Development of Role-Differentiated Bimanual Manipulation in Infancy: Part 2. Hand Preferences for Object Acquisition and RDBM—Continuity or Discontinuity?

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Abstract:

This second paper in a series of three investigated the development of hand preference for role-differentiated bimanual manipulation (RDBM) relative to the infant's hand preference for object acquisition and to the infant's hand-use for acquiring the objects used to assess RDBM. The same 90 infants (30 with a right preference, 30 with a left preference, and 30 with no preference to acquire objects) from the first paper were tested from 9 to14 months for hand preference for acquiring those objects used to assess RDBM and for a hand preference for RDBM. Multilevel analysis revealed that infants with a hand preference for acquiring objects decreased in their use of the preferred hand for object acquisition during the 11 to 14 month interval, which coincided with the development of a hand preference for RDBM. These results are discussed in relation to the cascade theory of hand preference development. © 2015 Wiley Periodicals, Inc. Dev Psychobiol 58:257–267, 2016.

Keywords: bimanual manipulation | reaching | hand preference | development | infancy

Article:

Introduction

This second paper, in the series of three, relates the development of hand preference for role-differentiated bimanual manipulation (RDBM) to patterns of hand preference for object acquisition. Based on the cascade theory of hand preference development (Michel, 1983,1988, 1998, 2002) described in detail in Paper 1 (Babik & Michel, this issue), there ought to be a continuity in the development of hand preference for different manual skills, so that early developing hand preference for object acquisition would be related to later developing hand preference for RDBM.

Although Fagard noted in 1998 that "the relationship between unimanual handedness and bimanual role-differentiation is not yet known" (p. 124), that relation-ship is still relatively unexplored 17 years later. There is little consensus about the relation (continuity or discontinuity) between the hand preference for reaching/acquisition and hand preference for

RDBM. Some researchers observed a significant relation between hand preference for reaching and hand preference for RDBM (e.g., Ramsay, 1980), others reported no relation (e.g., Fagard & Marks, 2000; Michel, Ovrut, & Harkins, 1985). The reported lack of consensus about continuity versus discontinuity in the developing hand preference for different manual skills might stem from differences in research methodologies and statistical analyses used by different researchers. Some researchers also emphasized that the question of continuity versus discontinuity cannot be answered without longitudinal designs, since the pattern of relation between the reaching and RDBM hand preference would depend on the stage of manual skill development (Ferre, Babik, & Michel, 2010; Michelet al., 1985). Others pointed out that continuity or discontinuity of hand preference from reaching to RDBM would depend on the type of reaching used for analysis, investigating both "simple" reaching for objects (usually tested in a separate unimanual procedure) and reaching that directly results in RDBM(Cornwell, Harris, & Fitzgerald, 1991; Fagard &Lockman, 2005; Michel, 1983).

Continuity of Discontinuity: The Role of Research Methodologies and Statistical Analyses

Ramsay (1980) claimed to have demonstrated the transition of hand-use preferences from the unimanual contact to RDBM by finding that bimanual hand preference identified at the age of 13 months corresponded with the unimanual hand preference observed at the ages 7 and9 months in 23 out of 28 infants (in 18 out of 22 (82%)right-handers and in five out of six (83%) left-handers) tested during play with 10 toys. It should be noted that Ramsay assigned a unimanual hand preference to infants based on their performance during the first session, arguing that a unimanual hand preference is present (and presumably stable) at the age of about 6.6 months (mean age of infants entering the study), which contradicted the majority of previous and subsequent research (e.g., Carlson & Harris, 1985; Connolly & Elliott, 1972;Corbetta & Thelen, 1999, 2002; Fagard, 1998; Fennell, Satz, & Morris, 1983; Gesell & Ames, 1947; Ingram,1975; McCormick &Maurer, 1988; McManus et al.,1988; Thelen, Corbetta, & Spencer, 1996). Also, hand preference of the infants was considered right if the infant performed more than 50% of toy contacts with this hand. This classification criterion was very different from those used by other researchers (e.g., Fagard &Lockman, 2005; Fagard & Marks, 2000; Michel et al.,1985) and was very unlikely to result in a classification that is statistically reliable.

