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Measuring Handedness in Infancy: Hand Preference and Hand Performance in 11-Month-Olds

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MEASURING HANDEDNESS IN INFANCY: HAND PREFERENCE AND HAND PERFORMANCE IN 11-MONTH-OLDS

A Thesis Presented

by

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DEDICATION

For Florence and Inky who passed during the writing of this thesis.

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ABSTRACT

MEASURING HANDEDNESS IN INFANCY:
HAND PREFERENCE AND HAND PERFORMANCE IN 11-MONTH-OLDS

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Lateral biases are evident in a number of behaviors across many organisms. The present work was concerned with the particular lateral phenomenon known as handedness. Previous research has suggested that handedness is not a one-dimensional trait. This study evaluated handedness using two factors: hand preference and hand performance. Hand preference refers to the hand chosen to carry out a given action whereas hand performance refers to each hand’s ability, or skill, at carrying out that action. The relationship between hand preference and hand performance has been studied extensively in adults, but the larger body of work with human infants has only assessed hand preference. The goals of this study were to develop a methodology to measure infant hand performance and to begin to examine the relationship between hand preference and hand performance in development. To this end, thirty-six 11-month-old infants were videotaped completing three tasks. The first task assessed hand preference and consisted of a free-play period during which infants were presented with a series of toys that afforded different types of manipulation. The second and third tasks were novel measures of infant hand performance. The second task assessed the infant’s gross motor skills and involved fitting a ball into the top aperture of a toy. The third task assessed the infant's fine motor skills by requiring infants to retrieve a Cheerio from a stationary plastic cup. Overall, the majority of infants were found to be right-preferent. This was in agreement with previous studies of hand preference in 11-month-olds as well as the pattern of hand preference seen in adults. There was no group-level asymmetry on either measure of hand performance. Hand preference was regressed on hand performance in an overall model of handedness. The right hand's performance on each task significantly predicted hand preference scores. This was the first study to demonstrate that hand preference can be predicted by hand performance in infants. Future work will examine infant hand proficiency in greater detail as well as the relationship between hand preference and hand performance in nonhuman primate infants.

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CHAPTER 1

HANDEDNESS

Lateral biases are evident in a number of behaviors across many organisms. For example, toads favor the right side for capturing prey (Vallortigara, Rogers, Bisazza, Lippolis & Robins, 1998); chicks have a right bias for discriminating food from non-food in a foraging task (Andrew, Tommasi & Ford, 2000); and groups of fish turn to the left or the right to avoid a predator depending on the species (Bisazza, Cantalupo, Capocchiano & Vallortigara, 2000). One of the most widely studied behavioral asymmetries in humans is handedness, yet despite its popularity, the definition of the term and the method with which it is measured varies immensely from study to study. There is increasing evidence from a number of researchers suggesting that handedness is not a one-dimensional trait (e.g. Corey, Hurley & Foundas, 2001; Annett, 2002; Brown, Roy, Rohr, Snider & Bryden, 2004). This thesis evaluated handedness along two factors, hand preference and hand performance. Hand preference refers to the hand chosen to carry out a given action whereas hand performance refers to each hand's ability, or skill, to carry out that action. The work presented here was the first to assess hand performance in infants and therefore the first to examine the relationship between hand preference and hand performance in development.

1.1 Handedness in School Age Children and Adults

Handedness has been studied extensively across much of the lifespan in individuals ranging from school age through adulthood and in many cultures throughout the world. The universal finding in these studies is that the vast majority of individuals are right-handed. There have been no reports where the majority of individuals are left-handed (Annett, 2002). Why should this be so? After decades of research, many theories have emerged but one in particular, the “Right-Shift Theory” by Marian Annett, stands out. Annett proposed a genetic model of cerebral dominance based on a single allele called RS for Right Shift. The RS allele is thought to offer an advantage to the left hemisphere such that a person with one copy of the allele will likely have speech localized to the left hemisphere and exhibit some degree of right-hand bias. An individual who does not have a RS allele will develop cerebral dominance and handedness by chance (Annett, 2002).

Using Annett’s theory we can view handedness as a continuum, with individuals ranging from consistent left preference to mostly left, mostly right and consistent right preferences. Hand preference can then be measured, either with self-report questionnaires such as the popular Edinburgh Handedness Inventory (Oldfield, 1971), or with a combination of self-report questions and actual observation of the participant doing various tasks (e.g. Annett, 2002).

But what about measuring how each hand performs on a task, not just what hand the participant prefers to use? Hand performance has been examined in many studies using tests that require various types of motor skill. One example is the Annett pegboard (instructions and norms as given in Annett, 2002) in which the participant is presented with an apparatus with two parallel rows, and must move ten pegs one at a time from the further row to the closer row. The participant is scored by how quickly they can move the pegs without making any errors. Annett has collected data from participants ranging in age from 3 to 60 years old. At every age the right hand is faster than the left on this task.

This matches findings of hand preference where the majority of individuals are right-preferent (Annett, 2002).

Independent researchers have confirmed Annett's findings. Bryden and Roy (2005) examined hand performance on the Annett pegboard in 302 right-preferent participants aged 3-24 years. They verified that performance improves with age, with older participants completing the task faster. More interestingly, there was a greater difference in performance between the left and right hands for the children in the sample compared to the adult participants. This is to be interpreted with some caution as baselines were likely to be different. These findings warrant greater attention to hand performance asymmetry in developing children, particularly those under the age of 3 for whom there are no data.

Additional studies have also found that the preferred hand outperforms the non-preferred hand on motor tasks other than the Annett pegboard. Corey, Hurley and Foundas (2001) tested the dexterity of sixty-two left- and right-preferent adults (19-54 years old) on a finger tapping task and the grooved pegboard task. They also measured hand strength with a hand dynamometer and hand preference with a combination of established handedness inventories. They tested a model predicting hand preference from the multiple measures of hand performance. Performance on the finger tapping and grooved pegboard measures were significant contributors but grip strength was not (Corey, Hurley & Foundas, 2001).

In a similar study by Triggs, Calvanio, Levine, Heaton and Heilman (2000) which also measured hand preference with handedness inventories, performance on finger tapping and pegboard tasks, and hand strength, performance on the pegboard task was significantly correlated with finger tapping in both left- and right-preferent participants (left-preferent $r = 0.50$, $p<0.005$; right-preferent $r = 0.57$, $p<0.005$). Grip strength however was only correlated with finger tapping in right-preferent participants ($r = 0.40$, p $p<0.03$) and with neither finger tapping nor pegboard performance in left-preferent participants.

These findings offer a few suggestions for measuring handedness. First, hand preference and hand performance asymmetries exist in children and adults, and are strongly related. The preferred hand performs better on various motor tasks that the non-preferred hand. Second, multiple performance measures should be employed. Third, grip strength does not seem to be the best predictor of hand preference. Finally, relationships between tasks should be examined, particularly between subgroups of the sample (e.g. left-preferent vs. right-preferent).

What remains to be seen is whether asymmetries in hand preference and performance stem from the same factor and are therefore present from birth as suggested by Annett's Right-Shift Theory (Annett, 2002) or whether an asymmetry in hand preference leads to an eventual asymmetry in hand performance as the result of practice as suggested by Peters' Attentional Theory (Peters, 1995). Annett's data suggests that the difference in hand performance arises because the non-preferred hand is weaker than the preferred hand, not because the preferred hand is more skillful (Annett, 2002). Peters' theory makes the opposite claim: one hand receives preferential attention and becomes increasingly more skillful with practice (Peters, 1995). Infants present a unique opportunity to test both researchers' predictions as they have not had extensive practice like older children or adults. Infant studies are therefore crucial to clarify the relationship between hand preference and hand performance.

1.2 Handedness in Infants

Investigations of handedness in school age children and adults have undoubtedly provided valuable information about hand preference, hand performance and the relationship between the two, yet they cannot address ontogeny. What is known then about handedness in infancy?

