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ROLE-DIFFERENTIATED BIMANUAL MANIPULATIONS EFFICIENCY: THE
DIFFERENCE IN SPEED FOR RDBMS BASED ON AGE, TOY-TYPE,
AND INFANT HAND PREFERENCE

SARAI MIKAL CORTINA

46 Pages

Role-differentiated bimanual manipulation (RDBM) is a complex behavior requiring the complementary movement of two hands to achieve a common goal. The current study investigated the relation of RDBM efficiency (speed to complete a successful RDBM) with hand preference, toy type (simple/difficult), age, and hand used to perform the RDBM. This study observed 46 infants between the ages of 9 to 14 months, each with a different hand preference category. Changes in RDBM efficiency across time were examined across different hand preference groups for RDBMs performed on simple toys using the right hand. The analysis revealed that early-right preference infants had a steeper slope than the no-preference/left-preference infants. The same was true for right-preference infants (early- and late-) for RDBMs performed on difficult toys using the right hand. A mixed ANOVA revealed that there were decreases in RDBM times across age therefore RDBM efficiency improves as the infants get older, regardless of toy type, hand used, or hand preference. The results of the present study suggest that when exploring the development of hand preference, we should consider the influence of age, hand preference, and hand used.

KEYWORDS: handedness, role-differentiated bimanual manipulation, multilevel analysis, infant

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AND INFANT HAND PREFERENCE

SARAI MIKAL CORTINA

A Thesis Submitted in Partial
Fulfillment of the Requirements
for the Degree of

MASTER OF SCIENCE

Department of Psychology

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CHAPTER I: INTRODUCTION

The focus of this study was to explore how infant acquisition hand preferences were related to differences in the ability to efficiently perform role-differentiated bimanual manipulations (RDBMs). RDBMs are actions in which two hands, each performing a different task, work together to accomplish a mutual goal (Babik & Michel, 2015). For the purpose of the current project, infants' acquisition hand preferences were used to predict infants' RDBM efficiency. Acquisition hand preference can be defined as the hand used when an infant reaches for an object and lifts the object off the table (Michel, Babik, Sheu, & Campbell, 2013; Nelson, Campbell, & Michel, 2013).

Because this study addressed the relation between acquisition hand preference and RDBM, it is important to examine the previous research which has established the relation between these two constructs. Nelson, Campbell, and Michel (2014) examined the developmental change from acquisition hand preference to RDBM hand preference. These authors found that handedness developed differently across time (infancy to toddlerhood) among the children in the study (Nelson et al., 2014). Some children exhibited a consistent hand preference during both infancy and toddlerhood, whereas others did not show a consistent preference until toddlerhood. Because acquisition hand preference is associated with differences in RDBM hand preferences, it is possible that acquisition hand preference can lead to differences in RDBM performance.

The development of hand preference is also used to gain a deeper understanding of other developmental factors, such as language (Nelson, Campbell, & Michel, 2014). In the study by Nelson et al. (2014), children who had a consistent right-hand preference had more advanced language skills in toddlerhood than those who did not exhibit a consistent hand preference.

Other studies have also examined the relation between hand preference and cognitive abilities such as word recall (de Nooijer van Gog, Paas, & Zwaan, 2013), and visual attention (Cochet, 2015). This link between handedness and cognition can make it easier for us to identify the presence of a developmental delay by examining both hand preference and ability for performing manual skills. Given that having a consistent right-hand preference is related to advanced language skills (Nelson et al., 2014), therefore it would be beneficial to watch for signs of language delay in those with inconsistent hand preference. Other signs of manual skill deficiency may be a useful indicator of delays in cognition as well. Many cognitive delays in language cannot be identified until around age 24 months (Mitchell et al., 2006). However, by establishing the typical developmental patterns for manual skills, we could identify a milestone for typical development, or a warning sign for atypical disorders, at an earlier age. For example, hand preferences have been identified as early as six months using a hand preference assessment that looks at single-hand object acquisition (Kimmerle, Mick, & Michel, 1995). Taking this information in conjunction with the knowledge that there is a relation between the development of handedness and hemispheric specialization, research in infant handedness development could possibly provide us with an easier and less invasive method of studying the infant brain and cognition development. Thus, getting a better understanding of the development of handedness during infancy could allow us to identify developmental disadvantages more easily and sooner in development.

Establishing a better understanding of the development of handedness begins with examining the onset of a consistent hand preference and how this preference influences the development of manual skill performance. Nelson et al. (2014) focused on identifying the onset and consistency of handedness preference. This study established that a unimanual hand

preference for acquisition (using only one hand to acquire or pick-up an object) has an influence on the development of RDBM hand preference (using two hands in different ways to complete an action). such that, a significant proportion of the infants who were lateralized to the right as infants maintained their right preference as toddlers. This finding provides information about the development of hand preference across time. However, the literature does not discuss whether having a unimanual hand preference has an influence on an infant's ability to efficiently perform a RDBM. Does having a unimanual hand preference influence how quickly an infant can successfully perform an RDBM?

A brief explanation of the viewpoint that led to a change in the examination of handedness will be presented. Second, newer techniques that have been used to assess the development of handedness will be explored. Third, a description of a procedure used to explore differences in timing for RDBMs among infants with different hand preferences will be presented. Finally, an account of the results produced from this procedure will be reported.

CHAPTER II: REVIEW OF LITERATURE

Exploration of Handedness Assessment Techniques

For any topic of research, there are an abundance of techniques that are used to explore a topic. When conducting research we want to ensure we are selecting the appropriate methods to answer our questions. In a paper that considers different methodological questions about assessing hand preference, Cochet (2015) suggests that the techniques that are best for exploring the development of differences in handedness are procedures using manual activities because these types of techniques are easily adaptable for infants, children, and adults. Many hand-preference studies have used manual activities to explore unimanual and bimanual manipulations as well as unimanual and bimanual handedness.