In contrast to Ramsay (1980), Michel et al. (1985) found that hand preference for bimanual coordinated actions (i.e., RDBM) during toy play at 13 months was not related to hand preference for reaching. They assessed hand preference for RDBM in 96 infants during play with a set of 21 different toys, some presented twice, which resulted in 28 presentations. To define a hand-use preference status of infants, Michelet al. (1985) first calculated z-scores using the following formula: $z = (R–L)/(R\text{þ}L)^{1/2}$, where R and L were the number of right- and left-handed actions; then converted the obtained z-scores into categorical hand preference status using $z = \pm 1.65$ as a cut-off point ($\alpha = .0495$). Thus, $z > +1.65$ was assumed to indicate right-hand preference at a particular age, $z < –1.65$indicated left preference, and the rest of the observations were considered to show no distinct hand-use preference.

Similar to Michel et al. (1985), Fagard and Marks (2000) did not find a significant correlation between hand preference for unimanual reaching and that of bimanual manipulation. They tested, cross-sectionally, 40 toddlers aged 18, 24, 30, and 36 months (n = 10 in each age group) for unimanual reaching using five objects (10 trials), and for bimanual manipulation using six objects (12 trials), all objects being presented twice in random order. Similar to Michel et al.

(1985), Fagard and Marks (2000) transformed raw binomial right and left-hand use scores into z-scores. However, for classification of infants into categorical status of right-, left-, or no hand-use preference for both unimanual and bimanual tasks, Fagard and Marks (2000) used the decision criterion of z = ±1.0. However, compared to the criterion of z =±1.65 used by other researchers (e.g., Hinojosa, Sheu, & Michel, 2003; Michel et al.,1985), z =±1.0 is more likely to underestimate the number of infants without a distinct hand preferenceand over-estimate the number of lateralized infants (both right- and left-handers).

Therefore, when Fagard and Marks (2000) assigned a handedness status to toddlers using the 10 trials for unimanual hand preference assessment, an infant would be categorized as right preferring if in at least seven trials the right hand was used (z = 1.26). Unfortunately, seven trials of 10 trials would not reflect a statistically reliable hand-use preference classification (p =.117, binomial probability distribution, Mendenhall, Beaver, and Beaver (2013)). Similarly, while classifying the bimanual hand preference, Fagard and Marks (2000) required at least eight right-hand actions of 12 item manipulations before assigning an infant to the right preference group using the criterion of z =±1, resulting in z = 1.15 and, again, this was a statisticallyunreliable classification of a hand-use preference (p = .121, binomial probability distribution). Although Fagard and Marks (2000) did not find a significant correlation between classified hand preference for unimanual reaching and hand preference of bimanual manipulation, their classification criteria was not statistically reliable.

Thus, disagreement about whether there is continuity or discontinuity in the development of hand preferences across manual skills could be attributed to differences in research methodologies and statistical analyses used by researchers. Moreover, the studies of Fagard and Marks (2000), Michel et al. (1985), and Ramsay (1980) used a cross-sectional design rather than a longitudinal design. Therefore, these results do not inform us about the individual developmental trajectories of hand preference for each skill and relations among those trajectories. This leaves the question of continuity versus discontinuity in the development of hand preference unanswered.

Continuity of Discontinuity: Taking a Longitudinal Perspective

Some researchers emphasized that the question of continuity vs. discontinuity between hand preference for reaching/acquisition and hand preference for RDBM cannot be answered without a longitudinal perspective (Ferre et al., 2010; Michel et al., 1985). Tracking the relation between hand preference for acquiring objects and hand preference for RDBM across time, Michel et al. (1985) reported that infant son average reduced their right-hand preference for acquisition at the age of 13 months. During 9 to12 month period, hand preference for acquisition and RDBM were almost always concordant, whereas at13 months hand-use preferences for those two skills were often discordant. Therefore, Michel et al. (1985) proposed that infants at 13 months might have different hand preference statuses for different manual skills. Ferre et al. (2010) came to the similar conclusion that hand preference for acquiring objects increases with age from 6 to 11 months, and decreases thereafter. They suggested that this trend might be explained by the developing hand preference for another skill that infants master during this time–RDBM.

Some researchers previously suggested that as RDBM is being mastered, infants might start “planning” their actions, and would reach to acquire objects with the non-preferred hand in order to stabilize them and “set-up” the “intentional” and “planned” role-differentiated bimanual

manipulation by the preferred hand (e.g., Babik, Campbell, & Michel, 2014; Fagard & Pezé, 1997; Ferre et al., 2010; Goldfield & Michel,1986; Kimmerle, Ferre, Kotwica, & Michel, 2010; Michel et al., 1985). Kimmerle et al. (2010) defined the "intentionality" as "an intention to engage in RDBM actions ... identified by evidence of a nonrandom pattern in the sequence of actions preceding the RDBM action" (p. 170). Thus, one might hypothesize a decrease in the hand preference for object acquisition at the age when the skill of RDBM gets mastered. In other words, hand preference for acquiring objects before the age of 12–13 months might be a better predictor of the hand preference for RDBM than after 12 months. However, this hypothesis needs further testing.

