline barrier" by having the non-reaching hand occupied in unilateral reach is CO. CO is computed as follows: $CO = (C/C+I \text{ (occupied)} - C/C+I \text{ (free)}) \times 100$. In both equations, C stands for the frequency of contralateral reaches and I stands for the frequency of ipsilateral reaches.

Table 12 shows that midline is indeed a barrier for 9 to 18 month-old infants. The all negative numbers indicate that infants rarely crossed their body midline to reach for food and/or utensils. They reached contralaterally much less often than they did ipsilaterally. Table 13 shows that the contralateral reaches occurred more frequently when the non-reaching hand was occupied by an object (food or utensils) than when it was free, although the differences were weak. Moreover, the differences became weaker with age.

TABLE 12

MIDLINE BARRIER - CONTRALATERAL VS. IPSILATERAL REACH (C SCORE)

	FRH Infants	FLH Infants	All Infants
9 Months	-81.7	-91.2	-85.4
12 Months	-96.6	-88.6	-93.5
15 Months	-81.5	-95.2	-86.8
18 Months	-92.0	-95.1	-93.2

TABLE 13

CONTRALATERAL REACHES WHEN NON-REACHING HAND WAS OCCUPIED VS WHEN IT WAS FREE (CO SCORE)

	FRH Infants	FLH Infants	All Infants
9 Months	6.7	2.4	4.6
12 Months	1.7	3.9	2.4
15 Months	-2.6	6.7	1.0
18 Months	1.4	0.4	1.0

DISCUSSION

Caution must be taken in interpreting the results, because of the small sample size and the disproportionate number of non-significant results.

In addition, standard derivations were large, which means the data were diverse. Although it is not surprising to have such results in an exploratory study, it severely constrains interpretation and generalization of the data.

A unique feature about the current study is that subjects were divided into two groups based on their familial handedness and analyses were conducted separately on data from the two groups. In the following discussion, we will not only try to deal with the general handedness of infants but also focus on the comparison of the FRH and FLH infants.

1. The development of handedness in infancy

A. FRH subjects

a. Grasping

Previous studies of unimanual grasping show that a right hand preference is evident as early as the age of 1 week (Halverson, 1937; Young, 1977), and continues to develop through 5 months of the first year of life (Caplan & Kinsbourne, 1976; Hawn & Harris, 1979). The data from the current study suggest that right hand preference in unimanual grasping is not fully developed at 5 months. For example, in the self-feeding situation, FRH infants continued to show increasing

right hand preference in unimanual grasping from 9 to 18 months.

A slight decline in rightward bias at 12 months serves as a reminder that the organization of hand preference is not a clean linear process.

Generally, the developmental patterns for hand preference in unimanual grasp duration, as illustrated in this and other studies suggest that although a rightward bias emerges very early in life and increases over the course of 18 months, it does not become stable until the middle of the second year of life. Therefore, the previous hypothesis that hand preference in unimanual grasping would maintain stability from 9 to 18 months of age needs to be modified. Whether another shift from right preference to left and/or to interchangeable pattern will occur after 18 months of age remains to be seen.

Contrary to the results for unimanual grasp, the current study found no increase in rightward bias in bimanual grasping from 9 to 18 months, which is contradictory with the previous prediction. Moreover, the magnitude of the right hand preference was small. One possible contribution to the lack of change in current study may be the fact that different methods and measurements were used in current study from those used by Hawn & Harris (1979). Infants in Hawn & Harris' study were forced to grasp the rattles that were placed in their hands by experimenters. Then duration of grasping of each hand was recorded and used to compute a ratio of hand preference. However, in the current naturalistic observation study, infants had various choices in manual activities related to self feeding. Bimanual grasping occurred only when the infant chose to grasp food and/or utensils with two hands. Duration of grasping with each leading hand was recorded

and used to compute an index of hand preference. More structural tasks (as in the Hawn & Harris' study) may reveal a more clear-cut hand bias, or may impose an artificial bias on a developmentally organizing system.

Furthermore, the shift from rightward bias to non-bias, or even slightly leftward bias at 12 months of age suggests that as handedness in bimanual grasping behaviors progresses, fluctuations in hand preference occur as suggested by Gesell and Ames (1947).