Unimanual and Bimanual Manipulations

Unimanual manipulations defined. A unimanual manipulation occurs when an individual is using one hand to complete an action (Babik, 2014). Babik (2014) reports that unimanual manipulations are the simpler form between unimanual and bimanual manipulations because unimanual actions do not require activation of both hemispheres as required for bimanual manipulations. Babik (2014) also suggests that the development of unimanual manipulation is likely the foundation for more complicated bimanual manipulations because it has been found to precede the emergence of bimanual manipulations. Babik's (2014) suggestion is supported by findings from Nelson, Campbell, and Michel (2013). Nelson et al., (2013) conducted a study in which they assessed handedness during infancy (6-14 months old) and then later assessed handedness again during toddlerhood (18-24 months old). During the infant trials, children were encouraged to reach for and manipulate different toys. During the toddler trials, each child was presented with toys that would elicit asymmetrical bimanual manipulations.

Asymmetrical bimanual manipulations involve manipulation with both hands, each doing a different action. In the infant trials, hand preference was determined via the hand that was used to acquire each toy. In the toddler trials, hand preference was determined via the hand that manipulated the toy. Nelson et al. (2013) found that the number of RDBMs increases with age, suggesting that the emergence of bimanual manipulations occurs later in development. Babik's (2014) suggestion that the development of unimanual manipulation is likely the foundation for more complicated bimanual manipulations is supported by the Nelson et al. (2013) study, which found that RDBMs began to emerge with higher prevalence as time (age) went on, after unimanual manipulation skills had begun to become established.

Bimanual manipulations defined. Bimanual manipulations are actions in which two hands are working together to manipulate an object and both hemispheres of the brain are activated (Nelson et al., 2013). There are two forms of bimanual actions. Symmetrical bimanual actions or non-differentiated manipulations are two different names for the first type of bimanual action (Nelson et al., 2013; Babik, 2014). Symmetrical bimanual actions, which are often referred to as mirror actions, are when both hands are doing the same exact movement (Babik, 2014). For example, a mirror action occurs when a child pushes the button of a toy using both index fingers. Asymmetrical bimanual manipulations, or role-differentiated bimanual manipulations (RDBMs) are the second type. These actions are when both hands are working at the same time to achieve a common goal, but the hands are performing different, but complementary, actions (Nelson et al., 2013; Babik, 2014). For example, in an adult, a RDBM occurs when they are aiming to open a bottle of soda. During this activity, one hand, usually the non-preferred hand, stabilizes the bottle while the other hand, usually the dominant hand,

manipulates the top by twisting it off to open the drink. This is a very simple action that is easily observable in adults, however among infants, this action is barely developing.

Bimanual techniques. There are several different methods that have been used to study handedness. Ramsay, Campos, and Fenson (1979) conducted two studies, one longitudinal and one cross sectional. The longitudinal study involved 24 infants tested monthly from 10 months and 15 months. The cross-sectional study included 100 infants between the ages of 14 to 16 months. In the longitudinal study, Ramsay et al. (1979) found that right-handed infants demonstrated a clear hand preference (using the same hand for all toys) at an earlier age (12.8 months on average) than left-handed infants (14.9 months on average). It was also reported that 23 of the 24 infants maintained a stable hand preference for bimanual coordination (same as RDBM) during the 5-month period following the first month the infants demonstrated a clear hand preference. In other words, the onset of bimanual hand preferences began and emerged between the ages of 10 to 18 months. In the cross-sectional study, Ramsay et al. (1979) reported that 85 infants met the criterion for a bimanual hand preference (71 right, 14 left) during initial testing and 9 additional infants demonstrated a bimanual hand preference after a retest (6 right, 3 left). In the cross-sectional study, most of the infants (94%) were demonstrating a hand preference for bimanual actions.

A later study investigated the development of bimanual handedness in another longitudinal study (Nelson et al. 2013). This study observed infants from 6 to 14 months (infant trials) and then again from 18-24 months (toddler trials). Hand-use for RDBM was assessed during the toddler trials using seven RDBM-specific toys presented twice non-consecutively, with three toys requiring multiple actions. Nelson et al. (2013) found that 71% of infants were showing RDBMs by 18 months of age for target actions. Although the methods were different,

each study involved the use of bimanual actions as the target behavior, and each study found the emergence of RDBMs by 18 months of age. This result is in agreement with what Ramsay et al. (1979) found. Ramsay et al. (1979) suggested that bimanual tasks should be the preferred type of task for determining handedness throughout out childhood, because it allowed them to find consistent hand preferences at an earlier age than prior research. Yet another study found the onset of RDBMs at an earlier age. Babik and Michel (2015) investigated the development of RDBMs among infants 6 to 14 months old. The procedure included 20 toys that elicited both simple and difficult actions. Simple toys elicited poking or stroking actions whereas difficult toys elicited actions like pulling, spinning, insertion, and pushing. When differentiating between simple and difficult toys, Babik and Michel (2015) found the emergence of RDBMs to occur as early as nine months. Although this study also involved the use of bimanual actions, the results differed from Ramsay et al. (1979) and Nelson et al (2013) because they categorized the types of bimanual actions elicited. This new addition to the methodology suggests that when studying the development of RDBMs, it is essential to factor in the type of toy used with the target behavior.

Development of *RDBM* assessments. A popular method for assessing young infant hand preference is to employ techniques that rely on observations of unimanual manipulations. Observing unimanual manipulations for young infants provides an accurate assessment of hand preference because the skill required to perform a unimanual manipulation continues to develop until around nine months, if the skill being observed is for acquiring objects (Michel, Babik, Sheu, & Campbell, 2014), so the use of unimanual manipulations is age appropriate for young infants. Campbell, Marcinowski, Babik, and Michel (2015) reported that hand preference for unimanual manipulations continue to become established through 14 months. However, for infants that are 18 months of age, using observations of unimanual acquisition to establish a hand

preference for unimanual manipulation becomes problematic because this task is too simple for 18-month-old infants. When the task is too simple, the infant can perform the task with either hand, making it impossible to establish hand preference. Also, Michel, Babik, Sheu, and Campbell (2014) reported that hand preference for acquisition (a unimanual manipulation) reaches its inflection point at 10 months for right-handed infants and at 11 months for left-handed infants. Thus, continuing to use acquisition observations beyond these months will not provide an accurate picture of hand preference, however, because hand preference for acquisition becomes established at ten months for most infants, it makes acquisition hand preference a good comparison point when exploring preferences for RDBMs, which are not established until later.