Studies of lateral asymmetries and the development of handedness in infants actually begin before the infant is even born. Through the use of ultrasound technology, researchers are able to study the movements of fetuses during gestation. One such study by McCartney and Hepper (1999) observed seventeen fetuses at 3 week intervals beginning at 12 weeks gestational age up through 27 weeks gestational age. Sessions lasted for 30 minutes. Arm movements per minute were calculated based on observations when both arms were visible. A significant population-level effect was found such that the majority of fetuses preferentially moved their right arm.

Another study by de Vries, Wimmers, Ververs, Hopkins, Savelsbergh and van Geijn (2001) examining just hand-to-mouth arm movements longitudinally in 12 to 38 week fetuses found inconsistency within individuals and no lateralized group preference. In addition there was no relationship between head position and hand preferences. These findings may have been due to a sampling issue as only ten fetuses were observed and sessions were just 15 minutes in length. Clearly there is a keen interest in fetal laterality and the potential implications. As the technology advances, additional studies will become increasingly informative.

Once the infant is born, head-orientation can be measured. Michel (1981) conducted a large study of head-orientation in 150 neonates. The infant's head was held at midline for 1 minute and then allowed to turn at will. Head-orientation was assessed every 6 seconds for 1 minute over three trials. The majority of infants showed a right head-orientation bias. Michel then followed twenty of these infants longitudinally, continuing to assess head-orientation at 3, 6 and 8 weeks of age. Hand use based on initial reach and manipulation of stimuli was assessed at 16 and 22 weeks of age. Head-orientation preferences mapped onto later reaching and manipulation preferences. For example, infants with a right head-orientation bias showed a right bias in reaching for and playing with the stimuli (Michel, 1981).

Infants begin reaching for objects around 4 months of age and traditionally infant hand preference has been quantified as the predominant hand used in reaching. Michel, Ovrut and Harkins (1985) developed a procedure for assessing infant hand preference. The protocol involves twenty-eight opportunities for infants to reach for toys. The majority of toys are presented as a single item at the infant's midline on the ground surface where they are sitting. In six of the presentations identical toys are presented in line with each shoulder. In five presentations the toys are suspended by wire and presented at shoulder height. After the infant contacts the toy(s), they are allowed 20 seconds of playtime. Michel *et al.* initially tested ninety-six infants ranging from 6 to 13 months of age. At just 6 months, the majority of infants preferred the right hand. This preference persisted through 12 months of age. At 13 months infants did not show a hand use bias and this may be related to the increase of bimanual manipulations during that time period. Overall this protocol was found to be a reliable and valid measure of infant hand preference (Michel, Ovrut & Harkins, 1985).

In a later study Michel, Tyler, Ferre and Sheu (2006) showed that infant hand preference is distributed similarly to that of adults and fairly stable over time. Hand preference was assessed longitudinally in fifty-one infants at four time points: 7, 9, 11, and 13 months using the procedure developed by Michel, Ovrut & Harkins (1985). Preferences ranged from consistent left to mixed left, mixed right and consistent right, and the majority of infants were right-preferent as seen in adults (Michel *et al.,* 2006). Thus hand preferences exist and can be measured in infants.

Data on hand performance in infants however is lacking. Previous attempts at quantifying hand performance have largely measured holding time or grasp duration. Caplan and Kinsbourne (1976) for example reported data on twenty-one infants aged 1-4 months on two holding time tasks. In the first task a single rattle was placed in either the left or right hand and the experimenters recorded how long the rattle was held before it was dropped. In the second task a rattle was placed in both hands and holding time was recorded as well as which hand dropped the rattle first. In both tasks the right hand held the rattle longer than the left, although the difference between the hands was only significant for the first holding task (Caplan & Kinsbourne, 1976).

While these data are interesting, it is not clear what holding duration means in the context of handedness, considering findings with adults and hand strength (Triggs *et al.*, 2000; Corey, Hurley & Foundas, 2001). Although these data suggest an early asymmetry in skill, other biases were not explicitly examined and therefore no relationships can be drawn between lateralized behaviors.

The studies mentioned here are meant to be examples of how handedness has previously been studied in infancy. Lateral biases seem to be present almost as early as they can be tested. When considering which tasks to use to measure handedness in infants, it is imperative to select tasks that are meaningful for the infant at the particular age that is being studied (Peters, 1983). Newly acquired skills may be more likely to induce use of the preferred hand as compared to highly familiar tasks. At the same time it may be important to assess the infant's regular use of their hands, such as during play, for comparison. Additional study of hand performance in relation to hand preference is therefore necessary to fully understand the development and early expression of handedness in infancy.

CHAPTER 2

MEASURING HANDEDNESS IN 11-MONTH-OLD INFANTS

Despite the growing body of work on handedness, there have been limited studies of hand performance in human infants (e.g. Caplan & Kinsbourne, 1976). The larger body of work with infants has only assessed one factor, typically hand preference (e.g. Michel *et al.*, 2006). Without studies involving comparisons between infant hand preference and their performance on motor tasks, it is unclear what conclusions can be drawn about the relationship between hand preference and hand performance in development and how such a relationship exists in later childhood and adulthood. The aims of this study were twofold: to develop a procedure for assessing hand performance in infants and to examine the relationship between hand preference and hand performance in development.

2.1 Method

2.1.1 Participants

Local families participated in this study. Infant names were acquired through newspaper birth announcements or a commercial source. Parents first received a letter describing the study (appendix A). They were then contacted by phone. If the parent(s) had an interest in having their child participate, an appointment was made within two weeks before or after the child's 11-month birthday. In total, thirty-six 11-month-old infants participated in this study (males=18). The mean age and the distribution of age did not vary with gender. The infants ranged in age from 331 to 349 days. The mean age of the infants was 334.2 days (SD=8.2) or 11.1 months.

2.1.2 Procedure

A researcher met the family in the parking lot and escorted them to the lab. Once in the lab area, the primary investigator reviewed the informed consent form (appendix B) with the parent(s) and explained the testing procedure. Throughout testing the infant was seated in a parent's lap. Parents were told not to interfere with their infant's play for the duration of testing. Infants were videotaped participating in three tasks. The tasks were presented in the same order for each infant. The average session lasted twenty minutes.

In the first task infants were presented with a series of five age-appropriate toys during a free-play period (figure 1A). The items consisted of a plastic toy block, a toy hammer, a toy phone, toy stacking rings and an animal pop-up toy. Toys were selected for maximum manipulation on the basis of bright coloration, noise/sound generation, and/or moveable parts. All toys were obtained from a local toy store. Each toy was presented individually at the infant's midline. A kitchen timer was started when the infant contacted the toy, and the infant was then given 90 seconds of playtime with each toy. The purpose of this series of toys was to establish the infant's baseline hand preference during his or her natural play.

The second task assessed the infant's gross motor skill on a fitting task. In this task the infant was expected to fit a ball into the top opening of a toy (figure 1B). The diameter of the opening was approximately 5 cm and the ball just fit through this opening. The toy itself measured approximately 17 cm in height. It was attached by industrial strength Velcro to a painted wooden platform measuring 45.7 x 26.7 cm. Two grooves were made 18.5 cm from the center point of the top opening to the center point of the groove on each side of the toy. These grooves served as the starting locations for the ball during the task. The starting location (left or right) was randomized across trials. The experimenter first demonstrated the task for the infant by fitting the ball twice with each hand. When the ball fell through the opening of the toy, lights and sounds came on which was an exciting visual and auditory reinforcer for the infant. The infant was then given twelve trials. If the infant used the contralateral hand or did not complete a trial, additional trials were given in an effort to achieve sufficient data for each hand. This task assessed hand performance.