The overall pattern indicates that hand preference in bimanual grasp emerges as early as 2 months (Hawn & Harris, 1979), but it does not become stable until at least 18 months of age, when infants prefer the right more than the left. Obviously, whether there may be more shifts in hand preference after 18 months, and when final hand preference in the bimanual grasping task is achieved cannot be determined from the current study. Clearly, however, future studies need to pay careful attention to the effects of Task by Developmental Age interactions that may influence hand preference behavior.

b. Reaching

For unilateral reaching, results for FRH infants partly confirm the general literature findings and previous prediction in that there were shifts in the direction of hand preference from 9 to 18 months of age and handedness did not stabilize at the middle of the second year. Nonetheless, the data only disclosed shifts from rightward bias to a mixed pattern and back to rightward bias again. The lack of left preference in unilateral reaching from 9 to 18 months is contrary to results reported by Gesell & Ames (1947). Perhaps the

inconsistency in the current results and those of previous studies can be attributed to differences in tasks and measurement procedures. Some previous investigations presented the objects at the midline and infants were scored for the hand used in reaching and contacting the objects (Gesell & Ames, 1947; Grapin & Perpere, 1968, cited in Young, 1977). In the current naturalistic task, food and utensils were manipulated by infants themselves during self-feeding. They could put the objects anywhere on the feeding table they preferred (more likely to be the right side than the left). They did not necessarily put them in the midline before they picked them up next time. Additionally, parents had a rightward bias in positioning food and/or utensils on the feeding table. Parental placement of objects on the infants' right side would make it difficult for infants to use the left hand since the left hand would have to cross the midline to obtain the objects, a tendency that is unlikely to occur in young infants (Bruner, 1970). Therefore, the left hand reaching observed in previous research might be "inhibited" during the feeding period.

Few previous investigations reported the magnitude of the infant's hand preference. In this regard, the current study showed that, except at 15 months, there was a continuous increasing right hand preference in unilateral reaching across the age period from 9 to 18 months, with approximately 57% more right hand use than left hand use at 18 months. Nevertheless, the decline in rightward bias at 15 months may indicate that handedness has not yet achieved stability.

For bilateral reaching, FRH infants preferred the right as the leading hand although there was a fluctuation at 12 months. Nevertheless,

hand preference for bilateral reaching is also not completely stable at 18 months since the right hand was preferred only 18 percent more than the left.

c. Bimanual manipulation

The findings of current study show that 9-month-old FRH infants preferred to use the right hand to hold food or utensils while using the left hand to manipulate them. This is completely opposite to their preference in reaching and grasping. It may be attributable to the fact that the pattern of bimanual manipulation of infants at this age was immature. For example, some babies used their right hand to "hold" a bottle of milk while the left hand manipulated the nipple of the bottle. However, since the bottle stood upright on the feeding table, it was difficult to tell whether babies were only resting their right hand on the bottle or holding it for the sake of manipulation with the other hand. Nevertheless, behavior in this situation was scored as bimanual manipulation with the left hand manipulating.

From 12 months of age, infants began to show right hand bias in bimanual manipulation. They began to use their left hand to hold food or utensils with the left while using the right to manipulate them. For instance, a 15-month-old girl used her left hand to hold a piece of chicken sandwich while the right hand picked up pieces of chicken meat. Nevertheless, hand preference in bimanual manipulation was far from achieving stable level yet by 18 months of life, not only because there was a decline in rightward bias at 12 and 18 months, but also because only about half of the babies showed bimanual manipulation

by 18 months. This finding is inconsistent with Ramsay et al (1979) and Ramsay (1980, 1982) and the previous prediction. Ramsay et al reported that handedness in bimanual manipulation achieved stability at 14.9 months of age. Moreover, FRH infants in current study demonstrated less right hand bias than FLH infants, a pattern contrary to that in reaching and grasping, where FRH infants always preceded FLH infants in right hand preference.

B. FLH infants

Generally, FLH infants showed either less right preference or more interchangeable patterns and left preference in various activities except for bimanual manipulation. The Fisher exact probability test failed to detect significant difference between groups in the direction of hand preference except for bimanual grasp at 18 months. Therefore, descriptive discussion is based on the trend of the results which suggested differences.

FLH infants were more diverse and heterogeneous as a group than FRH infants in their hand preferences. Although standard deviations were large for both groups, they were either larger or equal for the FLH infants in a majority of situations across ages and activities. Our results fit Annett's simple one allele model of handedness (1964, 1974, 1981). According to Annett, infants from families with at least one left-handed parent or grandparent lack the dextral-bias allele. Thus they are likely to demonstrate random patterns of handedness. As a group, they are more heterogeneous in nature and their hand preference in various activities is less predictable. Therefore,

the FLH infants were likely to show interchangeable patterns or even left bias in manual activities as compared to FRH babies.

