Development of Infant Prehension Handedness: A Longitudinal Analysis During the 6- to 14-month Age Period.

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Abstract:

Handedness is a developmental phenomenon that becomes distinctively identifiable during infancy. Although infant hand-use preferences sometimes have been reported as unstable, other evidence demonstrates that infant hand-use preference for apprehending objects can be reliably assessed during the second half of the infant's first year of life. The current study provides further insight into the stability of prehension preferences. We modeled individual and group level patterns of prehension handedness during the period from 6 to 14 months of age. We examined the developmental trajectories for prehension handedness in relation to the sampling rate at which preferences are assessed. The results revealed interesting developmental changes in prehension handedness that can only be identified when using monthly sampling intervals. We conclude that using non-linear multilevel models of infant handedness with monthly sampling intervals permit us to accurately capture the developmental changes in manual skills that occur during this period of infancy.

Keywords: handedness | prehension | infants | laterality | psychology | infant behavior | child development | child psychology

Article:

1. Introduction

Although some researchers argue that handedness cannot be identified until early childhood (Janssen, 2004), there is growing evidence to suggest that infant hand-use preferences for a skill such as prehension are relatively stable for a majority of infants during the age period of 7–13 months ((Michel et al., 2002 and Michel et al., 2006). Michel et al. (2006) demonstrated that infant prehension preferences (like adult handedness for skill) are distributed continuously from strongly left-handed to strongly right-handed and that patterns of variability tend to occur at the individual level. Variability in the use of a preferred hand after the acquisition of a skill such as prehension has also been noted in other longitudinal studies (Corbetta and Thelen, 1999, Fagard, 1998, McCormick and Maurer, 1988, Piek, 2002 and Thelen et al., 1996). However, the type of variability exhibited across studies is dependent upon the method used to assess handedness.

For example, Fagard and Lockman (2005) described differences in the choice of one particular hand or of a one-handed versus two-handed strategy during object grasping and exploration in children from 6 to 48 months of age. According to the authors, task constraints influence the expression of handedness. For reaching tasks that required precision grasping, the variability of hand-use decreased with the right hand clearly being preferred by a majority of the infants in each of three different age groups (6–12, 18–24, and 30–36 months). For objects that afforded several possible explorations, variability in the hand used for grasping increased across age groups. In addition, when grasping involved bimanual manipulation, hand-use preference emerged more clearly for 18- to 36-month-old infants.

Other studies report differences in the spatial and temporal characteristics of infant reaches. The number of peaks in the hand-speed profile of infants is argued to reflect the uncontrolled dynamics of the arms (Thelen et al., 1993) or the presence of multiple action or movement units (von Hofsten, 1991). According to von Hofsten, the number of peaks decreases with age, whereas Fetters and Todd (1987) found that the number of peaks is relatively stable with age. The patterns of variability identified in these studies reveal fluctuations in the characteristics of infant hand-use, yet they do not support the notion that handedness cannot be measured during infancy. What can be concluded from the disparate results of these studies is that the constraints of the task affect the expression of handedness. Furthermore, Berthier and Keen (2006) contend that although the studies provide dense longitudinal data, the number of infants in each sample is very low (Thelen reported data from 4 infants whereas von Hofsten used a sample of 5) thus limiting the ability to generalize from the results.

Rönnqvist and Domellöf (2006) assessed longitudinal (at the ages of 6, 9, 12, and 36 months) patterns of laterality for reaching using 2-D video recordings of unimanual reaches as well as 3-D kinematic measurements. Infants were presented with a series of six spherical objects (pegs were used at 36 months of age) at right, left, or midline position. Kinematic analyses revealed stable patterns of fewer movement units and straighter reaching trajectories for right-handed reaches. The right-side bias in reaching trajectory was observed for the majority of infants at all ages. The authors did not find a stable pattern of hand preference in regards to the frequency of right or left reaches prior to the age of 12 months.

Given the variability in methodologies and the limits of small sample sizes, it may not be surprising that the conventional conclusions about handedness during early development are that the trait is neither reliable nor stable until sometime between the very broad age range of 6–10 years (Janssen, 2004). However, infant handedness might be described as unstable and variable during infancy because of variation across studies in the sampling rates and types of skills being assessed as opposed to reflecting some underlying instability within individual infants. Moreover, the manner by which a hand-use preference is identified can affect its apparent stability. For example, a hand-use "preference" that is defined by a simple difference in use between the hands (Ramsay, 1980) may be less stable than a preference defined by statistical estimates of whether the intermanual differences are unlikely to have occurred by chance (Hinojosa et al., 2003 and Michel et al., 2002).

Longitudinal studies, such as the present study (i.e. assessments at monthly intervals from 6 to 14 months of age), may be used to identify trajectories in handedness development. Using statistical estimates of the reliability of the preference for each individual for each age permits identification of potential non-linear trajectories across individuals as opposed to "instability" of development as a characteristic of infancy.

