MARCINOWSKI, EMILY C., M.A. The Influence of Sex and Handedness on the Development of Constructing Skills During Infancy. (2013)
Directed by George F. Michel 65 pp.

Towards the end of their first year, infants are initially learning to construct objects. Construction, or merging multiple objects into a single, unifying structure, requires combining cognitive and sensorimotor abilities. Since infants with a hand preference have greater manual proficiency than infants with no hand preference, infants with a hand preference are expected to be more skilled at construction. Since some evidence suggests that females may develop motor skills more quickly than males, sex may play a role in the development of construction; however no specific predictions are made. Fifty-three infants (26 females) were brought to the lab from the ages of 6-14 months across 9 monthly visits. Infants were given a handedness task across all visits to assess their handedness, and additionally given a construction task from 10-14 months to assess their constructing skill. Using multilevel Poisson longitudinal modeling, left-handed males constructed at a significantly slower rate across 10-14 months than all other groups. Left-handed males follow a unique trajectory of constructing skill, which could indicate differences in their spatial abilities and may also affect related cognitive abilities at later ages, such as hierarchical structuring or seriation.

THE INFLUENCE OF SEX AND HANDEDNESS ON THE DEVELOPMENT OF

CONSTRUCTING SKILLS DURING INFANCY

by

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A Thesis Submitted to
the Faculty of the Graduate School at
the University of North Carolina at Greensboro
in Partial Fulfillment
of the Requirements for the Degree
Master of Arts

Greensboro
2013

Approved by

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To Shawn. Your quick wit, patience, and loving support enabled me to complete this project.

APPROVAL PAGE

This thesis written by Emily C. Marcinowski has been approved by the following committee of the Faculty of The Graduate School at The University of North Carolina at Greensboro.

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CHAPTER I

INTRODUCTION

The Development of Handedness

Soon after birth, newborns acquire knowledge about their bodies in a new, visually-perceived world. By moving their arms and hands within the visual field, the infant has the opportunity of seeing and coordinating motor control of these limbs. In this way, the infant develops more refined hand-eye coordination and eventually comes to organize these body parts into visually-guided actions, like reaching, object acquisition, and, later, more complex manipulations.

As a consequence of the infant's position *in utero*, most newborns prefer to orient their heads to one side when supine for the first 3-6 months of life (Michel & Goodwin, 1979). When the head is turned to one side, the visual field is mainly restricted to viewing that side while other areas are not visible or only seen peripherally. Michel (1981) suggested that infants preferring to orient their heads to one side have asymmetrical visual experience, such that right-oriented infants are viewing the right hand more than the left, and vice versa for left-oriented infants. Thus, for right-oriented infants, the right hand has more opportunities for hand-eye coordination and, hence, the infant is more adept at visually guiding the right hand, as compared to the left hand (and the opposite for left-oriented). Most infants prefer to orient toward their right side and a minority prefer to orient to their left side.

As one might expect, the direction of a neonate's head orientation preference (HOP) predicts later handedness (Michel, 1981). A right HOP leads to later right handedness, and a left HOP leads to later left handedness.

As motor control of the hands develops, the infant manually interacts with objects in the environment. Even seemingly simple actions, such as acquiring an object, are challenging for a very young infant; therefore, the infant is more likely to use the hand with more visually-guided coordination to attempt these types of actions. Michel (1981) suggests that infants with a HOP sees one hand more than the other hand (for example, a right HOP results in more visual experience with the right hand; Coryell & Michel, 1978). Since one hand is in the infant's visual field more frequently, the infant may develop greater visuomotor control over that hand (Michel, 1981). In this way, the more skilled hand becomes the preferred hand for acquiring objects by 6 months and this preference remains until 13-14 months of age (Michel, Babik, Sheu, & Campbell, 2013a; Michel, Tyler, Ferre, & Sheu, 2006).

Although most infants make the transition from a head orientation preference to a hand use preference, some do not exhibit a distinctive neonatal HOP and/or have no hand use preference (35%; Michel, 1981). Interestingly, infants with a hand preference for acquiring objects reach differently than those without a preference: the preferred hand leads the nonpreferred hand during a bimanual reach. In contrast, infants without a hand preference appear to be less skilled at bimanual reaching (Goldfield & Michel, 1986a). Goldfield and Michel (1986b) demonstrated this by presenting 7 and 11 month-old infant objects requiring bimanual acquisition and perturbing the movement path of one hand with a barrier. At both ages, infants with a hand preference successfully reached around the barrier when the preferred side is blocked. In contrast, when the nonpreferred side is blocked, the nonpreferred hand stops at the barrier, while the preferred hand continues forward (Goldfield & Michel, 1986a). Infants without a hand preference are unable to reach both hands around the barrier regardless on which side the barrier is placed, thus they are less skilled in bimanual reaching.