Nelson et al. (2013) examined the change in manual skills from unimanual to RDBMs to develop a new technique for handedness assessment that could be used with older participants and to determine if there was a connection between unimanual preferences in infancy and bimanual preferences during toddlerhood. They conducted a longitudinal study with 38 children (21 girls). Each child went into the lab each month from 6 to 14 months (“infant visits”) and then again from 18-24 months “(toddler visits)”. During the infant visits, infant handedness was measured using a handedness assessment developed by one of the researchers on the team (Michel, 1985). Infants were presented with 34 different toys and were encouraged to reach for and manipulate the objects. The infant’s handedness was measured (only for unimanual actions) using the handedness assessment mentioned above. Nelson et al. (2013) reported that the assessment was 93% reliable. During the toddler trials, handedness was measured for *RDBMs* using a new test battery. Seven objects, which were shown to elicit *RDBM* actions, were each presented to the child two different times. The new *RDBM* assessment was found to have 96% reliability. Children were then categorized as left-handed, right-handed, or no preference based

on their %R (child's percentage of right-hand use). Nelson et al. (2013) reported that as infants, 39% of children had a right-hand preference whereas the rest did not have a clear hand preference. In toddlerhood, 97% of the children had a hand preference with only one child remaining as a no-preference individual. They concluded that this new technique was much better at assessing hand preference, and it did a better job at uniquely identifying left-handedness and right-handedness.

These techniques have been used in several different studies that have found equally large levels of reliability (Babik & Michel, 2016; Nelson et al., 2014; Campbell, Marcinowski, Babik, & Michel, 2015). The current study has analyzed data that used an assessment similar to the ones discussed above.

RDBMs: The Study of Different Factors

There are many different studies that explore the different factors that may have an influence on the development of RDBMs. Some studies have explored how handedness and language might be connected and how those factors vary with timing in development (infant vs. toddlerhood, Nelson et al., 2014). For example, Nelson et al. (2014) investigated whether language outcome at two years old was, in part, affected by handedness bias during infancy. They found that children who had a consistent right-hand preference for unimanual (during infancy) and bimanual (during toddlerhood) manipulations performed better on the Bayley III language task at two years old than other children. These results indicate that language has a relation with hand preference for unimanual and bimanual actions among children.

Whereas the previous study focused on the link between hand preference and language, other research has investigated the influence that the characteristics of different types of objects may have on bimanual actions. Kimmerle, Ferre, Kotwica, & Michel (2010) report that the type

of toy presented to an infant increases the probability of an RDBM action being performed on an object. Specifically, items that have two parts are more likely to result in an infant performing an RDBM than when infants are presented with items that are one piece. These authors did report that infants spend increasing amounts of time performing RDBMs on two-part objects from 7 to 13 months of age. However, the amount of time that an infant will spend on an RDBM before completing this action was not examined.

In an earlier study, Kimmerle, Mick and Michel (1995) explored the emergence of RDBMs in infants from 7 to 13 months. This study also explored how different toy characteristics affect the production of RDBMs. The authors observed infant interaction with 10 toys that differed on whether they had movable parts, graspability, and finger control (single finger or pincer actions). This study found that production of RDBMs are affected by the characteristics of the toy (Kimmerle et al., 1995). More specifically, a participating infant must have the ability to acquire the toy, manipulate it, and the movable parts must be easily accessible and match the movement capabilities of typical infants if RDBMs are to be elicited.

Whereas the previous studies have provided information about the kinds of toys that may elicit RDBMs, they did not describe whether some objects will be affected by RDBM efficiency, nor did they consider whether the RDBM efficiency is influenced by an established hand preference or even age. The goal of the current project is to examine whether having a hand preference will influence RDBM efficiency, or time to complete a RDBM.

A pilot study was conducted to establish that there is variability RDBM efficiency (Cortina, Flores, Mordan, Ghem, Campbell, & Michel, 2018). Archived video data of infant and toddler visits in which children were presented with different objects that have been shown to elicit *RDBM* actions were analyzed (Babik & Michel, 2016; Nelson et al., 2014; Campbell et al.,

2015). The goal of the pilot study was to establish whether infant hand preference had an effect on RDBM efficiency. Videos were coded for start and stop times of successful *RDBM* actions for 30 infants whose acquisition hand preference had previously been established (no-preference, right-hand, left-hand). The results revealed significant differences in *RDBM* efficiency between infants at nine months and all the other months (11, 12, 13, 14). *RDBM* Efficiency was significantly lower at nine months ($M = 9.19$, $SE = .52$) than at the other months (11 mo., $M = 6.58$, $SE = .38$; 12 mo., $M = 6.01$, $SE = .23$; 13 mo., $M = 6.37$, $SE = .36$; 14 mo., $M = 6.25$, $SE = .28$). There was no significant difference in average *RDBM* efficiency between nine and ten months ($M = 7.03$ $SE = .46$).

This pilot study also revealed that no-preference infants experienced a significant change in *RDBM* efficiency from nine to ten months ($F [1, 7] = 6.17$, $p < .05$). This change was significantly different than the one experienced by right-handed infants in the same time-period, who did not experience a significant change *RDBM* efficiency. A possible explanation for this difference could be due to a difference in the development of handedness between left- and right-handed individuals. Previous studies have shown that the right-hand preference is developed earlier than other types of hand preference. Because right-hand preference is established earlier than a left-hand or no preference, right-handed infants have practiced with their preferred hand starting at an earlier age. It is possible that by 9 months, the infant has already reached their peak *RDBM* efficiency. No preference infants probably show a significant change in *RDBM* efficiency because they are showing an improvement in skill. An improvement in *RDBM* efficiency would mean the time to complete a *RDBM* is decreasing.

For the current study, the independent variable was acquisition hand preference. Using acquisition hand-preference allows the examination of an established set of latent classes of hand

preference. These latent classes were established by Michel et al. (2013) and consist of four identified hand preferences (early right, late right, late left, no preference). Because infants have already been identified as belonging to one of these four latent classes, it was possible to compare their completion times for RDBM.