The third and final task also measured hand performance. In this task fine motor skill was assessed as infants were presented with a small stationary cup and asked to retrieve a Cheerio that had been placed inside (figure 1C). A clear 118 ml plastic cup was attached by industrial strength Velcro to the opposite side of the wooden platform used in the previous task. The cup measured 5 cm in height and had an opening of 7 cm in diameter. The cup was affixed to either the center, left or right of the infant. Cup placement was randomized across twelve trials. A single Cheerio was placed into the cup at the start of each trial and the infant was allowed as many tries as necessary to retrieve it. Infants were allowed to eat the Cheerio between trials. Food was a strong motivator for this activity. As in the previous task, additional trials were given if needed to try to obtain sufficient data for each hand.

Upon completion of the experimental tasks, the primary experimenter reviewed the optional video consent form with the parent (appendix C). This form authorized the use of their child's video for academic purposes (e.g. conference presentation). The parent was not obligated in any way to sign this form and could request to see their child's video before making a decision. Data collection concluded with a short questionnaire on the infant's developmental history and previous experiences (appendix D)

2.1.3 Data Analysis

Data were recorded onto DV tapes and scored using a digital component recording deck capable of 30 frames per second. Hand preference was scored from the free-play period in 6-second intervals. The first time point was taken when the infant first reached for and contacted the toy. Manipulations were coded as unimanual (left or right), bimanual, or no action/unable to score. This basic classification scheme resulted in seventy-five possible data points per infant.

A Manual Index (MI) score was calculated for each infant to determine the ratio of bimanual contacts to unimanual contacts. The MI was computed by subtracting the number of bimanual responses from the number of unimanual responses and then dividing by the total number of scorable actions [(U-B)/ (U+B)]. Values ranged from -1 meaning only bimanual actions to 1 meaning only unimanual actions. Unimanual actions were of particular interest because the hand performance tasks specifically measured unimanual activity. Analysis and interpretation of bimanual activity was therefore beyond the scope of this thesis.

A Handedness Index (HI) score was used to characterize unimanual hand preference and was calculated for infants with at least ten unimanual actions. The HI was computed by subtracting the number of left unimanual responses from the number of right unimanual responses and then dividing by the total number of unimanual responses [(R-L)/(R+L)]. Hand preference thus ranged from -1 to 1 with negative values interpreted as a left bias and positive values interpreted as a right bias. The degree or strength of each infant's hand preference was also calculated by taking the absolute value of the HI score (ABS-HI). Values closer to 1 indicated stronger hand preferences.

A secondary coder scored one-third of the hand preference data for inter-rater reliability. Reliability was calculated using a percent agreement score where the total number of disagreements was subtracted from the total number of data points, then divided by the total data points and multiplied by 100 {[(Total Data Points - Total Disagreements)/Total Data Points]*100}. The reliability was 89% for this subset of the data.

Proficiency on the hand performance measures was quantified by latency, or speed, to complete each task. For the fitting task, latency was defined by the frame when the ball first moved off the platform to the frame when it was fit into the opening of the toy. Trials were classified as one of four types: (1) direct, meaning the infant picked up the ball and fit immediately; (2) indirect, meaning the infant picked up the ball and manipulated it in some manner (e.g. mouthed ball) before fitting; (3) transfer, meaning the infant picked up the ball with one hand but moved the ball to the opposite hand for fitting; or (4) miss, meaning the infant made a mistake in fitting (e.g. overshot the opening). Infants must have fit the ball directly at least one time with each hand to be included in the statistical analysis. The number of direct fit trials varied from infant to infant depending on his or her fitting strategy and/or willingness to participate. Up to four direct fit trials (per hand) were scored for each infant. The average fitting time was then calculated for each hand. A Laterality Quotient (LQ) score was calculated for each infant on each performance measure. LQ_{FIT} was computed by subtracting the average fitting time for the right hand from the average fitting time for the left hand and then dividing by the sum of the fitting times [(L-R)/ (L+R)]. A positive score indicated that the infant fit faster with their right hand whereas a negative score indicated that the infant fit faster with their left hand. Finally, a secondary coder scored one-third of the fitting data. Inter-rater reliability on the performance tasks was calculated within 5 frames (30f/s) with a percent agreement score. Reliability for the fitting measure was 95%.

The Cheerio retrieval task was also scored with latency. In this task latency was defined as the frame when the infant's hand first entered the cup to when the Cheerio was retrieved and the hand was entirely removed from the cup. As in the previous task, an infant must have retrieved the Cheerio at least once with each hand to be included in the statistical analysis. The number of retrievals with each hand varied from infant to infant. Up to four trials with each hand were included in calculating the average left- and right-hand retrieval times. A Laterality Quotient was also calculated for Cheerio performance ($LQ_{CHEERIO}$). $LQ_{CHEERIO}$ was computed by subtracting the average Cheerio retrieval time for the right hand from the average Cheerio retrieval time for the left hand and then dividing by the sum of the fitting times [(L-R)/ (L+R)] such that infants with a positive score retrieved the Cheerio faster with the right hand and infants with a negative score retrieved the Cheerio faster with the left hand. As in the previous two measures, a secondary coder scored one-third of the Cheerio data. Inter-rater reliability was calculated within 5 frames (30f/s) with a percent agreement score. Reliability for the Cheerio measure was 86%.

The final portion of the data analysis involved the questionnaire. The questionnaire was largely concerned with assessing familial handedness, particularly instances of self-reported parental left-handedness. The remaining questions were primarily used to detect anything unusual in the infant's developmental history.

2.2 Results

2.2.1 Hand Preference

The parents reported that most of the infants had the same or similar toys at home as those used in the hand preference battery. Of the participants, 91% had blocks; 53% had a toy hammer; 97% had a toy phone or stated their child played with a real phone; 74% had a stacking ring set; and 50% had a pop-up toy. Despite equal unfamiliarity, the hammer was the least played with toy while the pop-ups were clearly the favorite of most infants (personal observation).

The majority of infants' actions at this age were unimanual, as evident by a one-sample t-test on Manual Index (MI) scores, $t(33)=4.23$, $p<.0001$ (figure 2). The mean MI value of 0.28 (SD=0.38) was significantly greater than the test value of 0. MI scores ranged from -0.57 to 1.00. Three infants were solely unimanual during the play session whereas no infant was solely bimanual. A two-sample t-test on MI scores grouped by gender was not significant [$t(32)=-0.30$, $p>.05$; $M_{MALESs}=0.26$, SD=0.43; $M_{FEMALES}=0.30$, SD=0.33].

Hand preference for unimanual actions in this sample as calculated by Handedness Index (HI) scores ranged from -0.45 (moderately left) to 0.84 (strongly right). A one-sample t-test revealed a significant population-level right-bias, $t(33)=4.46$, $p<.0001$ (figure 3). The mean HI value of 0.28 (SD=0.36) was significantly greater than the test value of 0. There was no gender difference for hand preference (two-sample t-test; $t(32)=0.09$, $p>.05$; $M_{MALES}=0.28$, SD=0.31; $M_{FEMALES}=0.27$, SD=0.42).

In terms of familial handedness, nearly three-quarters of the parents reported a left-handed individual in their family. In this sample there were nine families which contained a parent who was left-handed. Just two infants with a left-handed parent were characterized as left-preferent. The remaining four left-preferent infants had two right-handed parents. The relationship between parent and infant hand preference was therefore not significant (Fisher's exact test, $p>.05$).

2.2.2 Hand Performance

82% of infants were reported to have a fitting toy at home. However, only 42% of the study group or fifteen infants completed the fitting task with both hands. An additional six infants only fit with the right hand, two infants only fit with the left hand and four infants fit but had no direct (scorable) trials. Fitting performance in the subset of the sample with sufficient data as calculated by Laterality Quotient (LQ_{FIT}) scores ranged from -0.44 to 0.42 with a mean of 0.06 (figure 4). The right hand was slightly faster than the left ($M_{RIGHT}=1.29$ s; $M_{LEFT}=1.43$ s) but this difference was not statistically different (paired samples t-test; $t(14)=0.80$, $p>.05$). When infants were grouped into left- (n=3) or right- (n=12) preferent groups, there was no difference for left hand fitting (two-sample t-test; $t(13)=-0.20$, $p>.05$; $M_{LEFT\text{-}PREFERENT}=1.39$, SD=0.43; $M_{RIGHT\text{-}PREFERENT}=1.44$, SD=0.40) or right hand fitting (two-sample t-test; $t(13)=1.48$, $p>.05$; $M_{LEFT\text{-}PREFERENT}=1.62$, SD=0.64; $M_{RIGHT\text{-}PREFERENT}=1.21$, SD=0.38).