Infants with a hand preference to acquire objects also tend to manipulate objects using this same preferred hand (Hinojosa, Sheu, & Michel, 2003). Initially 3 – 5 month-old infants can only perform simple hand manipulations, like clutching, kneading objects, or putting objects to their mouth, which all provide tactile and visual information about the character of objects (Bushnell & Boudreau, 1993). As they develop, infants manipulate the object with increasingly complex exploration (Bushnell & Boudreau, 1993; Lederman & Klatzky, 1987). By manipulating objects in their environment and using visual feedback from such manipulation, infants can adapt their actions in anticipation of how the environment changes as a consequence of the manipulation (Piaget, 1952). Although not terribly accurate in their reaching ability, 4-6 month-old infants adjust the speed of reaching for objects with different properties, such as apparent rigidity, orientation, or size (Lockman, Ashmead, & Bushnell, 1984; Rocha, Silva, & Tudella, 2006; Ruff, 1980; Siddiqui, 1995). Nine-month-old infants appropriately rotate their hands while reaching for vertically- or horizontally-oriented dowels, whereas 5-month-old infants only rotate after they have touched the dowels (Lockman et al., 1984). Infants adjust their reaching grasp relative to the size of an object by 9 months, such as using a pincer grasp (thumb to index finger only) for acquiring objects <2 cm or whole hand grasps for acquiring objects larger than 7 cm (Siddiqui, 1995). Because they are successfully adjusting their action to accommodate an object's unique characteristics, infants in these studies are demonstrating a working knowledge of object size, orientation and rigidity, based on visual information.

In sum, many infants develop a hand preference which remains relatively stable throughout the 6-14 month period (Michel et al., 2013a; Michel et al., 2006). Infants with a hand preference tend to manipulate objects using the same preferred hand for a variety of actions (unimanual manipulation: Hinojosa, Sheu, & Michel, 2003; object management: Kotwica, Ferre, & Michel, 2008; etc.). Consequently, a hand that is used preferentially becomes more practiced, and thus more proficient than a non-preferred hand. Thus, the preferred hand is more motorically proficient and more adept at interacting with the environment than their non-preferred hand. An infant with a hand preference can manipulate objects in their environment more readily with their preferred hand. In contrast, a non-preferred hand is less practiced and not as proficient as a preferred hand. An infant without a distinct hand preference is likely to have poor motor precision in *both* hands, since *neither* hand is preferentially used (Flowers, 1975; Michel, 1998). Thus, the presence or absence of a stable hand preference throughout infancy likely changes the character of an infant's experience with the environment. An infant can explore the environment more readily with a skilled hand (those with a hand preference), than with two less-skilled hands (those without a hand preference).

The Emergence of Constructing Ability

Near the end of their first year, infants begin to relate objects to one another and even create more complex organizations of objects (Gesell & Amatruda, 1941). Infants, aged 7-15 months, are exploring object-on-object interactions through role-differentiated bimanual manipulation (two hands perform a single action in complementary, but different roles: Kimmerle, Ferre, Kotwica, & Michel, 2010), container play (objects are placed into other objects nonfunctionally: Largo & Howard, 1979), and object pairing (one object acts upon another object: Greenfield, Nelson, & Saltzman, 1972). Later, simple two-object interactions lose prominence in the repertoire, and infants attempt more complicated two-object interactions (such as, object retrieval using a tool: Bates, Carlson-Luden, & Bretherton, 1980) or multi-object constructing actions (such as, stacking blocks: Chen, Keen, Rosander, & von Hofsten, 2010; three cup nesting: Greenfield, Nelson, & Saltzman, 1972; stacking different objects: Largo & Howard, 1979). A constructing action is a manipulation of multiple objects into a different, unified form, so that the structure maintains itself using the physical properties of the objects. Some examples of constructing actions are stacking blocks into a tower, nesting seriated cups within each other, assembling a jigsaw puzzle, or adhering magnets together. An infant's actions must be motorically precise and the infant must have a working knowledge of the objects' properties, in order to create multiple object constructions successfully. Because construction enables infants to learn information about their environment, its development may inform how infant cognition might arise from physical manipulation of the environment (Takeshita, 2001).

Construction is a particularly challenging skill for late infancy, because it requires object management skills. Bruner (1973b) argued that object management skill, or storage of more than two objects, demonstrates a type of symbolic representation. Object management skill allows the infant to retain possession over an object not currently in use; but permits the infant to engage the object later, as it is still readily available (Kotwica, Ferre, & Michel, 2008). An object that is still possessed by the infant but not currently in use requires a mental representation of the object; therefore, an infant needs the representation to continue managing the unused object (Bruner, 1973b). If an infant is given more than two objects, the infant must store any overflow in order to retain control over the objects they have already acquired (e.g., placing objects on the forearm or on the table within reach: Bruner, 1973b). These management strategies permit the infant to reacquire and incorporate the placed objects into additional manipulations and collections of objects to further explore the objects' associations. Constructing skill requires manipulation of multiple pieces to create a structure; thus, the infant may utilize mental representation of unused objects in order to create a structure with multiple objects.

Since infants with a hand preference perform some of the skills associated with object management (object acquisition, etc.) better than infants without a hand preference, Kotwica, Ferre, and Michel (2008) examined whether handedness affected object management skill in 7-13 month infants. Infants were presented with a set of four objects one-by-one in order to elicit object management behavior. Not surprisingly, Kotwica, Ferre, and Michel (2008) found that infants with a hand use preference are better able to manage multiple toys, than infants with no preference. In this way, infants with a hand preference are more advanced in early symbolic representation than infants with no stable handedness.

Stacking is probably the most recognizable form of constructing skill during infancy, especially stacking blocks into a tower. For stacking to be successful, the infant must attend to the block's shape (e.g., placing the flat side of one block on top of the flat side of another block), weight (e.g., lighter items on the top), and size (e.g., larger items supporting the smaller ones, etc.) in order to properly place the block, otherwise stacking could fail. Not only must the infant utilize the block's properties appropriately, but the infant must be precise and controlled in the stacking action, in order to accomplish the task without perturbing the tower. Infants can usually stack a pair of blocks at 1 year of age; however there are significant developmental changes from 1-3 years old, where 3-year-olds can easily stack blocks and even replicate patterns and colors similar to a model (Hayashi, Sekine, Tanaka, & Takeshita, 2009).