Continuity or Discontinuity: Can We Infer "Intionality" Using Different Types of Reaching?

If infants are "planning" their intermanual activity at the end of their first year of life (e.g., Babik et al.,2014; Fagard & Pezé, 1997; Ferre et al., 2010;Goldfield & Michel, 1986), they might reach for and acquire toys differently depending on the properties, or affordances, of the toys (Kimmerle et al., 2010). For instance, the infant might reach to acquire a single-part toy, which does not readily afford bimanual manipulation, with the preferred hand, whereas the same infant might reach to acquire a multiple-part toy, which affords and encourages bimanual manipulation, with the non-preferred hand in anticipation of using the preferred hand for active manipulation. This understanding of object affordances and "intentionality" of actions was predicted to begin after the age of about12–13 months, when the skill of RDBM becomes mastered (Kimmerle et al., 2010). If so, then it could be predicted that there would be no differences in the hand preference for reaching/acquisition for both toys affording and toys not affording manipulation in infants before 11–12 months, but significant differences after this age. It could be predicted, also, that the relation between a hand preference for reaching/acquisition of toys not affording manipulation (i.e., "simple" toys) and hand preference for acquisition of toys affording RDBM (i.e., "complex" toys) would increase until the age of 11–12 months, and decrease thereafter. Testing this notion would require investigation of hand preferences for both types of reaching/object acquisition.

Previous research provided contradicting evidence about the relation among hand preferences for different types of reaching and RDBM. For instance, Cornwellet al. (1991) studied hand preference for unimanual reaching (five objects, up to 48 trials) and bimanual manipulation (four objects, four trials) in a cross-sectional sample of 63 female infants ages 9 to20 months. They coded the reaching hand for both the unimanual and bimanual tasks and observed that in bimanual tasks, 9-month-old infants tended to grab an object with one or two hands, and mouth it instead of manipulating. In contrast, 13-month-olds would reach for an object and then transfer it to the other hand in order to use the same hand for both the reaching and the active manipulation. At 20-months, toddlers would perform bimanual reaches, followed immediately by RDBM actions.

Exploring the continuity/discontinuity between hand preferences for different tasks, Cornwell et al. (1991) found no significant relations between hand preference for reaching in the unimanual task and that in the bimanual task for any age group. Only for 9-month-olds, hand preference in the unimanual task positively correlated with the manipulation hand preference (Cornwell et al., 1991). It should be noted that the preponderance of non-significant results could stem from the small sample of trials (only four) used in the bimanual manipulation task.

The question was investigated further by Fagard and Lockman (2005), who tested and related hand preference for "simple" reaching, hand preference for reaching leading to RDBM, and hand preference for RDBM. Using a cross-sectional design, they reported that 18 to36-month-old children (n ¼ 126) manifested stronger hand preference for reaching which was followed by the bimanual manipulation, suggesting that increased task demands decrease the variability of the reaching hand preference. However, the researchers did not compare hand preference of infants across tasks, rather they commented only on the consistency of hand preference of each age group for different tasks. Of course, the researchers could not track longitudinal trajectories of hand preference across different tasks. In contrast, the current study used a longitudinal design to investigate the relation between the hand preference for "simple" reaching in a unimanual task, the hand preference for reaching leading to RDBM in a bimanual task, and the hand preference for RDBM, while using a large number of participants and trials to provide statistically reliable estimates of a preference.

Continuity of Discontinuity: Current Hypotheses

For this study, we hypothesized that infants would increase their hand preference for object acquisition during 6 to 12–13 month interval (before RDBM begins to become a larger component of the infants' manual repertoire and infants start manifesting a hand-use preference for RDBM) and decrease there-after when object acquisition hand preference may become subordinate to the hand-use preference for RDBM. Infants with a right preference would be expected to decrease their right-hand preference, whereas those preferring the left hand would be expected to decrease in their left-hand preference for object acquisition at the age of approximately 12–13 months. The strength of relation between hand preference for acquisition of "simple" toys that do not afford manipulation and hand preference for acquisition of "complex" toys affording RDBM was predicted to increase until the age of 12–1 3 months, and decrease thereafter. Finally, the development of hand-use preference for RDBM would be examined not only in relation to the developing hand preference for object acquisition in a unimanual procedure, but also to the development of the hand preference for reaching in a bimanual procedure that affords RDBM.