The correspondence between the preferred hand (left or right) and the proficient (faster) fitting hand (left or right) was also examined. In seven of the infants the preferred hand matched the proficient hand, but this relationship was not significant at the group level (Fisher's exact test, p>.05). A two-sample t-test found no gender differences for left hand fitting performance [$t(13)= 1.54$, $p>.05$; $M_{MALES}=1.55$, SD=0.38, n=9; $M_{FEMALES}=1.25$, SD=0.37, n=6] or right hand fitting performance [$t(13)=0.16$, $p>.05$; $M_{MALES}=1.31$, SD=0.39; $M_{FEMALES}=1.27$, SD=0.56].

On the Cheerio task, 89% of the sample or thirty-two infants provided data with both hands. Another two infants only retrieved the Cheerio with the right hand. No infant exclusively used the left hand on this task. Infants were fairly experienced with Cheerios. On average infants had been eating Cheerios since 6.6 months of age (SD=2.1 months). One infant had not yet been exposed to solid food of any kind. This infant was allowed to retrieve the Cheerios but not eat them. The task was particularly difficult for that infant. Laterality Quotient ($LQ_{CHEERIO}$) scores measuring Cheerio performance for the group overall ranged from -0.37 to 0.32 with a mean of -0.03 (figure 5). In general the left hand was slightly faster than the right ($M_{LEFT} = 3.54$ s; $M_{RIGHT} = 3.79$ s) but this difference was not statistically different (paired samples t-test; $t(31)=-0.83$, $p>.05$).

As with the fitting measure, when infants were grouped into left (n=7) or right (n=25) hand preference groups, there was no difference for left hand Cheerio (two-sample t-test; $t(30)=-0.08$, $p>.05$; $M_{LEFT\text{-}PREFERENT}=3.51$, SD=1.32; $M_{RIGHT\text{-}PREFERENT}=3.55$, SD=1.49) or right hand Cheerio (two-sample t-test, $t(30)=-0.06$, $p>.05$; $M_{LEFT\text{-}PREFERENT}=3.76$, SD=1.39; $M_{RIGHT\text{-}PREFERENT}=3.80$, SD=1.47). There was also no relationship between preferred hand and skillful Cheerio retrieval hand as only sixteen of the infants showed matching biases or concordance (Fisher's exact test, $p>.05$). A two-sample t-test revealed no gender differences for left hand Cheerio performance [$t(30)=1.18$, $p>.05$; $M_{MALES}=3.82$, SD=1.59, n=17; $M_{FEMALES}=3.23$, SD=1.21, n=15] or right hand Cheerio performance [$t(30)=-0.68$, $p>.05$; $M_{MALES}=3.62$, SD=1.64; $M_{FEMALES}=3.97$, SD=1.19].

Fourteen infants had sufficient data to be compared on the two hand performance measures. Eleven of these infants were concordant for hand proficiency across the two measures. This finding approached significance ($p<.057$, sign test). However, only eight of the infants were concordant across all tasks (hand preference, fitting performance and Cheerio performance). This relationship was not significant (Fisher's exact test, $p>.05$). In sum, there were no population-level effects for either the fitting or Cheerio tasks. In addition, individual infants showed some inconsistencies in the direction of laterality expressed in the three experimental measures.

2.2.3 Predicting Hand Preference from Hand Performance

To evaluate the hypothesis that hand performance predicts hand choice, hand preference was regressed on hand performance. In the subset of infants who completed the fitting task with both hands (n=15), left hand fitting time was not a significant predictor of unimanual hand preference as measured by HI scores ($r=0.130$, $p>.05$). Right hand fitting time was also not a significant predictor of preference ($r=0.184$, $p>.05$). Entered together in the same model, left hand fitting time and right hand fitting time did not significantly predict hand preference ($r=0.198$, $p>.05$).

In the subset of infants who completed the Cheerio task with both hands ($n=32$), neither left hand Cheerio time ($r=0.007$, $p>.05$) nor right hand Cheerio time ($r=0.197$, $p>.05$) independently predicted unimanual hand preference. A model of hand preference regressed onto left hand Cheerio time together with right hand Cheerio time was not significant ($r=0.206$, $p>.05$). Thus neither dimension of hand performance (fitting or Cheerio) could predict hand preference on its own.

In the final model test, hand preference was regressed on both measures of hand performance (left hand fitting time, right hand fitting time, left hand Cheerio time and right hand Cheerio time as independent variables) using a backwards stepwise general linear model with an F-Statistic of 4 to enter and 3.9 to remove. Interestingly, right hand performance on the two tasks was predictive of hand preference ($r=0.700$, $p<.05$). Right hand fitting time was significant (figure 6, $\beta=-0.70$, $p<.05$) as well as right hand Cheerio time (figure 7, $\beta=0.15$, $p<.05$). Latencies with the right hand on the performance tasks seemed to increase as the degree of hand preference increased, although only the relationship between the absolute value of the HI scores (ABS-HI) and right hand Cheerio retrieval time was significant (figure 8, $r=0.548$, $p<.05$).

Additionally, there was a strong correlation between the fitting and Cheerio tasks for the right hand (figure 9, $r=0.577$, $p<.05$). Average left hand fitting time and average left hand Cheerio time were not significant predictors of hand preference and were removed from the model. The correlation between the fitting and Cheerio tasks for the left hand was not significant (figure 10, $r=0.248$, $p>.05$). Thus, multiple hand performance measures were necessary to predict hand preference, although predictive power was restricted to right hand performance on the two tasks.

CHAPTER 3

DISCUSSION

This study found that infants at 11 months of age are largely unimanual in their play. Therefore, comparisons between unimanual hand preference and hand performance were appropriate at this time point in development. There was no significant relationship between parent and child left handedness which was expected as handedness does not follow simple Mendelian genetics of inheritance (Annett, 2002). There were no gender differences in any of the analyses so findings will be discussed in terms of the entire group.

The results of the hand preference assessment confirmed previous work by George Michel's group (e.g. Michel *et al.*, 1985; Michel *et al.*, 2006) showing that the majority of 11-month-old infants are right-preferent. Thus hand preferences exist in infants and can reliably be measured across different protocols. An important difference between this study and the studies mentioned previously was the duration of the hand preference testing. This study cut the time to measure hand preference in half (7 ½ minutes compared to 15 minutes) which allowed for additional testing of hand performance with multiple tasks in the same lab visit. This shortened testing time has practical significance for infant researchers wishing to incorporate a laterality component into their studies.

The hand performance findings were less straightforward than that of the hand preference assessment. There was no group-level finding for the fitting measure, and this was confounded by the fact that less than half of the sample completed the task with both hands. The hand performance measures were designed to be difficult as well as fairly novel to reveal any differences that might exist in hand skill. At 11 months though, the fitting measure may have been more of a cognitive challenge than a motoric challenge. The infants not only had to fit the ball into the opening, they then had to let go of the ball with the realization that they could get the toy back afterwards. Some infants were content to hold the ball during the duration of this part of the experiment while others mouthed the ball or threw the ball to the floor.

There was also no group-level finding for the Cheerio measure. Unlike the fitting however, infants reliably completed the Cheerio task. Nearly the entire sample retrieved the Cheerios with both hands. Familiarity with Cheerios may have played a role in the success of this task, although most parents reported that their child picked up food from an open tray at home and not a small cup or dish where their hands would be confined as in the experimental Cheerio measure.