CHAPTER III: METHOD

The focus of the present study was to build on previous work on RDBM to explore how differences in acquisition hand preference are related to efficiency differences for RDBMs among infants. RDBM efficiency refers to the amount of time it takes to complete an RDBM, so the higher amount of time it takes to complete an RDBM, the lower the RDBM efficiency. There were four questions that this study explored. First, this study asked if there was a relation between age and RDBM efficiency. It was predicted that as age increased, the time to complete an RDBM would decrease indicating an increase in RDBM efficiency. It was also predicted that RDBM efficiency at nine months would be significantly different than all other months. This result was found in the previous pilot study (Cortina et al., 2018), so it was predicted that this trend would be observed again.

Second, is there a difference in RDBM efficiency among infants based on acquisition hand preference? It was predicted that there would be a difference between no-preference infants and right-handed infants, but not between no-preference infants and left-handed infants. This hypothesis was based on the findings of a pilot study that was discussed above (Cortina et al., 2018).

The third question asked if different toy types (simple v difficult) affect RDBM efficiency. It was predicted that there would be a difference between simple and difficult toys. This hypothesis was based on a study by Babik and Michel (2015) who found a difference in the frequency of RDBMs between different types of toys. The difference in frequency of RDBMs with different toys could be because infants are faster with the type of toy that elicits the most RDBM actions.

Finally, the fourth question asked, is there an interdependency between hand preference, toy-type, and age for RDBM efficiency? Based on the assumption that early right-handed infants get more practice with RDBM because they develop the ability sooner (Nelson et al., 2013), the right-handed infants were predicted to have the fastest RDBM completion times for simple and difficult objects, as compared to all other handedness groups; late-right infants would have the second highest RDBM efficiency. Late-left will have the second lowest RDBM efficiency. No preference infants will have the lowest RDBM efficiency.

Participants

The participants of this study were infants who were recruited for a larger study conducted by the University of North Carolina at Greensboro. Infants were eligible to participate in this study if they were healthy, full-term, and uncomplicated births. The infants needed to be observed between 9 to 14 months. The current study included 46 infants who were randomly selected from larger study. During the period from 6 to 14 months, acquisition hand preference was assessed. The infants for this study were selected based upon their previous hand preference classification for acquisition. Fifteen infants were previously classified as having an early right-hand preference, 9 infants had a late right-hand preference, 11 infants had a late left-hand preference, and 11 infants had no hand preference. The four handedness groups and age at each session were compared for efficiency to complete RDBMs (independent variable 1 and 2).

Materials

The current study used archived video data from a larger study. The procedure in the archived videos took place in a university lab room that was equipped with a table and two chairs (one for the researcher and one for the parent). There were several different toys used in the procedure. The current study only included 32 toys which previous studies have shown elicit the

target behaviors (role-differentiated bimanual manipulation, RDBM; Michel, 1985; Nelson et al., 2013; see Appendix 1). Two video cameras were used to record each session. The cameras provided a top view and a left side view; the footage was linked using a Videonics mixer. For the current study, the videos were coded using The Observer XT software package, which allows for frame-by-frame investigations.

Procedure

The following is the procedure carried out in the archived videos. The infants came in with their parents for six different monthly sessions between the ages of 9 months to 14 months. At each session, researchers conducted the procedure developed by previous studies, which is depicted in Figure 1 (Michel, 1985; Nelson et al., 2013). The parent sat at one long side of the table with the infant on their lap. The researcher sat on the other side of the table. The researcher presented the infant with 32 different toys and demonstrated to the infant what a successful RDBM looks like with the right hand and the left hand. The infant was allowed to explore and manipulate the objects for about 60-90 seconds. Each session lasted about 45 minutes.

Coding

Infant videos from ages 9-14 months were coded with the help of trained undergraduate research assistants. Interrater and intrarater reliabilities had to reach a level of .90 or above during training before coders begin coding videos on their own. The raters included the primary researcher and undergraduate research assistants. To remedy disagreements in coding, the primary researcher met with the disagreeing coder to discuss the discrepancies and came to an agreement.

The videos of each session were coded for RDBM efficiency (dependent variable) and toy type (independent variable 3). In the current study, RDBM efficiency refers to the time to

completion of a successful RDBMs, thus the start and stop times were recorded for each of the 32 trials per session. The definitions of successful RDBMs used the previously defined in the larger study described above. A successful RDBM occurred when one hand stabilized the body of a toy while the other hand manipulated the toy in some way. For example, with toy number 18 (see Appendix A) a successful RDBM would occur when the infant stabilizes the toy by holding the green part steady while their other hand removes the yellow part from the green part. While coding successful RDBMs, there was a potential for two start and two stop times. The first start time was marked at the instance the infant reached for and acquired an object. The first stop time was marked at the completion of a first successful RDBM. If there was a second successful RDBM, then the second start time would have been the stop time recorded for the first successful RDBM for that toy. The second stop time was marked at the completion of the second successful RDBM. Toys were categorized based on the type of action they elicit (simple or difficult) in previous research (Kimmerle, Mick, & Michel, 1995; Babik & Michel, 2016). Toys were categorized as simple if it elicited poking, stroking, or sliding. Toys were categorized as difficult when they elicited pushing, pulling, or removing. The type of toy was compared based on the potential efficiency for completion of RDBMs. Coders recorded the toy number for later identification during analysis. The goal of interrater reliability of agreement for identifying RDBMs of 90% or above was achieved for every rater.

CHAPTER IV: RESULTS

Overview

There were four research question which were addressed in this study. First, this study asked if there was a relation between age and RDBM efficiency. This question was addressed using a mixed ANOVA.

Second, is there a difference in RDBM efficiency among infants based on acquisition hand preference? This question was addressed using a mixed ANOVA where hand preference was the between-subjects factor.

The third question asked if different toy types (simple v difficult) affect RDBM efficiency. A mixed ANOVA was conducted to examine whether the average efficiency score was significantly different across the two toy types.

The fourth question asked whether there is an interdependency between hand preference, toy-type, and age for RDBM efficiency? A mixed ANOVA analysis was conducted in which all of the predictors, unimanual hand preference, toy type, and age were entered into a model with efficiency as the outcome. An HLM was also conducted to examine a model in which RDBM efficiency was examined across time, with unimanual hand preference and toy type entered as predictors. Each of these hypotheses and the analyses used to test them are described below in more detail.