Methods

Participants

The same 90 participants as in Babik & Michel (Paper 1, this issue) were used in this study.

Procedure

In this paper, we clearly differentiated between the unimanual procedure that tested infants' object acquisition hand preferences using a set of 34 single-part toys and the bimanual procedure that tested both object acquisition and RDBM hand preferences using a different set of 20 multiple-part toys. For each monthly visit, we recorded each infant's: 1) hand choice for object acquisition (right, left, or both) in the unimanual procedure; 2) hand choice for object acquisition (right, left, or both) in the bimanual procedure; and 3) hand choice (right or left) for RDBM. For

additional details on this study's procedure and measures, see methods in Babik & Michel(Part I, this issue).

Measures

Hand preference for acquisition in the unimanual procedure, hand preference for acquisition in the bimanual procedure, and RDBM hand preference were estimated to explore the relation between the three longitudinally assessed measures. Preferences were identified using the Handedness Index described in paper 1. Since our unimanual and bimanual procedures involved separate sets of toys having different affordances (single-part toys for acquisition in the unimanual procedure, and multiple-part toys affording RDBM in the bimanual procedure), we had an opportunity to explore the contribution of "intentionality" in infants' manual activity by studying a change in the strength of relation between acquisition hand preference in the unimanual and bimanual procedures before and after the age of 12–13 months.

Results

Development of Hand Preference for Object Acquisition (Unimanual Procedure)

The age-related change in the hand-use preference for object acquisition was analyzed using the multilevel analysis to test the hypothesis that infants would increase in their hand preference during 6 to 12 month interval and decrease thereafter. The multilevel analysis revealed significant quadratic trends of change in all infants (Table 1, Model 1 and Fig. 1). Inspection of Figure 1 shows that infants with a right-hand preference increased their right-hand preference during the period from 6 to 11 months and decreased thereafter, whereas those with a left-hand preference increased their left-hand use until the age of 11 months and slightly decreased thereafter. Infants initially without a stable hand-use preference increased their right-hand use during the entire 6–14month interval, but their rate of change increased after 11 months.

Development of Hand Preference for Object Acquisition (Bimanual Procedure)

Are the developmental trajectories of change in hand preference for acquisition in the unimanual procedure different from those in the bimanual procedure? The multilevel analysis of the data from the bimanual procedure revealed a significant linear trend (not quadratic and not cubic) of change with significant differences in trajectories between infants with different hand preferences (Table 2 and Fig. 2). Whereas left-hand preferring infants trended toward using more left-hand use, both right-hand preferring infants and those without a distinct hand preference for object acquisition trended towards more right-hand use with age. This pattern of change in hand preference differed from what we observed for acquisition hand preference in the unimanual procedure. The non-significant quadratic trend of change might be explained by the decrease in the number of data points from nine monthly observations to six in the bimanual procedure. When we analyzed only 9 to 14 month acquisition data (six data points) for the unimanual procedure, we did observe only the linear trend of change in hand preference (Table 1, Model 2).

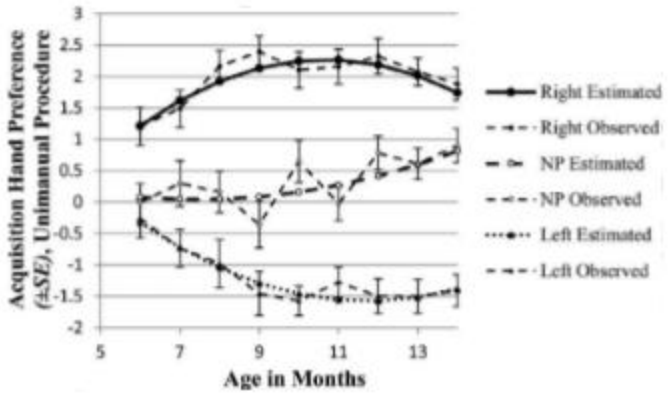

Figure 1. Observed (Mean and SE) and estimated trajectories of object acquisition hand preference in the unimanual procedure for infants with different hand preference; NP = no preference.