Chen et al. (2010) found that 18-21 month olds who were able to stack tall block towers early in development employed more refined and controlled motor strategies, than those who could not build tall towers. Toddlers who could build tall towers exhibited kinematic differences in their stacking actions, such that the arm greatly slowed near the tower (Chen et al., 2010). This slowed movement might have allowed these toddlers an opportunity to place a block more precisely, which permits the toddler to correct the placement more effectively using visual and haptic feedback. In contrast, toddlers who could only build short towers exhibited an increase in the action speed during the middle of the reach and slowed the rate of speed much later in the movement trajectory. These toddlers were less successful at tower-building using this action strategy, since it is not conducive to precise block placement. At 18-21 months, motor precision of the stacking action seems to be important to stacking blocks successfully. Perhaps more surprising, the two groups of toddlers still showed kinematic differences at the tower-building task a year later, even though both groups were comparable in tower height (Chen et al., 2010). In this older age period, the toddlers who could build tall towers at 18-21 months did not have the marked slowing of the stacking action, which the authors interpreted as evidence that these children were more skillful at stacking. The toddlers who built short towers at 18-21 months now resembled the kinematic data of the tall-building group at 18-21 months. Unfortunately, a measure of handedness was not included in this study. Nonetheless because a hand preference signifies increased motor precision of one hand, infants with a preference are likely to stack with their preferred hand more and exhibit more skilled stacking than infants without a hand preference. Right-handed toddlers (18 – 26 months) tend to use their right hand when stacking blocks, and as the strength of their right-handedness increases, their use of their right hand for stacking increases (Marschik, Einspieler, Strohmeier, Garzarolli, & Prechtl, 2007).

Infants typically exhibit nesting around the age of 10 or 11 months (Greenfield & Westerman, 1978). Greenfield, Nelson, and Saltzman (1972) presented infants with five nesting cups and recorded the types of cup interactions. At 11 months, infants almost solely perform pairing (two cup interactions); yet the use of pairing declines significantly and mostly disappears at 20 months (Greenfield et al., 1972). Pairing is replaced by multiple cups nesting which requires a correct serial placement of the cups, otherwise complete nesting fails. For instance, if an infant nests the smallest of 3 cups into the largest cup, then the middle size cup cannot be nested without removing the smallest cup. Infants first attempt to correct a nesting error, by only altering a single, non-fitting cup, whereas older children can make corrections in a sequence of multiple cups (DeLoache, Sugarman, & Brown, 1985). The infant can readily correct nesting errors (for example, the smallest cup in the largest cup before placing the middle size cup) by removing the smallest and replacing it with the middle size cup, or orienting the second cup's open side over the smallest cup. By early childhood (42 months), they are more likely to make fewer errors and more correct adjustments following an error (DeLoache et al., 1985).

Infants are also learning to affix objects together, in ways that require the use of special materials (as with magnets or clay) or based on the shape of an object (as with fitting puzzle pieces together). Affixing occurs when objects are merged together without the assistance of gravity to hold the objects together. In order to affix, infants first must identify unique materials or shapes, and how they react to other objects, substrates, or shapes. Morgante and Johnson (2011) found that 12-18 month-old infants adjust their object-on-object exploratory behavior, based on the object's utility. For instance, infants tended to stick a Velcro block on Velcro, rather than attempting to stick it on paper or in sand. On the other hand, infants drew with a crayon in sand or on paper, much more so than on Velcro (Morgante & Johnson, 2011). As an infant interacts with objects (such as, crayons) and substrates (such as, paper) the infant will come to identify their unique properties and consequences. A crayon drawn on paper creates a certain consequence (crayon lines), which is different from a crayon drawn on Velcro. Thus, the infant must not only associate this consequence (drawing lines) with the object (crayon), but the substrate (paper) as well. Successfully affixing objects also requires these kinds of associations, otherwise the objects are unlikely to affix. A Velcro object sticks on other Velcro items, but not the wall or on paper. Magnets can only be stuck to another magnetic object's opposing pole, but not on Velcro or a wooden table. In this case, the infant must associate the properties of a Velcro object or magnet with the properties of its substrate.

Although few studies have examined affixing during infancy, tasks requiring affixing ability have been studied more so in older children. Greenfield and Schneider (1977) gave children (ages 3 – 11) connecting straws in order to create a hierarchical structure resembling a branching tree. The complexity of the model increased from 3-6 years of age. The older ages (6, 7, 9, and 11 years) did not show new levels of complexity; yet these older groups did use different strategies to assemble their models (Greenfield & Schneider, 1977). Greenfield and Childs (1977) asked Mexican children ages 4 - 18 years from the Zinacantecos tribe to copy a number of patterns by weaving colored sticks into a wooden frame, using patterns and materials similar to those used in their wool clothing. The youngest ages (4-5 years old) were able to weave these sticks, and the older ages could replicate complicated striped patterns presented by the researchers (Greenfield & Schneider, 1977).