Developmental trajectories are defined by patterns of change across time (Michel, 2001). In order to fully understand the mechanisms underlying hand-use preference, strong evidence is needed about the nature of the behavior's developmental pathway. As noted earlier, hand-use preferences in infancy are subject to large individual variability. Thus, the character of its trajectory may appear quite different depending on the point of development at which one examines the phenomenon. Indeed, Adolph, Robinson, Young, and Gill-Alvarez (2008) illustrated some of the fundamental problems in assessing a skill that develops throughout a protracted period. Critical features of developmental trajectories can be distorted if sampling occurs at large intervals. For example, fluctuations or important changes in the development of a motor skill may be obscured by sampling too infrequently thereby making the development of the skill appear to have a single, step-like transition. Moreover, as Michel (2001) argued, it is important to consider the minimum number of data points that would permit the identification of individual and group developmental trajectories that can be compared for type of pattern, direction of change, and rate of change.

Sampling at bi-monthly intervals, Michel et al. (2006) demonstrated that a majority of infants exhibit a consistent hand-use preference when reaching for and acquiring objects during the 7- to 13-month age period. Among those infants that exhibit a consistent preference, an overwhelming majority prefer to use the right-hand to acquire objects (~40%) whereas only a small proportion prefer to use the left hand to acquire objects (~17%). Of the infants that demonstrated a consistent hand-use preference, there appeared to be subgroups of infants that manifested different patterns of development. That is, some infants maintained a consistent hand-use preference during the period studied while others appeared to shift in preference (i.e. left-to-right, right-to-left). Unfortunately, the four data points collected in the study did not permit effective modeling of potential non-linear trajectories for handedness.

The aim of the current study was to address the developmental character of hand-use preferences from 6 to 14 months of age. We also attempted to expand on earlier work by increasing the number of infants assessed in addition to the number of data points collected. The additional data points permit analysis of potentially interesting non-linear trajectories and analysis of variability at the individual and group level for infant handedness. In addition, we assessed patterns of change using mixed modeling techniques for models in which the sampling interval was varied. That is, using the same sample of infants assessed monthly from 6 to 14 months of age, we varied the number of data points that were included in various statistical models. This technique was used to determine the effect of sampling rate on the appearance of variability in handedness status, the apparent character of its developmental trajectory, and the rate of change for hand-use preference. We predicted that assessment of hand-use preference for prehension at monthly intervals would demonstrate a consistent right bias in the distribution of preferences for our sample. In addition, we expected that a non-linear model using monthly sampling intervals would reveal developmental transitions that were not captured by a simple, linear model. That is, the pattern of a non-linear trajectory is more likely to accurately reflect changes in prehension handedness that occur during the 6- to 14-month age period.

2. Methods

2.1. Research participants

Eighty-five infants (45 male and 40 female) were recruited using birth records from the Guilford County Court House in North Carolina. Consistent with the surprisingly diverse population of Greensboro, we were able to recruit infants that represented a mix of ethnic backgrounds including Hispanic (both Central American and Island), African American, and Asian (particularly, Korean and Southeast Asian). The procedure for recruitment, obtaining informed consent, data collection and presentation was in accordance with the regulations set by the UNCG Institutional Review Board for the protection of human subjects.

All infants in the study were from uncomplicated deliveries and full-term pregnancies (at least 37 weeks gestation). Parents were asked to bring their babies to the lab within 7 days of the infant's birthday beginning at 6 months of age. Each infant was assessed once a month from 6 to 14 months of age. At the start of the study, infants were 6 months old (M = 6.02, SD = .14, or 4 days), and at the end of the study they were 14 months old (M = 14.05, SD = .15 or 4.5 days).

Parents received a $10 gift certificate as compensation for each of their visits to the laboratory.

2.2. Apparatus

Thirty-four common infant toys were used for the prehension handedness assessment. The toys selected for the study were brightly colored and easy to grasp. They contained features that produced noise or had movable parts that increased the likelihood that the infants would reach for them and engage in some form of exploration (see Michel, Ovrut, & Harkins, 1986 for a full description of these toys).

2.3. Procedure

During the assessment, infants were seated on their mothers' laps at navel height to a table. At this height, infants were able to have their arms completely above the table so that any reaches or limb movements were unconstrained. Mothers were asked to sit as close as possible to the table so that infants maintained a steady posture. The table was designed with a half moon cut-out for the mother and infant so that the table top extended around the infant. While infants were seated on their mothers' laps, a validated handedness assessment for prehension was administered (Michel et al., 1986). The test was administered to infants once a month from 6 to 14 months of age.