2. Task Influence on Handedness.

Among FRH infants, the magnitudes of right hand bias were greater in "uni" activities (unimanual grasp and unilateral reach) than in "bi" activities (bimanual grasp and bilateral reach), except for bimanual manipulation, at almost all the age levels. "Bi" tasks were more difficult than "uni" tasks judging from the comparison of the number of the infants who demonstrated "bi" and "uni" behavior spontaneously during the self-feeding periods. All infants were more skillful in "uni" than in "bi" activities. Thus these results imply that the more skillful the infants were, the greater hand preference they possessed at a certain age. The level of skillfulness may contribute to the developmental differentiation of hand preference in "uni" and "bi" manual activities. This is consistent with the results of Hawn & Harris (1979) who found that, compared with 2-month-olds, 5-month-old babies who were more skillful in bimanual grasping showed greater right hand preference in grasping. It is also consistent with the report (Ramsay et al 1979, Ramsay, 1980, 1982) that development of bimanual grasp lagged behind unimanual grasp.

Our findings on task influence is not in the direction of the previous prediction of the current study. One possible reason might be the methodological discrepancy between the current study and Hawn & Harris' study (1979), where a greater right hand preference was found in bimanual grasp than in unimanual grasp. First, to actively

reach and grasp food and/or utensils (the current study's procedure) is a more difficult task and requires more effort than to passively grasp an object put into one's hand (the Hawn & Harris' procedure). Second, the ages of the infants are different in the two studies. Apparently, more work needs to be done with methodologically consistent investigations.

The current findings are consistent with the notion that the development of handedness is related to the maturation of cortical fine motor control. In the "uni" activities, fine motor control of the right hand, mediated by the left hemisphere, matured with age. In the "bi" activities, the pattern of development was the same, but the process of development of fine motor control -- the left hemispheric inhibitory control over the right hemisphere -- lagged behind. This is very understandable since "bi" activities were more difficult and required coordination of two hands and hence required greater fine motor control and increasingly sophisticated interhemispheric integration of function.

The pattern of age change in hand preference for reaching and grasping can also be interpreted by the maturation of fine motor control. There might be a fixed amount of maturation that the cortical fine motor control system can gain during a certain period of time. Maturation of the motor control system might be specific rather than general -- with enhanced function of some motor activities and no apparent change in other types of activities. Analogous to the allocation of attention hypothesis, during certain periods of time, right hand preference increased in "uni" activities, whereas it did not change

or even decreased in "bi" activities depending on the distribution of the maturation of the fine motor control system. But during other age periods, the pattern could be reversed. The magnitudes of increase in hand preference in older infant were always greater than that in younger infants, whereas the amounts of decrease were always less in older infants than in younger infants. This indicated that fine motor control became more mature with age. Of course this is only a speculative explanation which must be proven by independent investigations.

There are other contributing factors which may work together or separately to influence hand preference in different types of tasks as well as fluctuations and shifts in the magnitude and direction of hand preference in different tasks (Liederman, 1983). First, the state of arousal can affect the direction and extent to which behavior is lateralized. During infancy, the degree of rightward bias covaries with alertness (Michel & Goodwin, 1979) and degree of irritability (Liederman & Kinsbourne, 1980). Thus, in the current study, fluctuations of infants' state might change the functional organization of the brain and alter dominance relationships, resulting in instability of hand preference measured across time.

Second, the differentiated growth spurt for right and left hemispheres and for different regions of the brains at different times may be accompanied by shifts in laterality in motor development (Liederman, 1983). As one side of the brain undergoes a growth spurt, that side may be able to acquire a skill more thoroughly or more quickly. Thus, in this study, during the periods when the right hemisphere was more

developed than the left, there would be periods of less right-hand preference or even a left-hand preference.

3. Parental influence on infant hand preference

Our society is a right-hand dominant society. Social expectation and social norms provide pressure for children to use their right hands. The present study found that all of the parents tried to facilitate their infants' right hand use by holding their infants' right hand and/or positioning food and utensils on the right side of the feeding table (relative to the infants). Although there were a few correlations in direction between head orientation in the neonatal period and parental positioning in infancy, the incidence was too rare to be conclusive that parental positioning was based on perceived infants' behavioral asymmetry. Nevertheless, it certainly serves to bring attention to the individual variance in parental behaviors.