From these data it's apparent that there is a strong asymmetry in hand preference early in life. It is not clear however whether such an asymmetry exists for hand performance. While inconclusive, these data from the fitting and Cheerio measures represent the first attempt to quantify hand performance in infants. It's possible that the tasks used in this study did not appropriately measure differences in hand skill. It is also possible that differences in proficiency were not evident from the behavioral data alone. Future work will examine additional infants in this age group as well as subsequent ages using a motion analysis system to detect finer differences in hand use. Kinematic measures have previously been used to explore differences in infant reaching (e.g. Rönnqvist & Domellöf, 2006), but have yet to be used to examine differences in infant hand proficiency.

The most significant finding of this study was that hand preference was predicted by multiple measures of hand performance. This was the first study to examine the relationship between preference and performance in infants of any age. Findings from the right hand were especially interesting. Only variance in the right hand's performance on the fitting and Cheerio tasks was predictive of hand preference scores in the regression model. Upon closer examination of the right hand's performance on the Cheerio task, it was found that infants with a greater degree of hand preference regardless of direction took longer to retrieve the Cheerio with the right hand. It is possible that infants with a strong hand preference took additional time on a difficult fine motor task because they were incorporating feedback into their actions to improve their performance. This finding cannot be interpreted as infants simply taking longer on the task to improve the performance of their preferred hand because the analysis included infants who were left-preferent. However, there were only three infants classified as left-preferent in the overall model so it cannot be known if the pattern of increasing hand preference and increasing right hand Cheerio time would hold in a larger sample of left-preferent infants. In general data from a greater number of left-preferent infants are necessary to appropriately address questions regarding left hand preference and performance statistically.

Overall it seems that the two performance tasks were valid measurements of the right hand's performance because right hand fitting and right hand Cheerio performance were strongly correlated. As right hand fitting time increased, right hand Cheerio retrieval time also increased. In other words, infants who were slower to fit with the right hand also took longer to get the Cheerio with the right hand. Left hand performance across the two tasks was not correlated and did not significantly contribute to the overall model.

Contrary to studies with older children and adults, there was no outright bias towards the preferred hand outperforming the non-preferred hand although the predictive power of the right hand summed over both performance measures may indicate a subtle group-level trend.

Although there wasn't a clear population-level bias on either the fitting or the Cheerio measures, the performance of the right hand on those tasks was predictive of hand preference. This underlying relationship between hand preference and performance seems to be in opposition to Peters' (1995) theory which claims that extensive motor and life experience is required for hand performance asymmetry. At the time of testing, these infants had been reaching for 7 months at most. This is hardly sufficient experience, compared to that of older children and adults. However, it may be the case that the clear bias towards right hand preference is slowly shaping hand performance. Adults show both a group-level right bias for hand preference as well as hand performance. Further research exploring the developmental age at which a rightward bias in hand performance is present at the group-level will clarify this point.

At the same time the lack of clear asymmetries in the performance data does not directly correspond to Annett and others' findings of the preferred hand being the proficient hand. Only 8 of 14 infants were showed consistent hand use across the three experimental measures. Data analysis was greatly limited however by small sample size. Additional studies with increased subject numbers are necessary to fully characterize the hand performance in infancy. It is also possible that finer differences exist between the left and right hands that were not apparent from these hand performance measures. Future work will address this possibility by continuing to develop methodology for examining hand performance in development. Overall additional work is needed in order to truly evaluate existing handedness theories such as those by Peters and Annett.

Additional studies are also needed in developing nonhuman primates. Handedness in nonhuman primates has largely revolved around measuring preference in adult animals (For reviews see MacNeilage, Studdert-Kennedy & Lindblom, 1987; McGrew & Marchant, 1997; Papademetriou, Sheu & Michel, 2005). Studies of hand preference and performance have produced conflicting results (e.g. Andrews & Rosenbaum, 1994, 2001; Trouillard & Blois-Heulin, 2005). It is difficult to compare findings across studies due to variations in methodology and species. Future work will address the relationship between hand preference and performance in infant rhesus monkeys *(Macaca mulatta)* using measures similar to those used in this thesis with human infants. This work will provide a valuable comparative perspective on developing primates, both human and nonhuman, which is lacking in the handedness literature.

Overall this study was limited by the small number of infants who completed all three measures. In addition, infants were not followed longitudinally so no inferences can be drawn regarding the stability of hand preference and hand performance over time. Finally, no conclusions can be made as to whether there is a causal relationship between preference and performance. Despite these limitations, this thesis has provided the first glimpse into the ontogeny of hand performance. Future studies will contribute to understanding the relationship between hand preference and hand performance and to understanding laterality in general and its impact in development.

FIGURES

Figure 1: (A) Hand preference toy battery (B) Infant participating in fitting task (C) Infant participating in Cheerio task

Figure 2: Unimanual bias in manipulation style distribution (MI scores)

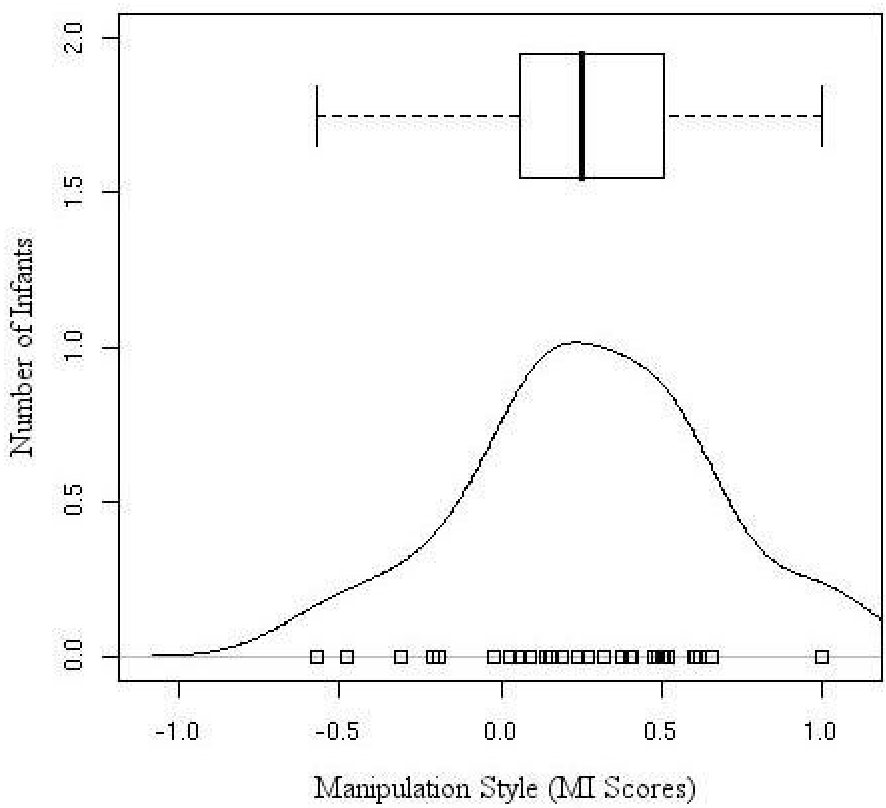


Figure 3: Right bias in hand preference distribution (HI scores)