Increased manipulation of objects in one's environment likely leads to a greater knowledge of the object's characteristics. One might expect for children who construct objects more effectively to exhibit better cognitive skills associated with construction. The literature shows this for the cognitive skill of conservation (Price-Williams, Gordon, & Ramirez, 1967). In two cultural groups of rural Mexico, children help their families in their trades, such as pottery or farm labor; thus children of potters regularly manipulate wet clay to make a variety of items (cups, pots, toys, etc.). Since children of potters gain more experience in constructing new items from clay, one would predict that these children would be better at conservation tasks. Price-Williams, Gordon, and Ramirez (1967) tested these Mexican children (6 – 9 years) on a number of conservation tasks with different substances, including, toy coins on a scale, toy coins arranged in shapes on the table, water in differently-sized glasses, and modeling clay. Children of potters responded correctly more often to conservation tasks and had more correct explanations of their choices, than children whose parents were not potters, particularly when the conservation task involved clay (Price-Williams, Gordon, & Ramirez, 1967). Additionally, children who formed pottery out of clay at earlier ages displayed greater knowledge of conservation, than those who learned later or never learned pottery-making (Price-Williams, Gordon, & Ramirez, 1967). Hence, when children manipulate objects and substances in their environment, they learn about it and may utilize these principles for other substances and in more general circumstances.

Although studies with older children (3+ years) capture strategies associated with constructing ability, they fail to capture the *onset* of constructing ability and how children acquire them. The current study seeks to capture the onset of constructing ability during late infancy (10-14 months) and identify the contribution of the infant's hand preference to the development of the ability to construct. As individuals develop, they continue to acquire knowledge about the properties of objects in their environment. Thus, early constructing skills reveal early knowledge of object properties, such as spatial relations between objects. A child who constructs may utilize or subsequently learn the consequences of spatial orientations, since construction requires that objects be placed in different spatial relations to each other. For this reason, infants entering this period with increased spatial abilities may have an advantage over others with poorer spatial abilities. Handedness could be a factor, since one study showed that left-handed children performed better than right-handed children on a spatial task at 10 years of age (Natsopoulos & Kiosseoglou, 1992). Not only could the development of construction inform us about the development of the individual's knowledge of object properties, but also could likely reveal something about the early development of spatial abilities or other cognitive abilities.

This project investigates the relation between infant's handedness and the development of manual construction skills from 10-14 months of age. The 10-14 month period was chosen because during this age period simpler object-on-object interactions make a transition into constructing ability with multiple objects. In addition, 10-14 month old infants are able to manage multiple objects, which is essential to constructing multiple objects. Since infants with a hand preference have better motor control of their limbs, greater experience with the properties of their environment, and increased object management skills, infants with a stable hand preference (regardless of left or right) are hypothesized to be more successful at constructing, than infants without a stable hand preference. Unfortunately, there is not much information about left-handed infants, as most studies combine left-handed infants into a stable handedness group. Most of the literature's information is based on right-handed or groups of stably-handed infants (collapsing left and right). There does not appear to be a theoretical reason for why left-handed infants will be different from right-handed infants, as both groups have increased experience using a preferred hand. For this reason, no differences between right- or left-handed infants are predicted. This study will test models with separate groups of infants with a left preference, right preference, or no preference, and groups of infants with a lateralized hand preference or no hand preference.

Sex Differences in Handedness and Constructing Ability

In the adult population, males seem to be more prone to be left-handed, mixed-handed, or less strongly lateralized in handedness, than females. A large scale meta-analysis by Papadatou-Pastou et al. (2008) found that males had significantly higher odds of being left-, mixed-[1], and non-right-handed[2], than females. Although the method of handedness assessment affects rates of handedness, a meaningful sex difference persists across multiple measurement types (Papadatou-

[1] Mixed-handed means that across multiple tasks, a participant was classified as having a different handedness (Papadatou-pastou et al., 2008).

[2] Non-right-handed is a classification which typically encompasses all handedness types which are NOT right handed. Left, mixed, ambidextral, or ambisinistral handedness would fall under this category (Papadatou-pastou et al., 2008).

pastou et al., 2008). Regrettably, Papadatou-Pastou et al. (2008) excluded studies that used hand performance as a measure for handedness, and only focused on questionnaires, self-report, or hand used for a single one-handed action (like, writing hand). Although some suggest that hand preference typically stems from which hand is more skilled (for e.g., Bishop, 1989), the method of assessing handedness can change the character of handedness data (Annett, 1992; Bishop, 1990). Self-reported handedness may derive from other factors unrelated to manual skill, such as cultural or social expectations about handedness (Michel, Nelson, Babik, Campbell, & Marcinowski, 2013b). Nevertheless, other large scale studies using manual performance methods often report that adult males are more likely to be left- or mixed-handed as compared to adult females (Annett, 1994). Annett (1970, 1994) reports that male children (3.5 – 17 years) exhibit higher rates of mixed- and left-handedness, than female children. Males also exhibit less of a difference in hand skill between their hands, whereas females are much more asymmetrical in hand skill (Annett, 1970). Lung et al. (2011) find that there are no sex differences for fine motor skills for manual tasks in 6 and 18 month olds; although 3-5 year-old females exhibit greater fine motor skills than males. Unfortunately, the authors do not entirely describe their measure of "fine motor skills" and handedness was not measured in this study (Lung et al., 2011).