Is There a Change in RDBM Efficiency Across Time?

Infants had a mean RDBM time of 7.34 seconds over all ($SD = 6.40$). At 9 months, the average time to complete a RDBM was 9.44 seconds ($SD = 2.96$). At 10 months, the average time to complete a RDBM was 8.51 seconds ($SD = 3.15$). At 11 months, the average time to complete a RDBM was 7.52 seconds ($SD = 2.00$). At 12 months, the average time to complete a RDBM

was 7.26 seconds ($SD = 2.31$). The fastest time to complete a RDBM occurred at 13 months ($M = 6.80$ s, $SD = 2.18$). At 14 months, the average time to complete a RDBM was 7.15 seconds ($SD = 2.14$). A mixed ANOVA was performed to address whether RDBM efficiency changed across time. This analysis revealed an overall increase in speed from 9 to 14 months. In other words, there were significant differences in RDBM efficiency across time, $F(5, 210) = 10.94$, $p < .001$, $\eta^2_p = .207$ (Figure 2). Pairwise comparisons of age with a Bonferroni adjustment, reveal that there are significant differences between 9 months and months 11-14 but not between 9 months and 10 months. There was also a significant difference between month 10 and month 13. Table 1 shows the mean difference between months and the significance levels. Within-subjects contrasts revealed there was a significant quadratic ($F[1, 42] = 9.49$, $p = .004$, $\eta^2_p = .18$) trend for age (Figure 2). The differences observed in the month to month averages support the hypothesis that infants will increase their RDBM speed across time.

Is There a Difference in RDBM Efficiency Among Infants Based on Acquisition Hand Preference?

A 4-way (age x toy x hand use x hand preference) mixed measures ANOVA was conducted to examine RDBM efficiency and hand preference. The main effects of hand preference revealed that there were no significant differences in RDBM efficiency between hand preference groups, $F(3, 42) = 0.96$, $p = .42$, $\eta^2_p = .06$. This is the opposite of what was predicted in the second hypothesis. The speed of RDBM performance was not significantly faster for any one acquisition hand preference group. The average time to complete a RDBM for no preference infants was 7.12 seconds ($SD = 1.63$), making the no preference group the fastest, but this did not reach significance. . For the early right infants, the average time to complete a RDBM was 8.19 seconds ($SD = 1.63$), making early right infants the slowest, but this is also not a significant

result. The average time for late right infants was 7.88 seconds ($SD = 1.63$). Finally, late left infants had an average time of 7.93 ($SD = 1.63$). This does not support the hypothesis that there would be differences among hand preferences.

Do Different Toy Types (Simple V Difficult) Affect RDBM Efficiency?

The 4-way (age x toy x hand use x hand preference) mixed measures ANOVA also addressed this question. There were no significant differences in RDBM efficiency between different toy type groups, $F(1, 42) = 0.12, p = .75, \eta^2_p = .003$. For simple toys, the average speed with which RDBMs were performed was 7.82 seconds ($SD = 1.72$), while for difficult toys, the average speed with which RDBMs were performed was 7.743 seconds ($SD = 1.93$), however, these differences were not significant. This analysis suggests that the main effect of toy type does not affect RDBM efficiency.

Is There Is an Interdependency Between Hand Preference, Toy-Type, and Age for RDBM Efficiency?

Multilevel analyses, using the Hierarchical Linear Modeling software, were performed to explore developmental trajectories of the speed with which simple and difficult role differentiated bimanual manipulations are performed with each hand, according to hand preferences for acquisition (early right, late right, late left, and no preference). The hand-use preference variable was coded as three dummy variables, “Early Right”, “Late Right”, and “Late Left”, with no preference being the reference group. It was determined in the analysis that there were no significant differences between the Late Left and the no preference group. A reduced model was formed, in which the no preference and the Late Left groups were combined. It should be noted that the hand used to perform the RDBMs was added to the model as a predictor,

to further explore trajectories because no effects were observed when examining the data without this variable.

The first HLM model predicted simple, right hand RDBM actions. The final reduced model for infant RDBM efficiency for simple toys while using the right hand was as follows:

$$\text{Level 1 model: } \text{SPEED}_{ij} = \pi_{0i} + \pi_{1i} * (\text{AGE})_{ij} + \varepsilon_{ij}$$

$$\text{Level 2 models: } \pi_{0i} = \beta_{00} + \beta_{01} * \text{Late Right}_i + \beta_{02} * \text{Early Right}_i + \delta_{0i}$$

$$\pi_{1i} = \beta_{10} + \beta_{11} * \text{Late Right}_i + \beta_{12} * \text{Early Right}_i + \delta_{1i}$$

Table 2 shows the fixed and random effects for simple RDBM actions performed with the right hand. On average, RDBM speed increased linearly ($\beta_{12} = -0.629, p < 0.05$) for the Early Right hand infants (see Fixed Effects in Table 2). In other words, infants with an early right preference increased in the speed with which they performed RDBMs across time, as compared to the no preference and late left group, however, there was no significant difference between early right and late right (Figure 3). The variance components for the intercept and linear slope were also significant (see Random Effects in Table 2). Random effects are the variance of the intercept and slopes across groups and indicate that there is significant difference of the within-group variance for each hand preference group.

For RDBMs performed on difficult toys with the right hand, early-right and late-right handed infants both had significantly steeper linear slopes than the no-preference and late-left handed groups, (Table 3, Figure 4). The model for infant RDBM efficiency for difficult toys while using the right hand was as follows:

$$\text{Level 1 model: } \text{SPEED}_{ij} = \pi_{0i} + \pi_{1i} * (\text{AGE})_{ij} + \varepsilon_{ij}$$

$$\text{Level 2 models: } \pi_{0i} = \beta_{00} + \beta_{01} * \text{Late Right}_i + \beta_{02} * \text{Early Right}_i + \delta_{0i}$$

$$\pi_{1i} = \beta_{10} + \beta_{11} * \text{Late Right}_i + \beta_{12} * \text{Early Right}_i$$

Table 3 shows the fixed and random effects for difficult RDBM actions performed with the right hand. On average, RDBM speed increased linearly ($\beta_{11} = -0.650, p < 0.05$) for the late right hand infants (see Fixed Effects in Table 3). In other words, infants with a late right hand preference increased in the speed with which they performed RDBMs across time, as compared to the no preference and late left group, however, there was no significant difference from the early right group. The early right infants also show a significant linear increase in RDBM speed ($\beta_{12} = -0.525, p < 0.05$) as compared to the no preference and late left groups. The data also revealed a significant difference in intercept for the early right group ($\beta_{02} = 2.417, p < 0.05$). This means that the early right group were initially performing RDBMs much slower than the no preference and late left group, but not slower than the late right group. The variance components for the intercept and linear slope were also significant (see Random Effects in Table 3).