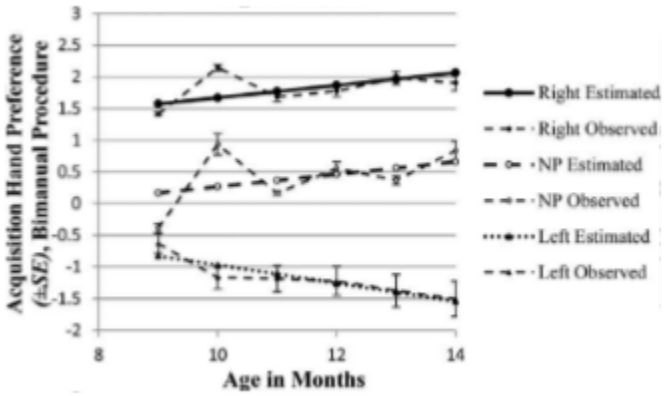

Figure 2. Observed (Mean and SE) and estimated trajectories of object acquisition hand preference in the bimanual procedure in infants with different hand preference; NP= no preference.

Table 1. Estimated Fixed and Random Effects for Acquisition Hand Preference in the Unimanual Procedure

Level 1 Effects	Level 2 Effects	Parameters	Model 1	Model 2
		Fixed Effects		
Initial Status, π_{0i}	Intercept	β_{00}	−3.216	2.437***
	HS1	β_{01}	6.876***	−3.594***
	HS2	β_{02}	4.254	−5.079***
AGE, π_{1i}	Intercept	β_{10}	1.026**	−.026
	HS1	β_{11}	−1.918***	–
	HS2	β_{12}	−1.294**	.282***
$(AGE)^2$, π_{2i}	Intercept	β_{20}	−.048**	–
	HS1	β_{21}	.086***	–
	HS2	β_{22}	.066**	–
		Random Effects		
Level 1:	Within-Person, ε_{ij}	σ_ε^2	2.394	–
Level 2:	Intercept, δ_{0i}	σ_0^2	1.743**	–
	AGE, δ_{1i}	σ_1^2	.017**	–

Note: $^{**}p < .01$. $^{***}p < .001$.

Table 2. Estimated Fixed and Random Effects for Acquisition Hand Preference in the Bimanual Procedure

Level 1 Effects	Level 2 Effects	Parameters	Model Estimates
	Fixed Effects		
Initial Status, π_{0i}	Intercept	β_{00}	.690
	HS1	β_{01}	−.230
	HS2	β_{02}	−1.404***
AGE, π_{1i}	Intercept	β_{10}	.098
	HS1	β_{11}	−.241**
	Random Effects		
Level 1:	Within-person, ε_{ij}	σ_ε^2	2.413
Level 2:	Intercept, δ_{0i}	σ_0^2	.380***

Note: $^{**}p < .01$. $^{***}p < .001$.

Table 3. Estimated Fixed and Random Effects for Acquisition Hand Preference in the Bimanual Procedure in Relation to Acquisition Hand Preference in the Unimanual Procedure.

Level 1 Effects	Level 2 Effects	Parameters	Model Estimates
	Fixed Effects		
Initial Status, π_{0i}	Intercept	β_{00}	.072
UNI_ACQ, π_{1i}	Intercept	β_{10}	.733***
	Random Effects		
Level 1:	Within-person, ε_{ij}	σ_ε^2	1.507
Level 2:	Intercept, δ_{0i}	σ_0^2	.193***

Note: $^{**}p < .01$. $^{***}p < .001$. UNI_ACQ – hand preference for acquisition in the unimanual procedure.

Hand Preference for Acquisition – Unimanual Versus Bimanual Procedure

Next, we related patterns of development of hand preference for object acquisition in the bimanual procedure to developmental patterns of hand preference for object acquisition in the unimanual procedure. The multilevel analysis showed a significant positive relation between the two measures (Table 3, Fig. 3). Thus, an increase in right-hand preference for acquisition in the

unimanual procedure was significantly associated with an increase in right-hand preference for acquisition in the bimanual procedure. Also, an increase in left-hand preference for acquisition in the unimanual procedure was significantly associated with an increase in left-hand preference for acquisition in the bimanual procedure. It should be noted that higher HI-scores for acquisition hand preference obtained in the unimanual procedure as compared to lower HI-scores of corresponding hand preference for acquisition estimated in the bimanual procedure do not mean that the former hand preference is stronger than the latter; it only means that we can be more confident about the acquisition hand preference originating from the unimanual procedure which is not surprising since it consisted of more opportunities (items) for using a hand. By testing infants for acquisition hand preference in two procedures consisting of separate sets of toys with different affordances (single-part toys for "simple" reaching in the unimanual procedure, and multiple-part toys affording RDBM in the bimanual procedure), we could determine whether infants change their hand-use for acquisition depending on affordances of toys. The strength of relation between hand preference for acquisition of toys that do not afford manipulation and hand preference for acquisition of toys affording RDBM was predicted to increase until the age of12–13 months, and decrease thereafter.