Infant sex differences are much less clear for handedness or manual development. Although many authors fail to find a sex difference for infant manual actions (e.g., Bryan & Davies, 1974; Babik, Campbell, & Michel, 2013; Solomons & Solomons, 1975), others have. Phillips, King, and DuBois (1978) observed 1-day-old newborns' behaviors, and found that males exhibited higher levels of low-intensity motor movements (including hand actions) than females. In contrast, Grattan, De Vos, Levy, and McClintock (1992) did not find a sex difference for upper limb reflexes; however they did find that females had a right bias for the strength of distal lower limb reflexes, while males had a left bias. From 3-6 months of ages, females are also more likely to contact moving objects and they are more successful at grasping the object, than males (von Hofsten & Lindhagen, 1979).

Some reports indicate that male infants may be lateralized differently than females for some manual skills (Carlson & Harris, 1985). In a longitudinal study of visually-directed reaching, males with familial right handedness consistently preferred reaching for objects with their left hand from 7 – 13 months, whereas females with familial right handedness preferred their right hand throughout the entire period (Carlson & Harris, 1985). Humphrey and Humphrey (1987) also observed infants at two age groups: 5-8 month-olds and 9-12 month-olds. Females reached using their right hand at both age groups, and exhibited a clear right bias for reaching. On the other hand, 5-8 month-old males were just as likely to reach with their left or right hand. The authors conclude that females show a right hand preference for contacting objects earlier than males. These authors also suggest that their data provides a potential "precursor" of the sex difference found in adults (Humphrey & Humphrey, 1987).

Unfortunately these results are suspect, because they fail to use a statistically reliable measure of hand preference. For example, Humphrey and Humphrey (1987) recorded the infant's reaching behavior on only 3 object presentations and 2 presentations were of the same object. Assuming an infant has no hand preference and any variability in hand use occurs by chance, an infant using one hand on all three trials still has a chance likelihood of 12.5%. In addition, Humphrey and Humphrey (1987) grouped a wide range of ages into two single groups (5-8 and 9-12 month-olds) with a large potential for heterogeneity of motor skills which could affect manual actions (such as, posture: Babik, Campbell, & Michel, 2013; trunk stabilization: Hopkins & Ronnqvist, 2002; babbling: Ramsay, 1984; etc.). Thus, inadequate methods of assessing an infant hand preference, such as these, results in a puzzling picture of sex differences for the development of infant handedness.

In contrast to handedness, sex differences for constructing ability do not appear to manifest in early childhood. The literature almost universally fails to find a sex difference in constructing ability for many of the action types (affixing straws: Greenfield & Schneider, 1977; stacking blocks: Chen et al., 2010; Marschik et al., 2007; Labarthe, 1997; weaving sticks: Greenfield & Childs, 1977; nesting seriated cups, building a bridge, or building a propeller: Goodson & Greenfield, 1975; assembling a jigsaw puzzle: Thompson, 1999), or does not report a sex difference (nesting seriated cups: Greenfield et al., 1972). Perhaps because the male and female Zinacantecos children typically are taught weaving beginning at an early age, there appeared to be no sex differences in the ability to correctly weave patterns from the ages of 4 – 10 years (Greenfield & Childs, 1977). Labarthe (1997) found that female and male two-year-olds could build block towers equally well, although this study utilized only one tower-building task. One of the few studies of constructing ability with a sex difference found that males show greater skill for forming jigsaw puzzles, than females aged 3-5 years (Levine, Ratliff, Huttenlocher, & Cannon, 2011); yet another puzzle-solving study failed to find a sex difference in the very same age group (Thompson, 1999). Levine et al. (2011) did find that males in their sample typically spent more time at home playing with puzzles compared to females, which may account for the discrepancy between the Levine et al. (2011) and Thompson (1999) studies.

In addition, there are mixed results on sex differences on spatial abilities. Ornkloo and von Hofsten (2007) gave infants aged 14-26 months a rotation spatial task, which required the infants to insert differently-shaped rods into corresponding apertures. Although there was an effect for age, there was no evidence of a sex difference. Barnfield (1999) also found no significant sex difference for spatial memory in 4-year-olds, although adult females performed better than adult males in an object location task. In contrast, others have found that females demonstrate significantly poorer spatial abilities from 4-5 years (e.g., Levine, Huttenlocher, Taylor, & Langrock, 1999; Spetch & Parent, 2006), while 4-year-old females made fewer errors and acquired spatial competencies earlier than males in a modified radial arm maze (Mandolesi, Petrosini, Menghini, Addona, & Vicari, 2009). The literature has created a complicated and unclear picture of what, if any, sex differences are present in the development of spatial abilities.

This overwhelming failure to find a sex difference for construction and the mixed results for spatial abilities may seem compelling; however this does not mean that infants will not show a sex difference for constructing. Kotwica, Ferre, and Michel (2008) *did* find a sex difference for object management during infancy. Females were more likely to manage objects by object placement (the most common strategy) at 11 and 13 months, than males. Although object placement is not the only management strategy, the infant is able to more readily interact with the stored object, rather than other management strategies which are more precariously stored (e.g., placement on the forearm or in the crook of the elbow, etc.). In fact, object placement allows each object thorough manual comparison, because each objects' properties can be explored on its own with the same hand (Kotwica, Ferre, & Michel, 2008). Perceiving an object's haptic properties, such as weight or size, will have great bearing on how it can be constructed. Perhaps this increased ability to manage objects means that females will be better than males at constructing during the 10-14 month ages.

Since studies examining constructing skills in children typically use children older than 24 months of age, this study will focus on the earliest onset of construction. Perhaps, the onset of constructing skills examined in the current study's 10-14 month age period would manifest initial sex differences that disappear as children continue to develop. Also, it is possible that there could be differences in the underlying motor strategy between males and females older than 24 months, which might not be captured by measuring constructing success or number of constructed items. Although it may not accurately reflect the motor strategy for constructing, using number of items as a dependent measure *is* appropriate for the onset of constructing ability, since this skill is newly developing and still challenging for infants.