The assessment consisted of the separate presentations of 34 toys. In order to ensure that task constraints did not play a significant role in the hand used to acquire objects, the presentations involved a pseudo-random sequence of a variety of toys. Ten presentations involved pairs of identical toys, each presented in line with the infant's shoulders, either on the table (7 pairs) or in the air (3 pairs). During air-presentations, the presenter held the toys about 20 cm from the infants' shoulders and about 12–15 cm above the table. Twenty-four presentations involved a single toy presented in line with the infant's nose, either on the table (19 toys) or in the air (5 toys). By mixing the type of presentation for the infant (i.e. in the air or on table; single or double toys) and providing sufficient degrees of freedom in how the infant could respond to the task, the assessment is less likely to be influenced by biases that may occur as a result of constraints imposed by the task itself. That is, infants were less likely to acquire self-induced biases during the performance of the task. Given the unequal number of presentations, the current study did not analyze the effects of single versus double presentations and the occurrences of infants' hands crossing midline.

After each presentation and upon apprehending the object, infants were allowed to play with each toy for at least 15 s. Each toy was removed before the subsequent toy was presented. All of the infants received the same pseudo-random order of toy presentations that represented increasing complexity in the features of the toys and variability in the types of actions necessary for obtaining the toy. After every 3 presentations, or if infants' posture became biased such that they were slightly turned, the presenter tickled the palms of the infant and positioned them straight on the table to prevent any bias in reaching and to ensure continued activation of both hands.

Parents were instructed not to interfere with the assessment, and any presentations during which the parent became involved were excluded from data analysis. The complete assessment lasted about 15–20 min. In the few instances when infants began to cry or became fussy, a short break was taken so the infant could return to an alert/active state. In rare cases when the infant was inconsolable, the visit was rescheduled within a 5-day window.

All of the infants' manual actions were recorded using two Panasonic digital cameras connected to a Videonics mixer and recorded on a Panasonic DVD recorder. One camera was placed directly overhead and the other to the right of the infant, which permitted two different views of the presentations. The mixer and DVD recording provided split screen capability so that simultaneous recordings of the two camera feeds could be obtained. These recordings were transferred to a computer containing the Noldus Observer© software for coding video.

2.4. Data coding

The software program "Observer" (Noldus©) was used to code observations. The options on the program permitted precise millisecond coding of prehension and manipulation behaviors. The observations were viewed in real time and, when necessary, in slow motion by two coders, one primary coder and one reliability coder. Coders for reliability coded 25% of all the sessions. Reliability between the coders reached a minimum Cohen's Kappa of 92%. Coders were blind to the hand-preference status of the infants.

Coders determined the hand that made the initial contact and the hand that initially acquired the object. An initial acquisition was defined as the point at which infants' fingers closed around a feature, edge, or area on the toy in a grasp-like motion. In the event of bimanual reaches, the digital file was watched in frame-by-frame motion so that coders could determine the hand that made the initial grasp. For cases in which both hands attempted to acquire the object within a small time-interval, a distinction criterion of 250 ms was used to distinguish between a single-handed or dual-handed acquisition.

3. Results

Prehension preferences were examined for the entire 6- to 14-month age period to assess the stability of preferences during that period. Prehension preferences were also analyzed using different monthly intervals to examine the effect of sampling on the apparent rate and shape of developmental change. Table 1 indicates the number of infants from whom prehension data was observed for each of the 9 time points. For most of the time points, at least 82 infants provided data. The only exceptions were at 6 and 13 months of age where only 77 and 78 out of the 85 infants in the sample provided data. Table 1 also provides data for mean frequency of total acquisitions per age group. At each visit, every infant received all 34 presentations in the assessment. Because some infants did not reach for all of the toys, the average number of total unimanual acquisitions ranged from 24.19 at 6 months to 30.9 at 11 months. Bimanual acquisitions were excluded from the current analysis since they were relatively rare and they are more helpful in identification of the degree to which hand-use is lateralized rather than whether there is a reliable difference in use between the two hands. When infants did not grasp the object, the toy was removed and the subsequent toy was presented in order to avoid the infant becoming fussy.

Table 1. The number of infants who provided data for the mean number of acquisitions for each age.

Age (mos.)	Number of infants	Mean acquisitions (SD)
6	77	24.62 (5.61)
7	83	27.47 (4.88)
8	82	28.11 (4.48)
9	83	28.96 (4.29)

Age (mos.)	Number of infants	Mean acquisitions (SD)
10	83	29.83 (4.63)
11	82	30.90 (5.17)
12	82	30.01 (5.50)
13	78	30.12 (6.07)
14	85	29.02 (6.48)

A one-way repeated-measures analysis of variance was conducted to evaluate whether there was a change in the average number of acquisitions across the nine age groups. The ANOVA was significant, $F(8, 488) = 12.33$, $p < .001$. Follow-up polynomial contrasts indicated a significant linear effect $F(1, 61) = 32.57$, $p < .001$ and significant quadratic effect $F(1, 61) = 38.57$, $p < .001$. The quadratic trend suggests that the trajectory of the average number of acquisitions increases steadily until it peaks at 11 months of age, and then decreases from 11 to 14 months. The abrupt shift at 11 months indicates that the character of infant prehension may follow a non-linear profile.