We correlated monthly hand preferences for acquisition in the unimanual procedure and hand preferences for acquisition in the bimanual procedure, and plotted them while adding a trend-line with its equation (Fig. 4). Statistical significance for all six reported Pearson correlation values reached $p < .0001$. Figure 4allowed us to suggest that the average strength of the relation between the hand preference for acquisition coming from the two procedures increased until about the age of 11–12 months (as estimated by the trend-line), and decreased thereafter. Thus, it is likely that after the age of 11–12 months, infants start adjusting their hand-use according to the anticipated affordances of toys. This adjustment would be observed in acquisition patterns for multiple-part toys rather than single-part toys. This might be the source of differences in patterns of hand preference for acquisition obtained in the unimanual vs. bimanual procedure.

Hand Preference from Acquisition to RDBM – Continuity or Discontinuity

Is the development of a hand-use preference for RDBM predicted by the developing hand preference for object acquisition in a unimanual task and/or the development of the hand preference for acquisition preceding RDBM in a bimanual task? First, we related patterns of development of hand preference for object acquisition in the unimanual procedure to developmental patterns of RDBM hand preference. The multilevel analysis revealed that hand preference for object acquisition did not significantly predict hand preference for "simple" RDBM (Table 4, Model 1), but it did predict hand preference for "difficult" RDBM (Table 4, Model 2).The estimated trajectory of hand preference for "difficult" RDBM in relation to the acquisition hand preference in the unimanual procedure is illustrated in Figure 5.

Second, we related patterns of development of hand preference for object acquisition in the bimanual procedure to developmental patterns of RDBM hand preference. The multilevel analysis revealed that hand preference for object acquisition did not significantly predict hand preference for "simple" RDBM (Table 5, Model 1), but it did predict hand preference for "difficult" RDBM (Table 5, Model 2). The estimated trajectory of hand preference for "difficult" RDBM in relation to the acquisition hand preference in the bimanual procedure is illustrated in Figure 5. Thus, in both unimanual and bimanual procedures, hand preference for object

acquisition was found to be positively related to hand preference for “difficult” (but not “simple”) RDBM.

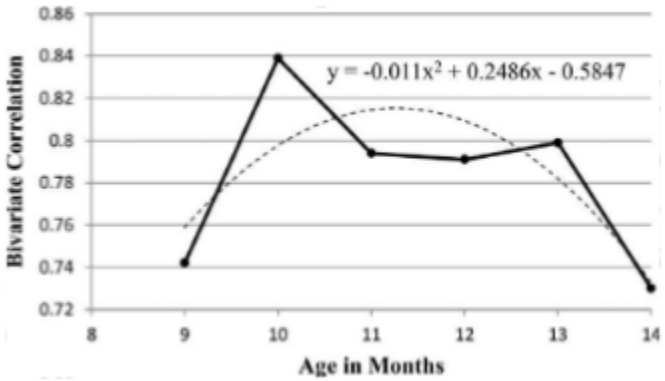

Figure 4. Plotted bivariate correlations between monthly hand preferences for acquisition in the unimanual procedure and hand preferences for acquisition in the bimanual procedure; added trend-line with its equation

Table 4. Estimated Fixed and Random Effects for RDBM Hand Preference in Relation to the Acquisition Hand Preference in the Unimanual Procedure (“Simple” RDBM – Model 1, “Difficult” RDBM – Model 2)

Level 1 Effects	Level 2 Effects	Parameters	Model 1	Model 2
		Fixed Effects		
Initial Status, π_{0i}	Intercept	β_{00}	.779***	.926***
UNI_ACQ, π_{1i}	Intercept	β_{10}	−.019	.091*
		Random Effects		
Level 1:	Within-person, ε_{ij}	σ_ε^2	1.891	1.890
Level 2:	Intercept, δ_{0i}	σ_0^2	.835***	1.214***

Note: $^*p < .05$. $^{***}p \leq .001$. UNI_ACQ – hand preference for acquisition in the unimanual procedure.