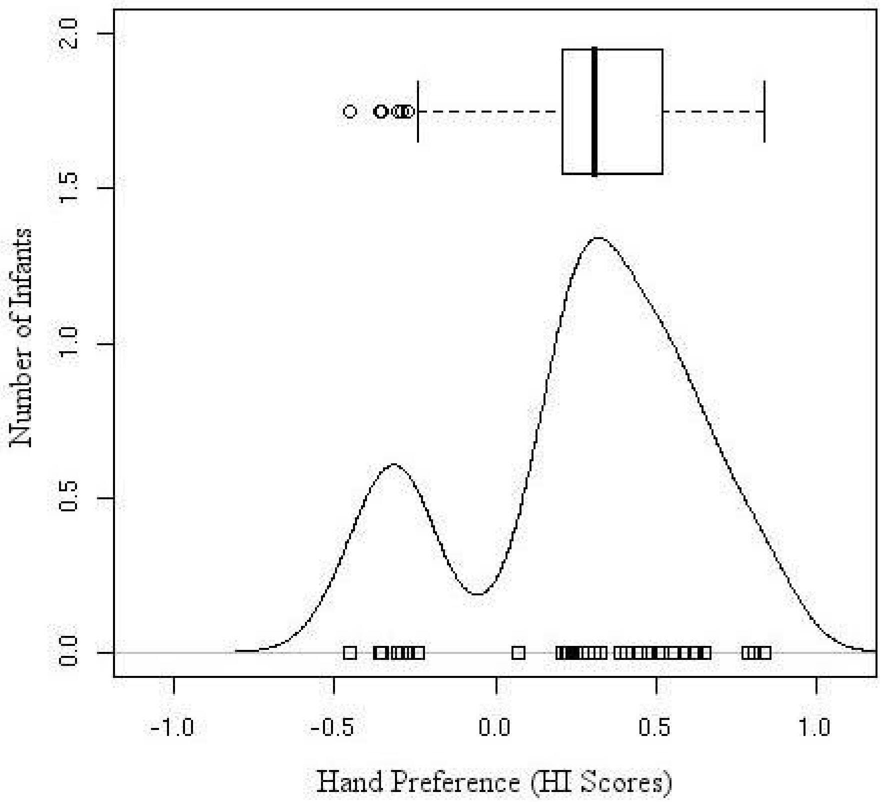


Figure 4: No difference in hand performance on the fitting task (LQ_{FIT} scores)

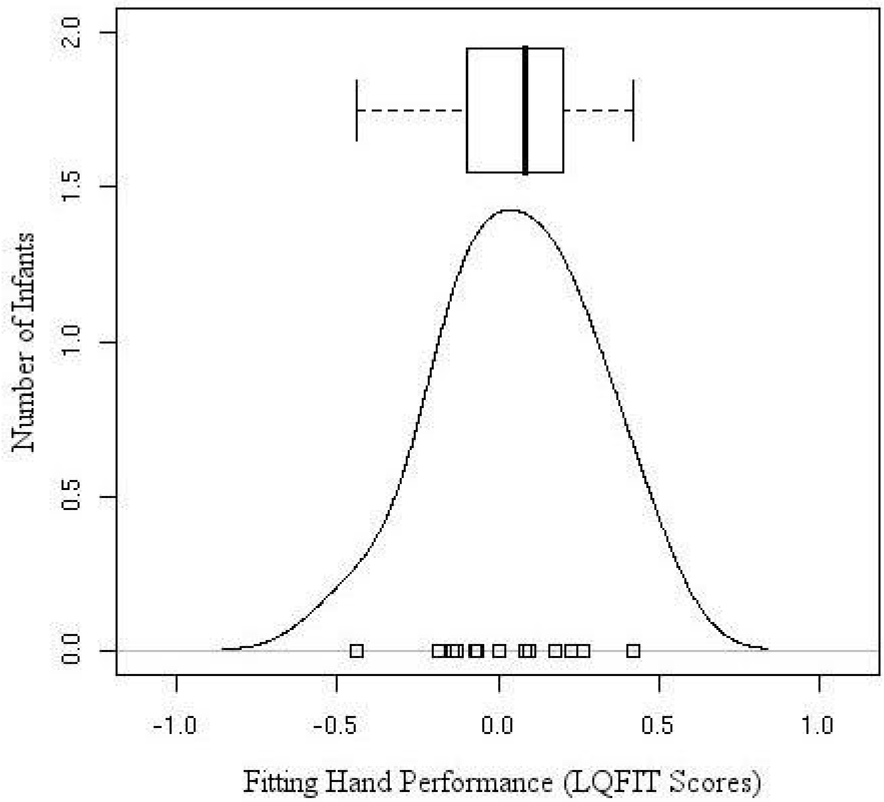


Figure 5: No difference in hand performance on the Cheerio task ($LQ_{CHEERIO}$ scores)