3.1. Linear prehension handedness from 6 to 14 months

Individual growth modeling techniques were used to analyze the longitudinal data for infant prehension handedness. The proportion of right acquisitions at each age was calculated for each infant by dividing the frequency of right acquisitions by the total number of right and left acquisitions for that specific time point. The proportion of right reaches was modeled for each individual using SAS PROC MIXED, full maximum likelihood method. Multilevel models of change permit the simultaneous analyses of two research questions: (1) a Level 1 (within-person) question focused on how an individual's handedness for prehension changes over time and (2) a Level 2 (between-person) question focused on how individual changes in handedness for prehension vary across infants (Singer & Willett, 2003). Initial exploratory analyses indicated variations in the rates of change for individual trajectories.

First, a linear unconditional growth model that includes the passage of time (i.e. age) was proposed:

Level 1:	$PREHENSION_{ij} = \pi_{0i} + \pi_{1i}(AGE-6)_{ij} + \varepsilon_{ij}$
Level 2:	$\pi_{0i} = \gamma_{00} + \zeta_{0i}$
	$\pi_{1i} = \gamma_{10} + \zeta_{1i}$

In Level 1, $PREHENSION_{ij}$ represents the proportion of right acquisitions for child *i* at time *j*. Age is centered around 6 months. Such temporal recentering simplifies interpretation of the model's parameters (Singer & Willett, 2003). By centering infant age around 6 months, the individual growth parameters have the following interpretations: π_{0i} represents infant *i*'s true proportion of right-handed acquisitions at 6 months of age and π_{1i} represents infant *i*'s true instantaneous change in proportion of right acquisitions. The residual in level 1 of the model, ε_{ij}, represents that portion of infant *i*'s proportion of right acquisitions that is not predicted by his or her age.

The Level 2 (between-person) portion of the multilevel model for change used the individual growth parameters from the within-person (Level 1) submodel as outcomes and enabled us to determine whether infants vary in their initial status and how their hand-use preference for prehension changes during this time period. γ_{00} represents the population average true initial status (proportion of right acquisitions at 6 months); γ_{10} represents the average true rate of change in proportion of right acquisitions. The Level 2 submodel also contains stochastic components that allow the value of each infant's growth parameters to be scattered around the population averages. ζ_{0i} or ζ_{1i} represent those portions of the Level 2 outcomes that remained unexplained. The Level 1 and Level 2 submodels can be combined in the following form:

$$PREHENSION_{ij} = \gamma_{00} + \gamma_{10}(AGE-6)_{ij} + [\varepsilon_{ij} + \zeta_{0i} + \zeta_{1i}(AGE-6)_{ij}]$$

The model contains both fixed and random effects. The random components of the model are contained within the brackets. One advantage of the longitudinal model is that it permits unexplained portions of each infant's outcome to have unequal variances across occasions of measurements. A portion of the model's stochastic components (ζ_{1i}) is multiplied by the time parameter so that its magnitude can differ across occasions (Singer & Willett, 2003, p. 84). Table 2 displays the results of fitting the linear model to monthly data containing all nine time points.

Table 2. Parameter estimates for linear and quadratic models containing monthly data from 6 to 14 months.

	Parameter	Linear estimates	Quadratic estimates

		Parameter	Linear estimates	Quadratic estimates
Fixed effects				
$\pi_0 i$	Intercept	γ_{00}	$.59^{***}$	$.57^{***}$
$\pi_1 i$	(Age-6)	γ_{10}	.003	$.025^{*}$
$\pi_2 i$	$(\text{Age-6})^2$	γ_{20}		$-.0026^{*}$
Random effects				
Level-1:	Within-person	σ_g^2	$.032^{***}$	$.032^{***}$
Level-2:	Intercept	σ_0^2	$.006^{***}$	.006
	Linear term			
	Variance	σ_1^2	$.003^{***}$	0
	Covariance w/intercept	σ_{01}^2	0^{*}	0
	Quadratic term			
	Variance	σ_2^2		.001
	Covariance w/intercept	σ_{02}^2		0
	Covariance w/linear term	σ_{12}^2		0
Goodness-of-fit				
	AIC		−252.314	−341.874
	BIC		−206.315	−295.875

* $p < .05$.

*** $p < .001$.

The fixed effects, γ_{00} and γ_{10}, estimate the starting point and the slope of the population average change trajectory. Fig. 1 displays the average fitted growth trajectory based on the model. The figure demonstrates that the average infant shows a greater proportion of right acquisitions, with the proportion slowly increasing over the 6- to 14-month time period. We reject the null hypothesis for the intercept (*p* < .001), estimating that the average true change trajectory for PREHENSION has a non-zero intercept of .59 and a slope of .003 that is not significantly different from zero. Estimates for the random effects indicate that after accounting for the effects of age, significant variation exists at the individual level (σ_e^2). This is in accordance with the data presented in Michel et al. (2006).