In sum, the current study will investigate the effect of sex on the development of manual building skills from 10-14 months of age. Since infants with an early hand preference exhibit increased manual precision and experience with the environment, infants who are more lateralized should show increased constructing ability. Left- and right-handed infants are hypothesized to construct better than infants with no preference. There is only some support for sex differences for infant handedness. Older children and toddlers do not show sex differences for constructing tasks; however there is some evidence that infants exhibit sex differences for object management. Thus, sex and its interaction with handedness will be included in the model. Because the relation between sex and constructing is unclear, its inclusion will be exploratory and there are no specific predictions about how sex will relate to the development of constructing skills. The statistical model will include the interaction of handedness and sex, as well as the main effects for handedness and sex.

CHAPTER II

METHODS

Participants

Infants (n=328) were recruited using Guilford County birth records in Greensboro, NC. All had full-term pregnancies and births without complications. The infants were brought to the Infant Development Center within seven days of their birth date from 6 to 14 months at monthly intervals, as a part of a larger longitudinal project. Procedures for recruitment, obtaining informed consent, and data collection were in accordance with the regulations set by the UNCG Institutional Review Board for the protection of human subjects. For each visit, parents were given a $10 Target gift card. From 6-14 months, infants were administered a reliable handedness assessment (Michel, Ovrut, & Harkins, 1985) and from 10-14 months, a construction assessment. From this larger dataset, a subsample (n=54) comprising infants born between March, 2010 to March, 2012 and who had missed 1 visit or less across the 6-14 month ages were selected for this study (excluding, 274 infants). In addition, one female was dropped due to fussiness, leaving a working sample of 53 infants. Only two infants have a missing visit during the 10-14 months, both due to sickness. One right-handed male missed his 10 month visit and a male with no hand preference missed his 12 month visit. All infants interacted with at least 4 construction objects at a visit, although the vast majority interacted with 6 (17.39%) or 7 toys (76.68% of the visits).

Our sub-sample comprised 67% Caucasian, 12% African American, 6% Hispanic, 2% Middle Eastern, and 14% multiracial infants, which is roughly representative of both the overall study sample (Michel et al., 2013a) and Guilford County's ethnic demographics (US Census Bureau, 2010; see Table 1).

Table 1. Demographics for the Sub-sample: Race, Income, and Education Level

Race Percentages

	Sub-sample (n=53)	Larger sample (n=328)	Guilford County
Caucasian	66% n=35	58%	60%
African-American	13% n=7	25%	33%
Hispanic	6% n=3	3%	7%
Middle Eastern	2% n=1	2%	*(not reported)*
Multiracial	13% n=7	12%	2%

Income

median	$70,000-$79,999	$70,000-$79,999	$46,288
range			
minimum	$10,000-$19,999	$10,000-$19,999	*(not reported)*
maximum	$150,000+	$150,000+	*(not reported)*

Education

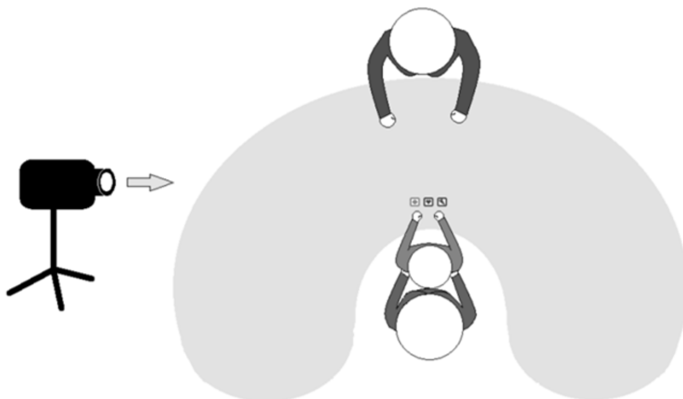
	Mother	Father
median	Bachelor's degree	Bachelor's degree
range		
minimum	Some college, no degree	High school graduate
maximum	Professional degree	Doctorate

Families' median yearly household incomes were $70,000-$79,999 (range: $10,000-$150,000). The mothers' education levels ranged from some college/no degree to a professional degree, while the fathers' education levels ranged from high school graduate to professional degree. The median education level for both was a bachelor's degree. The primary language spoken in the home was English for all participants, except 5 cases: 3 Spanish, 1 Arabic, and 1 French. Eighteen infants (33.96%) were right-handed, 11 infants (20.76%) were left-handed, and the remaining 24 (45.28%) were classified as having no stable handedness throughout the 6-14 month ages. Twenty-seven infants (50.94%) were male, and 26 were female (49.06%). See Figure 3 for the cell sizes.

Procedure

The experimenter sat directly across from the infant on the convex side of a rounded crescent-shaped table, while the infant sat on the concave side. The infant sat on the parent's lap, so the infant's navel was at table height, leaving his/her arms unconstrained. The parent sat close to the table and held the infant on either side of the infant's waist to maintain a stable posture. A camera (Panasonic WV-CP240) was placed to the side and directly above the infant's hands, allowing two views for coding accuracy (Figure 1). Each visit was recorded in its entirety for later data coding. If the baby became fussy during the session, a short break was taken. If the baby was still fussy after a second break, another appointment was scheduled within 5 days, and the measure was restarted at the second visit. Both the construction and the handedness tasks were in the same setting.