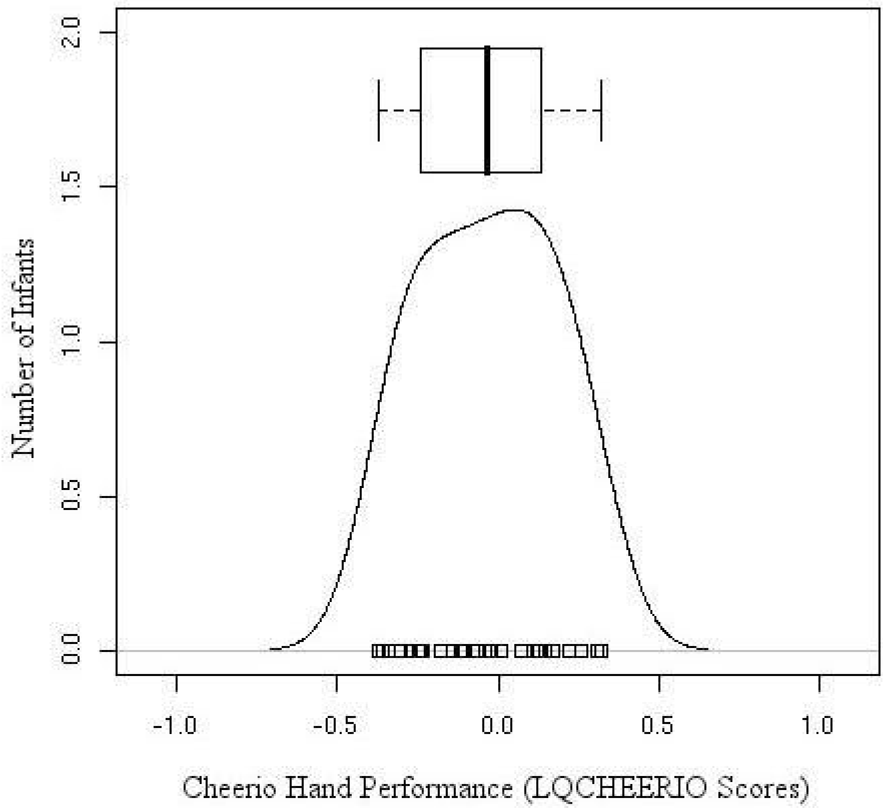


Figure 6: Right hand fitting time predicts hand preference

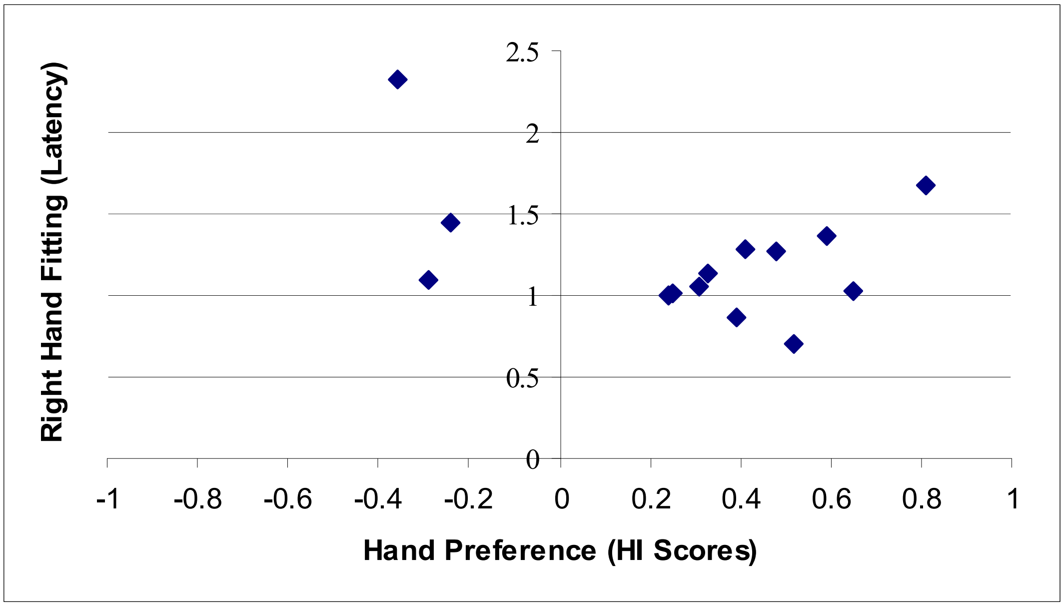


Figure 7: Right hand Cheerio retrieval time predicts hand preference

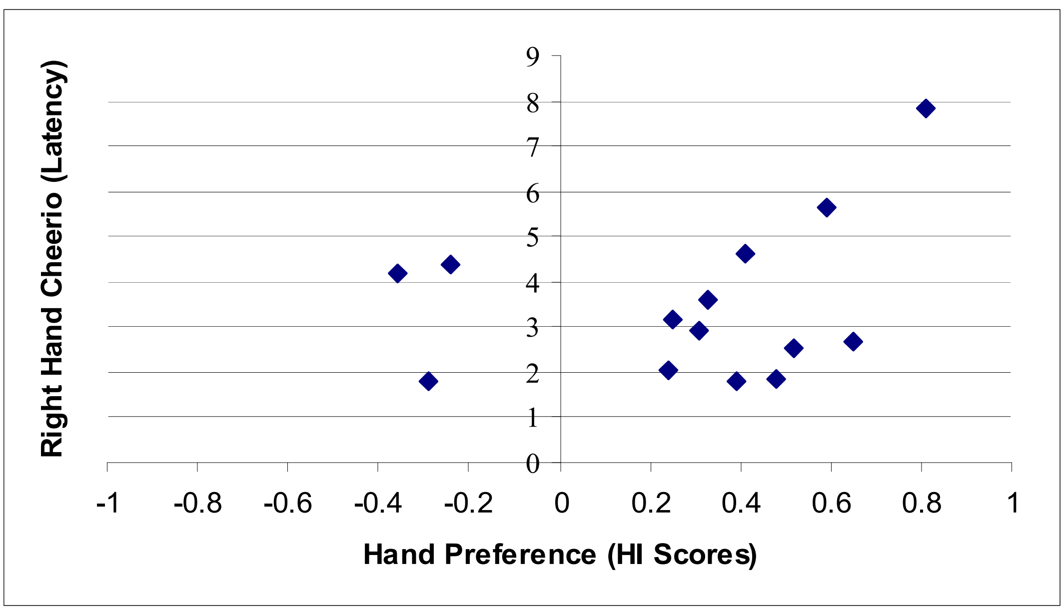


Figure 8: Right hand Cheerio retrieval time predicts degree of hand preference

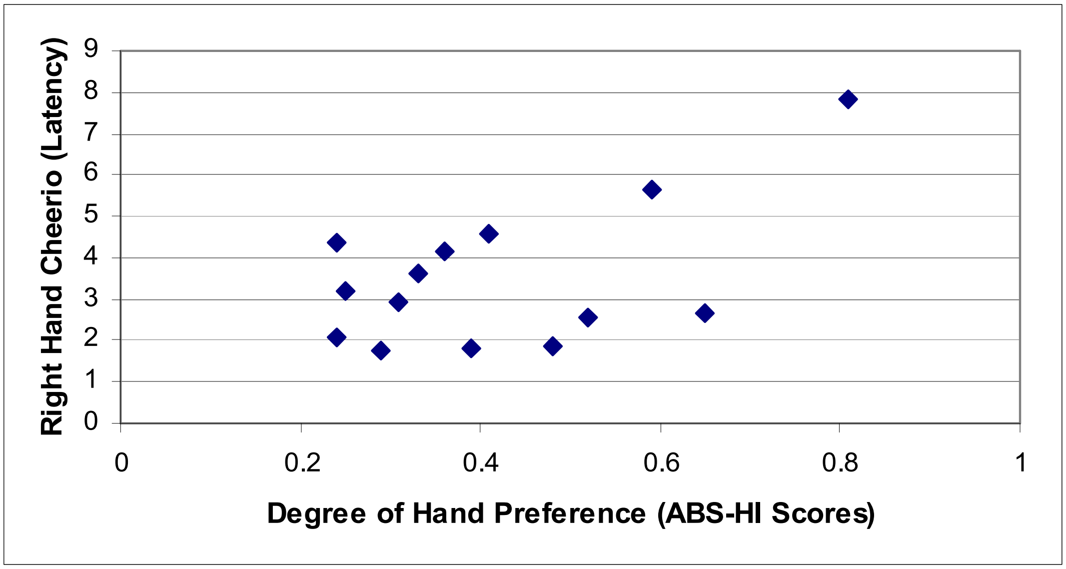


Figure 9: Performance measures strongly correlated for the right hand

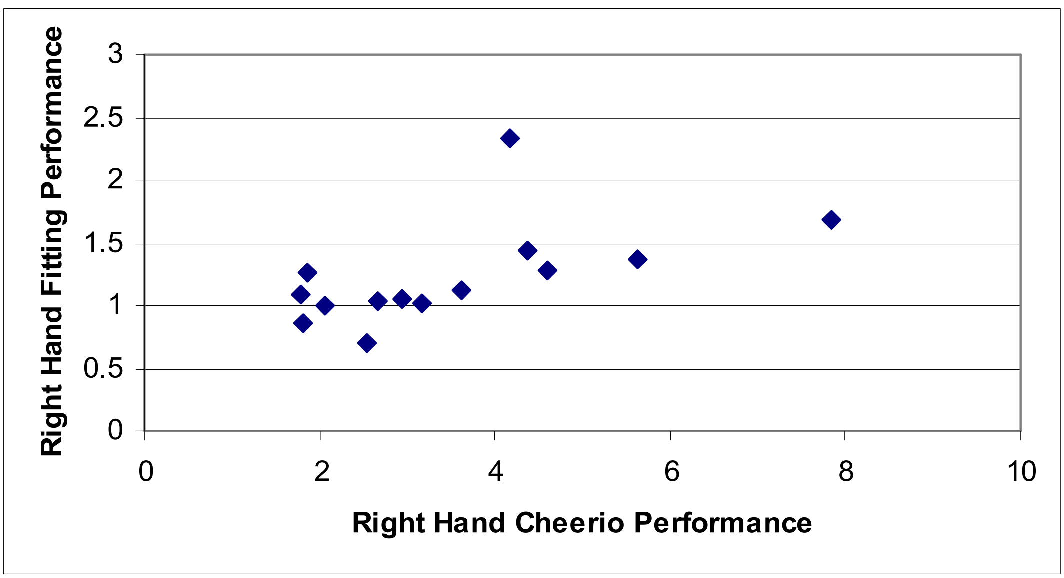
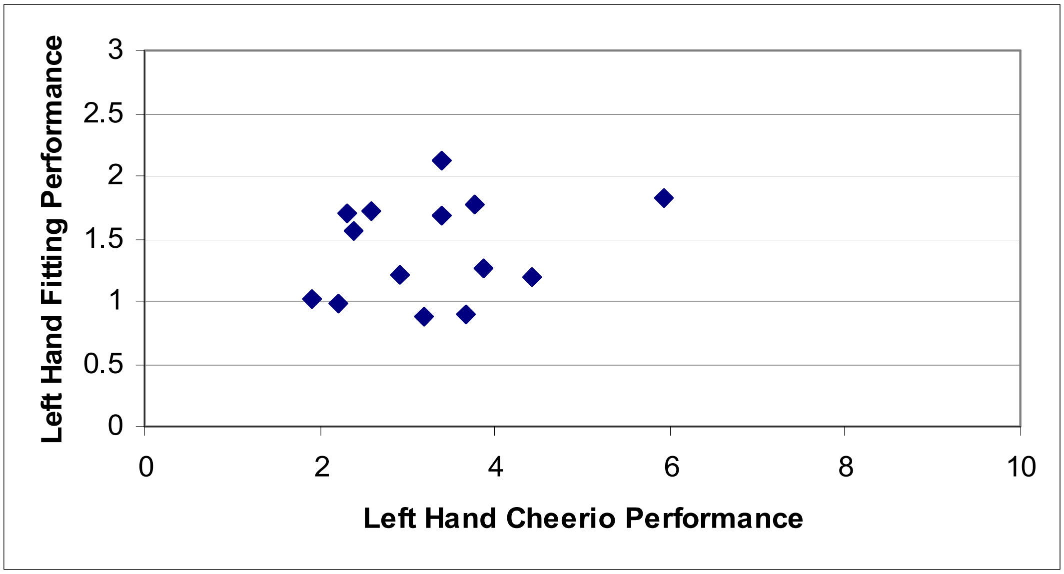