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The linear model was applied to the sample using data from only bi-monthly intervals. Fig. 2 displays the average fitted growth trajectories for the different models. First, the model was applied to the sample using data only from 6, 8, 10, 12 and 14 months of age. Similar to the model described above, Fig. 2A demonstrates that the average infant shows a greater proportion of right acquisitions, with the proportion slowly increasing at a rate similar to the previous model, over the 6- to 14-month time period. We reject the null hypothesis for the intercept .59 (p < .001). The slope, .003, however, was not significantly different from zero.

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Next, we wanted to compare the effects of sampling four bi-monthly data points when varying the starting point (i.e. 6, 7, or 8 months). Table 3 presents the empirical results of fitting the models and Fig. 2 presents the average population trajectories for the four different models. As expected, data from the bi-monthly 8 to 14 months had a slightly higher intercept (.60, p < .001) than the bi-monthly 6 to 12 month data (.58, p < .001). Although it appears that the trajectory in Fig. 2B increases at a much lower rate than the trajectory in Fig. 2C, the slopes for both models were not significantly different from zero.

Table 3. Parameter estimates for linear models containing bi-monthly odd and even months.

		Parameter	A	B	C	D
Fixed effects						
$\pi_{0}i$	Intercept	γ_{00}	.589***	.581***	.598***	.575***
$\pi_{1}i$	(Age-6)	γ_{10}	.003	.006	.002	.015
Random effects						

		Parameter	A	B	C	D
Level-1:	Within-person	σ_e^2	.031***	.037***	.027***	.036***
Level-2:	Intercept	σ_0^2	.01*	0	.026*	.017*
	Variance	σ_1^2	0	0	0	0
	Covariance w/intercept	σ_{01}^2	−.001*	0	−.002	−.002
Goodness-of-fit						
	AIC		−184.473	−100.22	−168.848	−66.883
	BIC		−160.391	−77.537	−146.017	−45.802

Model A-6, 8, 10, 12, 14 mos.; Model B-6, 8, 10, 12 mos.; Model C-8, 10, 12, 14 mos.; Model D-7, 9, 11, 13 mos.

* $p < .05$.

*** $p < .001$.

The multilevel linear model was then applied to the data collected at 7, 9, 11, and 13 months of age. Fig. 2D displays the average fitted growth trajectory. Again, the figure demonstrates that the average infant shows a greater proportion of right acquisitions. We reject the null hypothesis for the intercept parameter (p < .001), estimating that the average true change trajectory for PREHENSION has a non-zero intercept of .58. Again, the slope was not significantly different from zero.

3.2. Non-linear prehension handedness from 6 to 14 months

As performed with the linear 6- to 14-month prehension data, mixed modeling techniques were used to analyze the longitudinal data for infant prehension handedness for 6–14 months as a non-linear function. The proportion of right acquisitions was modeled using SAS PROC MIXED, full maximum likelihood method. Initial inspection of the individual trajectories revealed a number of cases that appeared to be best captured by a quadratic function. In addition, the trend analysis conducted on the average number of total acquisitions for the group revealed a significant quadratic change. Fig. 3 shows an example of four individuals that demonstrate what appear to be non-linear developmental trajectories.

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The quadratic model representing prehension data for 6–14 months was:

Level-1:	$PREHENSION_{ij} = \pi_{0i} + \pi_{1i}(AGE\text{-}6)_{ij} + \pi_{2i}(AGE\text{-}6)_{ij}^2 + \varepsilon_{ij}$
Level 2:	$\pi_{0i} = \gamma_{00} + \zeta_{0i}$
	$\pi_{1i} = \gamma_{10} + \zeta_{1i}$
	$\pi_{2i} = \gamma_{20} + \zeta_{2i}$

The model introduces an additional “time” predictor, $(AGE\text{-}6)_{ij}^2$, that yields a second order polynomial for quadratic change. Thus, a constant linear slope does not define the rate of change. Instead, two parameters that define a quadratic function indicate how the trajectory changes over time. Table 2displays the results of fitting the model.

Fig. 4 displays the average fitted growth trajectory based on the model (parameters are provided in Table 2). The figure demonstrates that the average infant shows an increasing propensity to acquire objects with the right hand until about 11 months of age. Using the formula provided by Singer and Willett (2003, p. 215), we calculated that the trajectory's point of inflection is indeed at 11 months. Thus, from 11 months onwards there is a reduction in the average proportion of right-handed acquisitions.