Figure 1. The Set-up for the Handedness and Construction Measures from the Top Camera View.



Handedness Task

In the handedness task during the 6-14 month visits, 32 objects of varying shapes and sizes were presented to infants, one-by-one. These objects were meant to interest the baby, enough to entice them to pick up and manipulate the objects. The objects were presented either singly (26 objects) or in pairs (6 objects). Single objects were presented either on the table (29 objects) or in the air (3 objects) to the infant's midline, in line with the baby's nose. Air objects were held 20 cm from the baby's shoulders and 12-15 cm above the table. The paired objects were two identical objects placed on the table in line with the baby's shoulders. All paired objects were presented on the table. These different types of presentations were included to introduce more variety into the session; however prior research suggests that type of presentation does not appear to have an impact on the hand used (Michel, Ovrut, & Harkins, 1985).

The presenter allowed the infants to manipulate each object until its pick-up or after 20 seconds (whichever occurred first). The hand(s) initially used to pick-up the object(s) were recorded by the camera for later coding. The entire handedness task lasted approximately 15 minutes. Videos were coded using Noldus © Observer XT 10.1, which allows coders to stop or slow down the videos for coding accuracy. On 20% of randomly-selected videos, overall inter-rater agreement was 93.22% with a Cohen's kappa of 0.898. On a separate set of 20% of randomly-selected videos, overall intra-rater agreement was 97.9% with a Cohen's kappa of 0.969.

Construction Task

In the construction task at the 10-14 month visits, six objects comprising the construction task were presented. The six constructing objects are: Stand with Rings, Cylinder Blocks, ABC Blocks, Magnet Sticks, Stacking/Nesting Cakes, and Magnet Spheres. The Stand with Rings is a yellow stand with three rings of differing sizes and colors (blue, yellow and red). The Cylinder Blocks are comprised of six cylindrical wooden blocks which are painted red (3) and purple (3). The ABC Blocks are six wooden cubes with alphabet letters painted with multiple colors on all sides. The Magnet Sticks are three evenly sized sticks with magnets on each end (1 yellow, 1 green, and 1 red). The Stacking/Nesting Cakes are four differently-sized cups colored to look like cakes (2 brown and 2 white). The Magnet Spheres are comprised of 5 rounded shapes: 2 short cylinders (both teal) and 3 half-sphere magnets (2 blue and 1 red). The Stacking/Nesting Cakes can be used to stack in a tower or nest within each other. For this reason, these were presented twice; one presentation demonstrated stacking and one presentation demonstrated nesting. With the two construction presentations available for the cakes, each infant is provided with seven construction opportunities for each visit.

Before giving the object to the infant, the presenter would demonstrate how the object could be constructed and then de-constructed. Then the object was presented using both hands to the baby in a completely deconstructed state. For instance, the ABC Blocks were stacked one-by-one into a tower using all the blocks, the blocks were de-stacked one-by-one, and then the deconstructed blocks were simultaneously presented to the infant. The presenter hand demonstrating construction alternated with each stack (e.g., right-left-right) and the initial hand used alternated in a pseudo-random fashion between objects. The infant played with each object for at least 20 seconds. The entire construction task lasted approximately 6 minutes.

Videos of the construction task were also coded using Noldus © Observer XT 10.1. Data for determining both inter-rater and intra-rater reliabilities were balanced so that each age (10-14 months) was represented equally in the reliability score. Coders were blind to the infant's handedness. On 20% of randomly-selected videos, inter-rater reliability was calculated using Cohen's kappa (κ= 0.953) and overall agreement (96.6%). In addition, intra-rater reliabilities for 20% of randomly-selected videos using Cohen's kappa (κ= 0.975) and overall agreement (97.9%).

The three coded construction actions are stacking, nesting or affixing, although each object had only one or two actions which were possible. "Stacking" is defined as placing an individual object on top of another. Stacking was possible for the Cylinder blocks, ABC blocks, Stacking/Nesting cakes, and the Stacking rings (rings stacked on each other without the stand). When an object had an open end (as with the cakes), stacking can only be observed when the base object has a solid side facing up. "Nesting" is defined as when an infant places or settles an individual object inside another object. Nesting can only be observed when the open end of the base object is facing up, and cannot be observed when its solid side is facing up. Nesting is only possible in the Stacking/Nesting Cakes. "Affixing" is defined as joining or attaching an individual object to another. This action is only observed when objects can remain together without the assistance of gravity. Affixing is only possible with the Magnet Sticks or Magnet Spheres (due to magnetism), or the Stacking Rings (when the rings are fitted onto the stand).

Only successful constructions are counted towards this analysis. A successful construction is defined as when the object in the infant's hand was built upon the base object, *and* the infant removes his/her hand without the object immediately losing its placement. If the object fell out of place once the infant let go of the object, then this is not considered a successful construction (e.g., the infant places a block onto a tower, and it falls off the tower immediately). A successfully nested object is when all included objects were completely settled within each other; that is, the objects must be nested in the correct order based on descending size. A magnetic object could be affixed in one of two ways. First, the infant could affix two magnets using two hands. Second, an infant with one hand could move one magnet to the other magnet which resulted in adherence. If another magnet rolls toward their hand and adheres to a magnet in the infant's stationary hand, this is not considered a successful affix. The Stacking Rings could be affixed by the infant placing the rings over the stick stand, and the ring maintains its position after the infant's hand is removed.