The model for infant RDBM efficiency for simple toys while using the left hand was as follows:

$$\text{Level 1 model: } \text{SPEED}_{ij} = \pi_{0i} + \pi_{1i} * (\text{AGE})_{ij} + \pi_{1i} * (\text{SQAGE})_{ij} + \varepsilon_{ij}$$

$$\text{Level 2 models: } \pi_{0i} = \beta_{00} + \beta_{01} * \text{Late Right}_i + \beta_{02} * \text{Early Right}_i + \delta_{0i}$$

$$\pi_{1i} = \beta_{10} + \beta_{11} * \text{Late Right}_i + \beta_{12} * \text{Early Right}_i + \delta_{1i}$$

$$\pi_{2i} = \beta_{20} + \beta_{21} * \text{Late Right}_i + \beta_{22} * \text{Early Right}_i$$

For RDBMs performed on simple toys using the left hand, the early-right and late-right handed infants demonstrated a quadratic slope which was significantly different than no-preference and late-left handed infants (early right, $\beta_{22} = 0.484, p < 0.01$; late right, $\beta_{21} = 0.484, p < 0.05$; Table 4, Figure 5). These results indicate that the early and late right hand groups change in a quadratic way that was different from the no preference and left groups. The model also

indicates that the late right group had an intercept that was significantly different from the no preference and left preference groups, but not different from the early right group ($\beta_{01} = 3.422, p < 0.05$). This significant difference in intercepts indicated that the late right infants began performing simple, left hand RDBMs much slower than the no preference and left groups at 9 months of age. In other words, initially, the no preference and the late left groups were faster at performing simple, left hand RDBMs than the late right infants. However, the quadratic slopes indicated that the right preference groups increased in their speed, passing the no preference and left groups at 10 months, but ending at about the same speed at 14 months. For RDBMs performed on difficult toys with the left hand, no significant effects were demonstrated.

These HLM results lead us to question whether infants *within* each hand preference group perform RDBMs significantly faster with their right or left hand. For instance, are the early right infants performing difficult RDBMs with their right hand faster than they are with their left hand? To further explore the findings of the HLM analysis, a 4-way (age x toy x hand use x hand preference) mixed measures ANOVA was conducted. There were no significant differences in RDBM performance between different hands used to perform an RDBM, $F(3, 42) = 0.17, p = .69, \eta^2_p = .004$.

Table 5 shows the means and standard deviations of RDBM efficiency for different toy types, hand used to complete RDBMs, age, and hand preference. The mixed ANOVA also provided support for the results found in the HLM analysis. There was a significant interaction between age and hand preference ($F[15, 210] = 1.99, p = .02, \eta^2_p = .13$). Within-subject contrasts revealed there was also a significant quadratic trend in the age by hand preference interaction, $F[3, 42] = 4.07, p = .01, \eta^2_p = .22$ (Figure 6). There were no other significant

interaction effects, however within-subject contrasts demonstrate a significant quadratic trend for the toy type by age interaction, $F[1, 42] = 6.44, p = .02, \eta^2_p = .13$ (Figure 7).

Table 6 provides statistics for the non-significant interaction effects. Overall, hypothesis 4 predicted a hand preference-toy type interaction. This was not supported by the analysis. The quadratic trends observed in the main effect of age, the interaction effect of age and hand preference, and in the interaction effect of toy type of age generally supported the significant difference in the quadratic slope observed across time among different hand preferences in the HLM analysis under the simple-left hand use conditions (Figure 5).

CHAPTER V: DISCUSSION

The purpose of this study was to explore questions regarding the development of infant role-differentiated bimanual manipulation (RDBM) performance. RDBM efficiency or time to complete an RDBM is an aspect that has not been previously explored in the literature, thus the aim of this study was to expand on current RDBM knowledge.

The first hypothesis that RDBM efficiency would increase across time was supported by the HLM analysis as well as the mixed ANOVA. Generally speaking, the HLM analysis revealed decreases in RDBM times across time for simple toys using the right hand and for difficult toys using the right hand (Figure 3 and 4). The ANOVA revealed that there were decreases in RDBM times between 9 months of age and all other months of age except 10 months indicating that in general, RDBM efficiency improves as the infants get older, regardless of toy type, hand used, or hand preference (Figure 2). Contrasts also revealed quadratic trends for age (Figure 2). The linear trend indicates that as age progresses, an infant will improve in RDBM efficiency (becoming faster as performing RDBM actions), however the quadratic trend indicates that at certain points RDBM efficiency improves but as infants approach 14 months, they decrease in RDBM efficiency.

The second hypothesis that there would be a difference between no preference infants and right-preference infants was supported by the multilevel analysis conducted on the HLM software. When looking at the change in RDBM efficiency across time between different hand preference groups for RDBMs performed on simple toys using the right hand, the analysis revealed that early-right preference infants had a steeper slope than the no-preference/left-preference infants (Figure 3). The same was true for right-preference infants (early- and late-) for RDBMs performed on difficult toys using the right hand (Figure 4). Additionally, the first

hypothesis was supported by the finding that early-right and late-right preference infants demonstrated a higher quadratic slope than no-preference/late-left preference infants for RDBM performance on simple toys using the left hand (Figure 5), more on this later. These findings suggest that right-preference infants improved their RDBM performance across time at a faster rate than the no preference/left-preference infants when using their right hand or left hand.

By looking at the plot in Figure 3 it appears that the performance between right-preference and no-preference/left-preference infants will demonstrate a bigger and bigger difference as the infants get older. The same can be said about Figure 4. This finding might be explained by the assumption that right-preference infants get more practice with RDBM because they develop the ability sooner (Nelson et al., 2013) so right-preference infants demonstrate better performance.