Table 5. Estimated Fixed and Random Effects for RDBM Hand Preference in Relation to the Acquisition Hand Preference in the Bimanual Procedure (“Simple” RDBM – Model 1, “Difficult” RDBM – Model 2)

Level 1 Effects	Level 2 Effects	Parameters	Model 1	Model 2
		Fixed Effects		
Initial status, π_{0i}	Intercept	β_{00}	.760***	.932***
BIM_ACQ, π_{1i}	Intercept	β_{10}	.033	.077*
		Random Effects		
Level 1:	Within-person, ε_{ij}	σ_ε^2	1.897	1.896
Level 2:	Intercept, δ_{0i}	σ_0^2	.807***	1.218

Note: $^*p < .05$. $^{***}p \leq .001$. BIM_ACQ – hand preference for acquisition in the bimanual procedure.

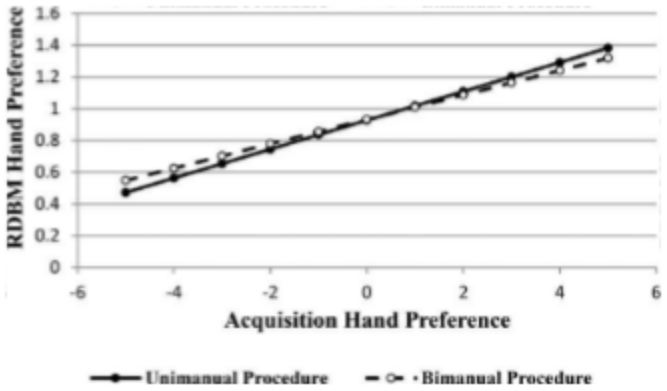

Figure 5. Estimated trajectory of RDBM hand preference in relation to the acquisition hand preference in the unimanual procedure and to the acquisition hand preference in the bimanual procedure

Discussion

The goal of the current study was to examine the development of hand preference for role-differentiated bimanual manipulation (RDBM) in relation to the developing hand preference for acquiring objects in a unimanual procedure (using sing le-part toys) and to the hand preference for acquiring objects in the bimanual procedure (using multiple-part toys). For the current study, we identified the three groups of infants with hand-use preferences (left-, right-, and no hand preference) based on their latent classes derived from the trajectories of their development of a hand-use preference for object acquisition assessed monthly from 6 to14 months. Then, the trajectories of hand preference development for each of these three initial hand preference groups were examined separately for object acquisition in the unimanual versus the bimanual procedure. Finally, relations among the developmental trajectories of change in hand preference for object acquisition in both unimanual and bimanual procedures, and RDBM were explored.

Michel et al. (1985) reported that infants reduced their right-hand preference for acquiring objects by the age of 13 months. Also, Ferre et al. (2010) showed an increase in infants' right-hand preference for object acquisition during 6–11 month interval and a decrease thereafter. Thus, in the current study, infants were predicted to increase in their lateralization of object acquisition hand preference during 6 to 12–13 month interval and decrease thereafter. Multilevel analysis of change in the development of hand preference for object acquisition with age showed that right- and left-hand preferring infants increased in their hand preference for object acquisition during 6 to11 month interval and decreased thereafter, confirming our hypothesis and previous reports (Ferre et al.,2010; Michel et al., 1985). Infants without a stable hand-use preference were found to increase in their hand preference for object acquisition during 6–14month interval, but with a steeper increase in lateralization after the age of approximately 10–11months.

Different results were obtained for acquisition hand preference assessed with the bimanual procedure. For example, right-hand preferring infants decreased their right preference for acquisition of "simple" toys after the age of 11 months, whereas this trend was not observed in acquisition of "complex" toys. Why would different sets of toys elicit somewhat different develop-mental patterns of acquisition hand-use in infants?

Previous research suggested that as RDBM is being mastered, infants might start acquiring objects with the non-preferred hand "anticipating" the need to use the preferred hand for active manipulation (e.g., Babiket al., 2014; Fagard & Pezé, 1997; Ferre et al., 2010; Goldfield & Michel, 1986). This "anticipation" was predicted to develop at the age of 12–13 months when infants begin to master the skill of RDBM and develop hand preference for RDBM. We predicted that before12–13 months, infants would not adjust their hand-use for acquisition according to the properties of toys. Therefore, we expected that the strength of relation between hand preference for acquisition of toys that do not afford manipulation and hand preference for acquisition of toys affording RDBM might increase until the age of 12–13 months, and decrease thereafter. We found that this change happens sooner than predicted—at the age of 11–12 months. Correlations between hand preferences for acquisition assessed with the unimanual and bimanual procedures increased until the age of 11–12 months, possibly indicating that as the skill of acquisition is being mastered, hand preference for it becomes more distinct; but the same correlation decreased after the age of 11–12 months consistent with the suggestion that infants start discerning RDBM affordances of objects and adjust their manual activity, accordingly.