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The quadratic model was also applied to the bi-monthly data from 6, 8, 10, 12 and 14 months of age, 6, 8, 10, and 12 months of age, the data from 8, 10, 12, and 14 months of age, and finally the data from 7, 9, 11, and 13 months of age (the results of fitting the model are provided in Table 4). Fig. 5 displays the average fitted growth trajectories for the respective models.

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Table 4. Parameter estimates for quadratic models containing bi-monthly odd and even months.

		Parameter	Age periods included in model			
			A	B	C	D
Fixed effects						
$\pi_0 i$	Intercept	γ_{00}	.573***	.572***	.582***	.547***
$\pi_1 i$	(Age-6)	γ_{10}	.017	.019	.037	.041
$\pi_2 i$	(Age-6)2	γ_{20}	−.002	−.002	−.003	−.004
Random effects						
Level-1:	Within-person	σ_e^2	.032***	.038***	.028***	0
Level-2:	Intercept	σ_0^2	.008	.002	.075***	.217***
	Linear term					
	Variance	σ_1^2	.001	0	.005	.139
	Covariance w/intercept	σ_{01}^2	−.001	0	−.02	−.156
	Quadratic term					
	Variance	σ_2^2	0	0	0	.003
	Covariance w/intercept	σ_{02}^2	0	0	.001	.023
	Covariance w/linear term	σ_{12}^2	0	0	0	−.022
Goodness-of-fit						
	AIC		−167.757	72.712	−64.605	−67.319
	BIC		−127.62	110.519	−26.554	−32.186

Model A-6, 8, 10, 12, 14 mos.; Model B-6, 8, 10, 12 mos.; Model C-8, 10, 12, 14 mos.; Model D-7, 9, 11, 13 mos.

*** $p < .001$.

As indicated in Table 4, only the intercepts were significantly different from zero, $p < .001$. The rate of change patterns did not differ significantly from zero for the four models. Thus, a quadratic trend of change in prehension is only observed when using monthly intervals for data collection. Moreover, the analysis of data using bi-monthly intervals (with even as well as odd months of age data points) leads to the false conclusion that there is no change in prehension during 6–14 months interval.

4. Discussion

The goal of the current study was to assess the developmental character of hand-use preferences for prehension during a period in which infant handedness has been described as unstable. Although there is considerable debate about the stability of handedness during infancy, reliable hand-use preferences can be identified with longitudinal measurement techniques that take into account task demands, postural constraints, and the motor skill repertoire of the infant (Michel et al., 2006). To our knowledge, this is the first study to longitudinally examine infant hand-use preferences for prehension at monthly intervals using a mixed-models approach. The advantage of this method is that it permits identification of potentially interesting trajectories that would otherwise go unnoticed when using statistical techniques that are not designed to account for longitudinal data. In addition, by assessing handedness monthly from 6 to 14 months of age, we were able to examine the effect of different bi-monthly sampling interval rates on the type of pattern and rate of change for these developmental trajectories.

The data support several conclusions. First, regardless of the sampling interval used or the functional form for trajectories, the results suggest that there is a distinctly significant right shift in the distribution of hand-use preferences for prehension. By 6 months, the average infant shows a greater proportion of right acquisitions and this proportion tends to be right-biased throughout the rest of the age period sampled. The right shift in the distribution is in accordance with results from Michel et al. (2006) that indicate the majority of infants exhibit a stable right hand preference for acquiring objects during the age range of 7–13 months. Thus, infants exhibit a right shift pattern in their prehension hand-use preferences that are similar to the adult and child right shift pattern in handedness (Annett, 1985).

A second conclusion supported by the results is that hand-use preferences for prehension seem to exhibit interesting shifts during the 6- to 14-month age period that might reflect developmental changes in manual skills. Applying linear models to bi-monthly data revealed average group trajectories that indicate infants show a greater probability to acquire objects with the right hand by 6 months. However, as indicated by the results of the parameter estimates for rates of change, the infants did not show any significant change over time. The results from the linear model using data from all nine ages also indicate that most infants tend to prefer to acquire objects with the right hand at 6 months, but the likelihood to acquire objects with the right hand continues to increase throughout infancy at a non-significant rate.

Unfortunately, application of a linear model gives the potentially false impression that the proportion of right acquisitions continues to increase at a monotonic, steady pace throughout development. However, based on previous results which suggest that there may be infants that demonstrate reliable changes in the propensity to acquire objects with the right or left hand (Michel et al., 2006) and visual inspection of the current data, we suspected that developmental change would be best captured by a non-linear trajectory. Thus, we applied quadratic models to the various sampling intervals from 6 to 14 months of age. As was the case for bi-monthly sampling intervals for linear models, the bi-monthly sampling intervals for the quadratic models did not reveal significant non-zero estimates for rates of change.