Interestingly, the quadratic trend observed in Figure 5 suggests something different for RDBMs performed using the left hand. In Figure 5, it appears that RDBM efficiency for simple toys using the left hand decreases for right-preference infants as infants approach 13 and 14 months of age, while the no-preference/left-preference infants appear to present a continued improvement in RDBM efficiency. This could also be explained by the assumption that as infants get older, their tendency toward their preferred hand gets stronger (Nelson et al., 2013), therefore while right-preference infants may show greater improvement in RDBM performance with both their right and left hands, there will be a point where right-preference infants will become less skilled than no preference and left-preference infants in using the left hand for RDBMs. Further study is needed to confirm the assumptions of Figures 3, 4, and 5.

The third hypothesis predicted that there would be a difference in RDBM efficiency between simple and difficult toys, this prediction was not supported in general, however

contrasts revealed a quadratic trend of toy type by age (Figure 7), showing that infants increase in their speed for both simple and difficult toys across time, but again, as they approach 14 months, they slow.

The fourth hypothesis predicted that early-right preference infants would have the fastest completion times for RDBM followed by the late-right preference, late-left preference, and no preference, in that order. Looking at the results from the first hypothesis, the fourth hypothesis was somewhat supported by the HLM analysis. The HLM results indicated that right-handed infants demonstrated a faster rate of improvement in RDBM efficiency. The ANOVA analysis however did not support a hand preference by toy interaction which demonstrates there were no differences between hand preferences in RDBM performance within simple or difficult toys.

Limitations

A limitation of this study was the small sample size observed. Having a small sample size impacts the generalizability of the results and it may have also affected the power, specifically, there were small sample size distribution in each of the hand categories. Had there been a greater number of participants in each hand preference category, there may have been more significant results in terms of differences among hand preferences. Additionally, this study observed infants within a small range of ages. Having a small age range can result in missing data that show differences only visible at later ages. For example as infants get older, their hand preferences become stronger, therefore they may experience greater differences between hand preference categories. Another limitation would be the type of analysis and coding processes. When the analysis was conducted, an additional variable was added (hand use). During the coding process, hand use was added as a variable, and thus it is possible that there were times coders indicated either hand as the hand that was used for completing a RDBM in order to make the

coding process go faster. If this was the case, it may be possible that significant results were obscured due to the coding procedure.

Future Directions

In the future, it is important to expand the number of participants to get better generalizability as well as greater statistical power. It would also be interesting to explore how a wider age range to determine if later ages showed further effects. . This study used archived video data with data for about 300 infants from 6 months of age to 18 months of age, so expanding the study to include more infants and a wider age range it might show improved results. RDBM efficiency, or time to complete successful RDBMs, is a variable that has not been previously researched. RDBM efficiency should be researched to determine its role in language ability and handedness, particularly since the current study found some differences across hand preference. In addition, several investigations have found links between language and handedness (Nelson et al, 2014).

Conclusion

The results of the present study suggest that when exploring the development of hand preference, we should consider the influence of age as well as the interactive influence of age and hand preference on RDBM performance. We should also consider the difference in RDBM performance based on the hand used to perform RDBMs because before adding differences in hand use, there were few notable results. For example, a study by Babik and Michel (2015) suggests that it is important to compare action types (simple versus difficult) because it allows for a deeper understanding of RDBM development. However, the current study did not find such differences. Overall, this study revealed that there is still a lot to learn about the development of infant handedness. In conclusion, RDBM efficiency is a factor that should be considered when conducting RDBM research.

Table 1*Significant Mean Differences in RDBM Performance Across Different Age Comparisons*

Age	9	10	11	12	13	14
9	0					
10	0.93	0				
11	1.92**	0.99	0			
12	2.18***	1.25	0.26	0		
13	2.64***	1.71**	0.72	0.46	0	
14	2.30***	1.36	0.38	0.12	-0.34	0

Note. ** $p < .01$, *** $p < .001$

Table 2

Estimated Fixed and Random Effects for Simple, Right-Hand, RDBM Duration According to Hand Preference for Acquiring Objects

Level 1 Effects	Level 2 Effects	Parameters	RDBM Efficiency (Duration)
Fixed Effects			
Initial status, π_{0i}	Intercept	β_{00}	8.180***
	Late Right	β_{01}	1.347
	Early Right	β_{02}	1.452
AGE, π_{1i}	Intercept	β_{10}	-0.172
	Late Right	β_{11}	-0.585
	Early Right	β_{12}	-0.629*
Random Effects			
Level 1:	Within-person, ϵ_{ij}	$\sigma\epsilon^2$	6.811***
Level 2:	Intercept, δ_{0i}	σ_0^2	0.209*

Note. * $p < .05$. *** $p < .001$.

Table 3

Estimated Fixed and Random Effects for Difficult, Right-Hand, RDBM Duration According to Hand Preference for Acquiring Objects

Level 1 Effects	Level 2 Effects	Parameters	RDBM Efficiency (Duration)
Fixed Effects			
Initial status, π_{0i}	Intercept	β_{00}	7.645***
	Late Right	β_{01}	2.182
	Early Right	β_{02}	2.417*
AGE, π_{1i}	Intercept	β_{10}	-0.162
	Late Right	β_{11}	-0.650*
	Early Right	β_{12}	-0.525*
Random Effects			
Level 1:	Within-person, ε_{ij}	$\sigma\varepsilon^2$	3.048***
Level 2:	Intercept, δ_{0i}	σ_0^2	8.033*

Note. * $p < .05$. *** $p < .001$.

Table 4

Estimated Fixed and Random Effects for Simple, Left-Hand, RDBM Duration According to Hand Preference for Acquiring Objects

Level 1 Effects	Level 2 Effects	Parameters	RDBM Efficiency (Duration)
Fixed Effects			
Initial status, π_{0i}	Intercept	β_{00}	8.499***
	Late Right	β_{01}	3.422*
	Early Right	β_{02}	2.686
AGE, π_{1i}	Intercept	β_{10}	-0.246
	Late Right	β_{11}	-3.281**
	Early Right	β_{12}	-2.786**
SQAGE, π_{2i}	Intercept	β_{20}	-0.221
	Late Right	β_{21}	0.519*
	Early Right	β_{22}	0.484**
Random Effects			
Level 1:	Within-person, ε_{ij}	$\sigma\varepsilon^2$	7.747***
Level 2:	Intercept, δ_{0i}	σ_0^2	6.670*

Note. * $p < .05$. ** $p < .01$. *** $p < .001$.