Figure 10: Performance measures not correlated for the left hand



APPENDIX A

LETTER TO PARENTS

Summer 2006

Here at the University of Massachusetts, we have been conducting projects on children's development for more than twenty years. Some of you may have visited our labs with your children in the past or have read about our research. If you have internet access, you can view some of our work at http://www.umass.edu/devpsych. These studies have only been possible through the generosity and participation of area families, to whom we are very grateful. We are contacting you at this time to invite you to participate in one of our current studies designed for 11-month-old children.

In our current study, we are exploring the relation between hand preference and performance in human infants. In this study, we present infants with a series of attractive toys. Infants are encouraged to reach for and play with the toys. We are interested in seeing how infants manipulate objects with their hands. We videotape the infant's behavior for later coding. A parent is with his or her child at all times during the session.

There are no discomforts or risks involved in our studies, and parents and their children usually find these experiences to be interesting and fun. We are always happy to show you the videotape after the session and to discuss with you the findings of this particular study as well as other studies that we have conducted. All of the data that we collect will remain strictly confidential. Participation in the study is entirely voluntary, and if at any point during the visit you wish to terminate your participation, you may do so.

Participation in this study involves one visit of approximately 45 minutes to our lab. A map is enclosed for your convenience, showing you where to park near our building on campus. When you arrive, we will meet you by your car and help you into the building. If you have another child who will be accompanying you, we are happy to arrange for an adult to entertain him/her in our playroom during the session.

Our work has led to new insights about development in infancy and early childhood, and clearly none of it would be possible without the assistance of parents in the community. We are deeply grateful to all of the parents who have helped us out in the past, and would appreciate your participation in this study. We will be telephoning you in the near future to answer any questions you may have, and to see if you are interested in participating. If you would prefer to contact us, please feel free to call Dan Johnson at 545-5968, or email at dpjohnso@psych.umass.edu. Thank you very much for considering our project.

Neil Berthier, Ph.D.	Dan Johnson	Eliza Nelson, B.S.
Professor of Psychology	Lab Coordinator	Doctoral Student
(413)545-0535		
berthier@psych.umass.edu		

APPENDIX B

INFORMED CONSENT

Consent Form

The Human Studies Research Committee has approved this study and the recruitment of subjects.

Purpose of Study
The study is designed to investigate hand preference and performance in human infants. In particular, we are examining whether there is a difference in left- and right-hand performance on various motor tasks and if so, whether this difference is correlated with the development of hand preference.

Procedure
Your infant will sit on your lap while we present a series of attractive toys. Your infant will be encouraged to reach for and play with the toys. We are interested in assessing your infant's ability to manipulate objects with his/her hands. Please do not assist your child in any way during this experiment. The testing session will be videotaped so that we can later code your child's behavior. Testing will last about 30 minutes.

Possible Risks and Benefits
There is no risk to your child and no expected benefit.

Confidentiality of Records
The records generated by this study will be confidential. Videotapes and paper records will be stored in a locked room and will only be available to researchers involved in this study. Your child will not be individually identified in any publication or presentation that results from this experiment.

Request for More Information
Feel free to ask any question about our study. We will be happy to show you the videotape of your child at the end of the session. If you wish to speak with someone involved in this study regarding any problems or concerns you may have, contact the principal investigator, Professor Neil Berthier, at (413) 545-0535 or if you would like to discuss your rights as a participant in a research study or wish to speak with someone not directly involved in the study, you may contact the Human Subjects Review Board at HumanSubjects@ora.umass.edu; (413) 545-3428.

Voluntary Nature of Participation
Your participation in this study is purely voluntary. You may withdraw at any time for any reason.

I, ____________________________, have explained to __________________________ the purpose of the research, the procedures required, and the possible risks and benefits to the best of my ability.

____________________________________   ________________________

Researcher's Signature   Date

I confirm that ______________________________ has explained to me the purpose of the research, the study procedures that my child, _____________________, will undergo, and the possible risks and discomforts as well as benefits that my child may experience. I have read and I understand this consent form and will be given a copy. Therefore, I agree to give my consent to have my child participate as a subject in this research project.

____________________________________   ________________________

Parent's Signature   Date

APPENDIX C

OPTIONAL VIDEO CONSENT

Consent Form

I, ______________________________, hereby give permission to the Child Study Center of the University of Massachusetts to show a brief segment of the videotape of my child, _________________________, for scientific or educational purposes. I understand that I may see the videotape before giving this permission.

I understand that if I change my mind I should contact Neil Berthier at 545-0535 or berthier@psych.umass.edu.

I have read and I understand this consent form. I understand that I will receive a copy of this form.

____ ___________________
Parent's Signature Date

____
Researcher's Name

____ ___________________
Researcher's Signature Date

APPENDIX D

PARENT QUESTIONNAIRE

NAME OF STUDY __HAND 06___ **SUBJECT #____** **TAPE #____**
TEST DATE _____/_____/____ **AGE _____ days** **EXP ____**

NAME ___________________________ **SEX** M F **WKS GEST (**40 ± 2) _____

BIRTHDATE ____/_____/____ **MATERNAL AGE ____**
BIRTH WT ____lbs _____oz (5 – 9 lbs) **BIRTH ORDER ____**

SIB NAMES & BIRTHDATES
1. ________________ ____/____/____ **3. ________________ ____/____/____**
2. ________________ ____/____/____ **4. ________________ ____/____/____**

DAYCARE Y N **AGE MOS ____** Currently ____Hrs/Day ____ Days/Wk
Other playgroup activities (hrs/day, days/wk)

____

Wake _____ am **Sleep _____** pm **Other childcare ______** hrs/wk

SIT ONSET **AGE MOS ____**
(vertical sitting for 30 s with no hands; avg. 6, range 4 – 8)

BELLY ONSET **AGE MOS ____**
(any style, belly touch sometimes, 10 ft across room; avg. 7, range 5 – 8)

CRAWL ONSET **AGE MOS ____**
(hands/knees, hands/feet, 10 ft across room, no belly touching; avg. 8, range 6 – 10)

CRUISE ONSET **AGE MOS ____**
(sideways holding furniture for support; avg. 9, range 8 – 11)

WALK ONSET **AGE MOS ____**
(10 ft across room, no holding, no falling; avg. 12, range 10 – 14)

FALLS ____

SURFACE EXPERIENCE (1 or more times week)
WW/CPT AREA-RUG WOOD LINO TILE GRASS CONCRETE TUB
BED/MATT COUCH PILLOW GYM-MAT LEAVES SAND MUD WATER

HAVE TOY/SIMILAR TOY
BLOCKS HAMMER PHONE STK-RINGS POP-UPS FITTING TOY

DATE BEGAN EAT CEREAL/SIMILAR SIZE FOOD ITEM AGE MOS ____

DOES CHILD EAT FOOD FROM A CUP OR SMALL DISH Y N

Breast-Fed starting ____mos **Bottle-Fed** starting ____mos **Mixed-Fed** starting ____mos
Hand Pref of bottle feeders
____

ARE THERE ANY IMMEDIATE FAMILY MEMBERS WHO ARE LH? Y N
(If yes, who/relationship)**____**

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