However, the quadratic model applied to the sample containing data from all nine age periods revealed a significant quadratic trajectory in which infants’ preference to acquire objects with the right hand increase until about 11 months. From 11 months on, there is a slight reduction in the proportion of right acquisitions. Thus, it is only when using a monthly sampling technique and accounting for the possibility of higher order functions for the age period from 6 to 14 months that a significant change pattern in the developmental trajectory of the average infant's hand-use preference for apprehending objects can be captured.

Interestingly, the shift or inflection point in the trajectory coincides with an age period in which role-differentiated bimanual skills begin to play a prominent role in the manual repertoire of the infant. Role-differentiated bimanual manipulation (RDBM) is a skill in which one hand stabilizes or holds an object while the opposite hand manipulates the features of an object. Previous studies have shown that infants will manifest a hand-use preference for RDBM with the majority of infants preferring to manipulate objects with the right hand while the left hand holds the objects (Kimmerle, Mick, & Michel, 1995). Also, at this age period, infants are typically shifting to bipedal locomotion and Corbetta and Bojczyk (2002) have proposed that such a shift would interfere with the expression of lateralized hand-use preferences.

Thus, there are two possibilities that might account for the drop in the average proportion of right acquisitions from 11 to 14 months in the current sample. In one, infants are beginning to coordinate their reaches in subordination with their hand-use preferences for RDBM. That is, infants that preferred to acquire objects with the right hand for the majority of the time period studied might begin acquiring objects with the left hand with greater frequency by 11 months so that they can begin immediate exploratory manipulation of the objects with the right hand during bimanual manipulations. Indeed, Kimmerle, Ferre, Kotwica, & Michel (2010) demonstrate that at 11 months infants begin to coordinate the sequence of events leading up to an expression of RDBM that indicates they are coordinating their actions in a way that reflects their hand-use preference.

The alternative possibility is that infants increase two-handed reaching when they are in the stage of active acquisition of walking skills; subsequently, the proportion of two-handed reaches would decline as walking develops and they gain better balance control. Corbetta and Thelen (2002) reported that arm coupling increases at the onset of independent upright locomotion around the end of the first year. This tendency to use both hands simultaneously is not specific to reaching preferences, but also applies to a considerable array of other motor tasks. Thus, the decline in right hand-use preference for reaching would be the consequence of an increased manifestation of bimanual symmetry induced by initiating an upright locomotion posture and gait.

It is also important to note that although there is a slight shift in the average proportion of right acquisitions, the majority of acquisitions are still performed with the right hand. Thus, there is no change in the stability of the preference, but rather there are developmental changes occurring as bimanual skills begin to play a larger role in the infant's exploration of objects.

The fitted models also provided information about individual variation. The parameter summarizing within-individual variance, $\sigma 2$, suggests that significant variation remains unexplained for individual infant trajectories. This is not surprising given that age has been described as a poor predictor of the state of the nervous system (Wohlwill, 1970). Future models would benefit from the inclusion of time-varying predictors that can be substituted for age at Level 1 of the model. For example, multilevel models might benefit from the inclusion of time-varying predictors that represent the development of gross motor skills in infancy since developmental changes in handedness appear to be related to developmental transitions from pre-sitting status to sitting, then to crawling, and eventually to the onset of walking (Corbetta and Thelen, 2002, Goldfield, 1993 and Rochat, 1992). These changes could be assessed monthly and may serve as better predictors of individual change than age alone.

Unfortunately, the data in our current sample revealed only three infants had a consistent pattern of left-handed preference for prehension. Thus, we cannot draw any concrete conclusion about the development of left hand-use preference from our model. This finding speaks to an important issue in studies of the development of infant hand-use: a relatively large sample of infants is needed to assess classes of hand-use preference. For example, if the intent of a researcher is to reveal different patterns of developmental trajectories for prehension or to determine the number of handedness classes (sub-populations) in a population based on a sample of subjects, a large number of subjects is needed (in addition to a large number of observations per subject). A minimal sample size of about 150 might be sufficient to reliably determine whether a 2-class or 3-class model of handedness fits the data best (c.f., Michel et al., 2002).

The present study provides growing evidence for the stability of hand-use preferences during infancy. It also demonstrates that to achieve an accurate representation of the type and shape of developmental change that is occurring, manual skills need to be assessed at least on a monthly basis using a large sample of infants. With the use of longitudinal techniques, sophisticated modeling of data, and careful assessment of different manual skills, we can begin to create a model of lateralization of motor skills during infancy that can be used to assess the development of other forms of lateralization for this developmental period.