Table 5

Means and Standard Deviations of RDBM Efficiency for Different Toy Types, Hand Used to Complete the RDBM, Age, and Hand Preference

Toy Type	Hand Used	Age	Early Right	Late Right	Left	No Preference
			<i>M (SD)</i>	<i>M (SD)</i>	<i>M (SD)</i>	<i>M (SD)</i>
Simple	Right	9	10.07 (4.48)	10.36 (7.31)	9.12 (4.76)	7.12 (2.31)
		10	9.63 (6.37)	10.27 (4.8)	7.65 (4.31)	7.97 (5.02)
		11	7.14 (3.16)	6.95 (3.17)	9.89 (6.28)	6.44 (3.3)
		12	5.93 (1.73)	7.42 (1.8)	8.47 (7.44)	7.1 (2.74)
		13	6.33 (2.71)	5.69 (2.07)	6.18 (1.67)	6.98 (1.73)
		14	7.08 (4.88)	8.15 (2.72)	7.07 (4.02)	7.52 (3.57)
	Left	9	12.46 (4.08)	11.74 (4.41)	9.74 (5.17)	9.26 (2.62)
		10	7.77 (3.8)	8.66 (3.73)	9.71 (8.42)	8.2 (4.4)
		11	5.98 (1.25)	6.26 (2.43)	6.59 (1.75)	7.74 (3.46)
		12	6.13 (1.88)	6.61 (3.03)	8.65 (6.17)	5.57 (2.9)
		13	8.66 (5.62)	5.8 (2.15)	6.74 (3.6)	7.36 (4.14)
		14	7.24 (2.94)	8.2 (5.96)	6.87 (2.85)	6.89 (2.21)
Difficult	Right	9	11.6 (7.3)	9.66 (3.01)	8.7 (3.17)	6.75 (3.32)
		10	9.84 (5.6)	8.28 (4.08)	5.56 (3.22)	8.5 (1.44)
		11	8.73 (4.74)	8.74 (5.12)	8.93 (8.94)	6.9 (3.04)
		12	6.59 (2.52)	6.74 (2.02)	7.79 (5.31)	7.15 (2.87)
		13	8.21 (4.21)	6.84 (2.14)	7 (5.19)	6.3 (2.44)

(Table Continues)

Table 5, Continues

Toy Type	Hand Used	Age	Early Right <i>M (SD)</i>	Late Right <i>M (SD)</i>	Left <i>M (SD)</i>	No Preference <i>M (SD)</i>
		14	6.74 (2.24)	5.93 (2.14)	6 (2.49)	6.91 (1.7)
	Left	9	9.72 (6.48)	9.46 (1.96)	7.93 (5.82)	7.4 (3.3)
		10	10.38 (7.64)	8.28 (3.29)	9.29 (4.56)	6.16 (1.64)
		11	6.05 (2.61)	8.26 (3.72)	9.74 (4.5)	6.05 (2.37)
		12	9.05 (4.68)	6.82 (1.78)	9.17 (5.98)	7.02 (3.11)
		13	6.83 (4.39)	7.28 (2.46)	5.71 (2.83)	6.96 (2.04)
		14	8.52 (4.38)	6.66 (1.72)	7.86 (3.99)	6.71 (2.53)
N			15	9	11	11

Table 6*Interaction Effects of Hand Used to Perform RDBM, Toy Type, Age, and Hand Preference*

Interactions	<i>F</i>	<i>df</i> effect	<i>df</i> residual	<i>p</i> -value	η^2_p
toy type x hand preference	1.45	3	42	.24	.09
hand use x hand preference	0.21	3	42	.89	.02
toy type x hand use	0.003	1	42	.96	.00
toy type x hand use x hand preference	0.68	3	42	.57	.05
toy type x age	1.43	5	210	.21	.03
toy type x age x hand preference	0.53	15	210	.92	.04
hand use x age	0.87	5	210	.50	.02
hand use x age x hand preference	1.02	15	210	.44	.07
toy type x hand use x age	1.53	3.88	163.19	.20	.04
toy type x hand use x age x hand preference	0.63	11.66	163.19	.81	.04

Figure 1

Diagram of the Set Up for the RDBM Procedure

Assessment

Note. The individual in purple represents the parent, the individual in the light blue represents the infant, and the individual in the dark blue represents the researcher.

Figure 2

Differences in RDBM Efficiency Across Different Ages

Note. Quadratic change (dashed line) across age.

Figure 3

Change in RDBM Efficiency Across Time Between Different Hand Preference Groups for RDBM Performed on Simple Toys Using the Right Hand

Figure 4

Change in RDBM Efficiency Across Time Between Different Hand Preference Groups for RDBM Performed on Difficult Toys Using the Right Hand

Figure 5

Quadratic Change in RDBM Efficiency Across Time Between Different Hand Preference Groups for RDBM Performed on Simple Toys Using the Left Hand

Figure 6

Differences in Change in RDBM Efficiency Across Time Between Different Hand Preferences Demonstrate a Quadratic Trend

Figure 7

Differences in Change in RDBM Efficiency Across Time Between Different Toy Types Demonstrate a Quadratic Trend

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APPENDIX A: THE 32 OBJECTS USED IN THE RDBM TASK

Toy # 1

Toy # 2

Toy # 3

Toy # 4

Toy # 5

Toy # 6

Toy # 7

Toy # 8

Toy # 9

Toy # 10

Toy # 11

Toy # 12

Toy # 13

Toy # 14

Toy # 15

Toy # 16

Toy # 17

Toy # 18

Toy # 19

Toy # 20

Toy # 21

Toy # 22

Toy # 23

Toy # 24

Toy # 25

Toy # 26

Toy # 27

Toy # 28

Toy # 29

Toy # 30

Toy # 31

Toy # 32