Furthermore, the decrease in the hand preference for object acquisition was predicted to relate to a significant shift towards greater lateralization of hand preference for RDBM. We demonstrated in this study that this decrease in hand preference for acquisition happened at the age of about 11 months, and we showed elsewhere (Michel & Babik, Part 1, this issue) that a significant increase in the proportion of infants lateralized for RDBM occurred on average at 11 months for "simple" RDBMs, and at 13 months for "difficult" RDBMs. Therefore, it is likely that the change in object acquisition hand preference is related to the development of hand preference for "simple", but not for "difficult" RDBMs.

We also found that hand preference for object acquisition (measured in either unimanual or bimanual procedure) was positively related to a hand preference for "difficult" (but not "simple") RDBM. Although the hand preference for acquisition of multiple-part toys and hand preference for RDBM could be confounded (because they are assessed in the same procedure), the same results were obtained with hand preferences for acquisition in unimanual and bimanual procedures and that can be considered as evidence against such confounding. A similar relation between a hand preference for object acquisition during 6–14 month age period and hand preference for role-differentiated bimanual manipulation during 18–24 month age period was shown by Nelson, Campbell, and Michel (2013). They reported that 93% of infants exhibiting right-hand preference for reaching during 6 to 14 month period, manifested right-hand preference for RDBM during 18to 24 month period. The current study adds the influence of a left-hand preference to this relation, although it is restricted to the 9–14 month age period.

Current results are in accord with the cascade theory of hand preference development which proposes that the development of hand-use preferences during in-fancy represents a cascade of hand preference across the development of different manual skills, each with its own time line, with hand preference in earlier developing skills concatenating into hand preference in later developing skills (Michel, 1983, 1988, 1998,2002). Such evidence is not consistent with the notion that a hand-use preference that develops in each new skill is derived from some underlying "unchanging" hemispheric specialization (e.g., Kinsbourne, 1975,1981; Witelson, 1980). Thu s, the hand preference in each manual skill contributes to the development of the preference in subsequently developing skills.

The cascade theory of hand preference development proposes that lateralization of hand preference might be weak in an emerging manual skill, increase as the skill is being mastered, and decrease somewhat when the skill becomes well-established and automatic. There-fore, in order to identify manual lateralization when assessing early hand preference, a researcher must choose the manual task with the appropriate degree of challenge for infants at that phase of their development. For example, Fagard and Marks (2000) described the development of a hand-use preference for unimanual reaching, as well as unimanual and bimanual manipulation in 18–36 month old children. They found a higher percentage of those with a right-hand preference for the bimanual manipulation than for unimanual reaching-to-grasp (similar to "acquisition" as defined in the current paper) and concluded that "grasping is not the best task to employ to look for robust evidence of hand preference, and that bimanual tasks offer a better way to estimate handedness in children" (p. 137). Of course, a hand-use preference for "simple" reaching may exhibit less distinct lateralization than a hand-use preference for bimanual manipulation once reaching is a well-established skill and becomes subordinated to the actions that are planned for the object once acquired (as would be likely by 18 months of age).

Although RDBM may be observed as early as at the age of 7 months (Kimmerle, Mick, & Michel, 1995), a hand-use preference for RDBM does not begin to appear until about 13 months of age as infants begin to master the skill of such actions (Kimmerle et al., 2010). Thus, assessing hand preferences for RDBM earlier than13-14 months of age might not provide a reliable assessment of a preference, whereas assessing preferences for acquiring objects in infants under a year of age does seem to provide a reliable characterization of their preference (Michel, Babik, Sheu, & Campbell,2014). Clearly, identifying the infant's hand preference requires systematic longitudinal investigation of several manual skills exhibited by a large number of infants assessed many times during their first two years. Moreover, understanding of the developmental cascade of change in hand preference may help a researcher to choose a correct time and task for hand preference assessment, which would improve considerably there liability of studies relating hand preference to other developing neuropsychological functions.

Notes

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