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References

K.E. Adolph, S.R. Robinson, J.W. Young, F. Gill-Alvarez. What is the shape of developmental change? Psychological Review, 115 (2008), pp. 527–543

M. Annett. Left, right, hand and brain: The right shift theory. Lawrence Erlbaum Associates Ltd., Hove, UK (1985)

N.E. Berthier, R. Keen. Development of reaching in infancy. Experimental Brain Research, 169 (2006), pp. 507–518

D. Corbetta, K.E. Bojczyk. Infants return to two-handed reaching when they are learning to walk. Journal of Motor Behavior, 34 (1) (2002), pp. 83–95

D. Corbetta, E. Thelen. Lateral biases and fluctuations in infants' spontaneous arm movements and reaching. Developmental Psychobiology, 34 (1999), pp. 237–255

D. Corbetta, E. Thelen. Behavioral fluctuations and the development of manual asymmetries in infancy: Contributions of the dynamic systems approach. S.J. Segalowitz, I. Rapin (Eds.), Handbook of neuropsychology, Elsevier, New York (2002)

J. Fagard. Changes in grasping skills and the emergence of bimanual coordination during the first year of life. Clinics in Developmental Medicine, 147 (1998), pp. 123–143

J. Fagard, J.J. Lockman. The effect of task constraints on infants (bi)manual strategy for grasping and exploring objects. Infant Behavior and Development, 28 (2005), pp. 305–315

L. Fetters, J. Todd. Quantitative assessment of infant reaching movements. Journal of Motor Behavior, 19 (1987), pp. 147–166

E. Goldfield. Dynamic systems in development: Action systems. L.B. Smith, E. Thelen (Eds.), A dynamic systems approach to development: Applications, MIT Press, Cambridge, MA (1993), pp. 51–70

T. Hinojosa, C.F. Sheu, G.F. Michel. Infant hand-use preferences for grasping objects contributes to the development of a hand-use preference for manipulating objects. Developmental Psychobiology, 43 (2003), pp. 328–334

J.P. Janssen. Evaluation of empirical methods and methodological foundations of human left-handedness. Pereceptual and Motor Skills, 98 (2004), pp. 487–506

M. Kimmerle, L.A. Mick, G.F. Michel. Bimanual role-differentiated toy play during infancy

Infant Behavior and Development, 18 (1995), pp. 299–307

M. Kimmerle, C.L. Ferre, K.A. Kotwica, G.F. Michel. Development of role-differentiated bimanual manipulation during the infant's first year. Developmental Psychobiology, 52 (2010), pp. 168–180

C.M. McCormick, D.M. Maurer. Unimanual hand preferences in 6-month-olds: Consistency and relation to familial handedness

Infant Behavior and Development, 11 (1) (1988), pp. 21–29

G.F. Michel. Growth curve analyses are best suited to examine the relation between developmental pathways and selective breeding: Comment on Hofer, Shair, Masmela, & Brunelli, "Developmental effects of selective breeding for an infantile trait: The rat pup ultrasonic isolation call". Developmental Psychobiology, 39 (2001), pp. 247–250

G.F. Michel, M.A. Ovrut, D.A. Harkins. Hand-use preference for reaching and object manipulation in 6- through 13-month-old infants

Genetic, General, and Social Psychology Monographs, 111 (1986), pp. 407–429

G.F. Michel, C.F. Sheu, M.R. Brumley. Evidence of a right-shift factor affecting infant hand-use preferences from 7 to 11 months as revealed by latent class analysis. Developmental Psychobiology, 40 (2002), pp. 1–13

G.F. Michel, C.F. Sheu, A.N. Tyler, C.L. Ferre. The Manifestation of infant hand-use preferences when reaching for objects during the seven- to thirteen-month age period. Developmental Psychobiology, 48 (2006), pp. 436–443

J.P. Piek. The role of variability in early motor development. Infant Behavior and Development, 25 (2002), pp. 452–465

D.S. Ramsay. Beginnings of bimanual handedness and speech in infants. Infant Behavior and Development, 3 (1980), pp. 67–77

P. Rochat. Self-sitting and reaching in 5- to 8-month-old infants: The impact of posture and its development on early eye-hand coordination. Journal of Motor Behavior, 24 (1992), pp. 210–220

L. Rönnqvist, E. Domellöf. Quantitative assessment of right and left reaching movements in infants: A longitudinal study from 6 to 36 months. Developmental Psychobiology, 48 (6) (2006), pp. 444–459

J.D. Singer, J.B. Willett. Applied longitudinal data analysis: Modeling change and event occurrence. Oxford University Press, Oxford, England (2003)

E. Thelen, D. Corbetta, K. Kamm, J.P. Spencer, K. Schneider, R.F. Zernicke. The transition to reaching: Mapping intention and intrinsic dynamics. Child Development, 64 (1993), pp. 1058–1098

E. Thelen, D. Corbetta, J.P. Spencer. Development of reaching during the first year: Role of movement speed. Journal of Experimental Psychology: Human Perception and Performance, 22 (1996), pp. 1059–1076

C. von Hofsten. Structuring of early reaching movements: A longitudinal study. Journal of Motor Behavior, 23 (1991), pp. 280–292

J.F. Wohlwill. The age variable in psychological research. Psychological Review, 77 (1) (1970), pp. 49–64