Teng et al's (1976) investigation, which demonstrated that the incidence of left hand use in eating and writing in Chinese American children was much lower than that of Chinese children who lived in Taiwan, implies that Chinese society is more conservative and American society is more liberal in rightward social pressure for eating and writing. In the current study, although the American parents tended to help infants' right hand, they did not do so exclusively as the Chinese parents apparently did. They facilitated right hand use about 20 percent more than the left by positioning food and/or utensils on the table. The American parents held infants' right hand about 55 percent longer than the left -- more rightward pressure. However,

parents seldom did hold infants' hands. The impression was that although parents in the United States still exerted social pressure on infants' right hand use, they left plenty of room to allow infants to develop their own hand preference.

The effectiveness of parental positioning on FRH infants' hand preference seemed to be inconsistent. In unilateral reaching, FRH infants would insist on using the right hand regardless of the direction of parental positioning. In unimanual grasping, the FRH infants' hand preference at 18 months was positively related to parental positioning. Nevertheless, parental rightward positioning seemed to be more effective in relating to FLH infants' hand preference in unimanual grasping, although it did not change the direction of the handedness of FLH infants. This also fits Annett's model (1964, 1974, 1981). Since FLH infants lacked the dextral allele, they were possibly more vulnerable to environmental influences in hand use.

4. Relationship between head orientation and hand preference

Results were not consistent with previous findings (Michel 1981, Coryell & Michel 1978, Coryell, 1985; Michel and Harkins, 1986; White et al, 1965) in that we did not find consistent relationships between the direction of HO and hand preference. Among the few significant correlations, there were more negative than positive ones. One possible reason may be that neither Spearman rank test nor the Fisher exact probability test are sensitive to test the relation between the HO and hand preference in this study. Apparently, more work is needed.

5. Sex Differences

The current findings support the literature suggestion in that female infants showed greater hand preference than male infants. Interestingly, the pattern of parental positioning behavior (positioning food and utensils on feeding table) revealed a stronger rightward pressure on male babies than on female babies, which may suggest that the sex differences observed during the self-feeding situation were not determined by parental behaviors. Our finding on parental rightward pressure on infants' hand use is consistent with reports that parents are more concerned with and emphasize more about their son's academic and occupational success, whereas they are more concerned with their daughter's interpersonal skills and nurturing ability (Block, 1983; Hoffman, 1977). Alternatively, parents might exert greater right bias pressure on male infants to compensate their weaker hand preference.

There are several alternative interpretations for the sex differences in hand preference in infancy. First, female infants might be more advanced in fine motor control as a result of their more advanced maturational level. Therefore, they would show stronger right hand preference than the male infants.

Second, although the evidence is somewhat inconsistent, clinical and EEG research indicates that the right hemisphere's growth spurt occurs earlier than the left hemisphere (See Liederman, 1983). Therefore, the female infants' left brain should be somewhat more mature than that of the male infants' and hence female infants would show stronger hand preference.

Third, as Geschwind (cited in Marx, 1982) suggested, left-hemisphere growth may be slowed by high levels of testosterone. Thus, male infants' rightward hand preference would be slower to develop than female infants' hand preference.

6. The "midline barrier" and the effectiveness of overcoming the "midline barrier" by having the non-reaching hand occupied

Our results confirm the report that young infants tended not to cross body midline to reach for objects (Bruner, 1970). However, when the non-reaching hand was occupied, both FRH and FLH infants demonstrated more contralateral reaches than when the non-reaching hand was free. This is consistent with Hawn & Harris (1979) report. Moreover, the differences in contralateral reaches between the conditions when the non-reaching hand was occupied vs. when it was free declined with age. This seems reasonable in that as infants became more skillful, they were more able to reach for food and/or utensils whenever they wished and did not need to attend to the status of their non-reaching hand.

CONCLUSIONS

1. As observed in a self-feeding situation, 9- to 18-month-old FRH infants showed right-hand preference in unimanual grasping, bimanual grasping, unilateral reaching, bilateral reaching and bimanual manipulating; whereas 9- to 18-month-old FLH infants showed diverse and unpredictable patterns in hand use in the same manual activities.
2. There were shifts and fluctuations in the development of hand preference.
3. For FRH infants, the development of hand preference in bimanual grasping and bilateral reaching lagged behind that in unimanual grasping and unilateral reaching respectively. But again FLH infants showed diverse patterns.
4. All parents exerted moderate right-hand use pressure on their infants regardless of their own handedness. The parents of FRH infants exerted stronger right-hand use pressure for male infants than for female infants. Nevertheless, the infants' hand preference was inconsistently related to right biased parental practice.
5. No relationship between the newborns' head orientation and infants' hand preference was found.
6. For FRH infants, female infants showed stronger right-hand preference than male infants.
7. The infants tended not to cross the body midline to reach for objects. However, the infants showed more contralateral reaches when their non-reaching hand was occupied than when it was free.

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