Variables

The independent variables were age, sex, and handedness. Sex was recorded at the first visit based on parent report. The infant's date of birth and sex were determined from the preliminary contact with the parent. Infant age, the time variable in all analyses, was calculated from the infants' dates of birth. An infant's hand preference was determined using Group-based trajectory modeling (GBTM; Michel et al., 2013). GBTM is a statistical technique which clusters similar patterns of trajectories together, and identifies sub-groups whose members follow a similar developmental trend (Haviland, Nagin, Rosenbaum, & Tremblay, 2008). Sub-groups may be qualitatively different within a population, but relatively homogeneous within the sub-group; since it assumes that the observations are drawn from a population with distinct sub-groups

(Michel, Sheu, & Brumley, 2002). The GBTM analysis was performed on the larger dataset (n = 328) prior to creating the sub-sample (n = 53).

For this analysis, first, the hand an infant used to initially pick-up an object was coded for each of the objects. Then, the handedness task data at each age were used to compute this formula: Hand use = $\frac{(\Sigma(Right\ pick-ups))-(\Sigma(Left\ pick-ups))}{\sqrt{(\Sigma(Right\ pick-ups)+\Sigma(Left\ pick-ups))}}$. This formula does not include a "Both Hand" pick-up in the denominator; because handedness is characterized by lateralized hand use. Both hand pick-ups may not represent the same phenomenon as a left or right hand pick-up, as there are different influences on its development (such as, postural development: Babik, Campbell, & Michel, 2013) than unimanual hand use. For these reasons, both hand pick-ups were not included in the analyses.

Next, the handedness of each infant was determined through GBTM using the SAS TRAJ procedure (Jones, Nagin, & Roeder, 2001; Babik, Campbell, & Michel, 2013). This method of obtaining handedness is beneficial for two reasons. First, it does not assign a hand preference, based on an arbitrary cut point (e.g., majority) or insufficient object presentations. Second, this method is based on a trajectory, and thus may more adequately represent a developmental perspective on infant handedness (e.g., lateralized handedness trajectories are curvilinear, whereas infants with no preference are linear; Babik, Campbell, & Michel, 2013). The GBTM was performed on the entire sample (n=328), and the sub-sample's handedness classification from the larger analysis was used for the current study. For the purposes of testing the hypotheses, two handedness grouping methods were employed. Infants were categorized based on whether they exhibited "Lateralized or Not Lateralized" handedness and for Left, Right, or No stable handedness.

The dependent variable, "Constructing," was calculated as a sum of all successfully constructed pieces to all available pieces across all construction objects. For example, if an infant constructed 1 ABC block, 2 Round blocks, and 0 of the other toys, the infant's score would be 3. Originally stacking actions for the Stacking Rings were coded; however very few infants ever stacked the rings (i.e., placing the rings on each other and not on the stand). Only 17 instances (or 6.46%) occur over all presentations, and in only 5 instances (or 1.90%) is this the highest stacking height (actually, one infant is responsible for 4 of these 5 instances in her 11-14 month visits). The mean of stacking both with and without the Stacking Rings was calculated, and it changes in only 16 cases (or 6.08%). The estimated mean of stacking with the Stacking Rings is ($\hat{\mu}$=3.250, $\hat{\sigma}$=4.010), but without the Stacking Rings is ($\hat{\mu}$=3.161, $\hat{\sigma}$=4.032). Because the mean difference is very small (0.089 pieces) and this type of construction occurred very infrequently, it was excluded from the analysis and only affixing of the Stacking Rings was included.

CHAPTER III

RESULTS

Analytic Plan

This data was analyzed with longitudinal multilevel modeling (LMM), using the software program, Hierarchical Linear Modeling (HLM v.6.06). This type of data analysis describes change over time, and how these changes vary across individuals and groups (Singer & Willett, 2003). There are benefits to using LMM over traditional methods of longitudinal analysis. First, it can accommodate variables that change over time (Level 1) and variables that are stable over time (Level 2) into a single model. Second, missing data points do not eliminate a participant from analyses, as with least squares regression repeated measures analyses (Howell, 2008), since individuals' trajectories are calculated using all available data points. More specifically, missing data are accommodated more effectively than in other longitudinal methods (such as repeated measures ANOVA), because participants' data are mapped as trajectories as a function of time. Finally, unequal sequencing of observations can be easily accounted for by modeling the children's unique ages at each assessment.

The current study's Level 1 (time-varying) variables include Age and Age^2, and Level 2 (time-stable) variables are sex, handedness status, and their interactions. Age was centered at 10 months and Age^2 was coded as an orthogonal polynomial to decrease multicollinearity (Bock, 1975). The time-stable characteristics were Sex (females =1, males=0), Handedness (Left/Right/No), Handedness (Lateralized/Not lateralized), and their interactions. Handedness (Left/Right/No) was coded as two dummy variables for "Right" and "Left" with no preference infants as the handedness reference group.

The dependent variable (sum of constructions) is a count variable, which comprises non-negative integers. The current study's data have many low values (such as, 0 or 1), especially at the younger ages, and so, their distributions are right-skewed. Poisson distributions are often used to model count variables in models where the assumptions about normality of errors is untenable (Long, 1997). Thus, the data were analyzed using a Poisson distribution of errors (residuals), rather than a normal distribution. Thus, a "multilevel Poisson longitudinal model" was chosen, which is a longitudinal generalized linear model useful for longitudinal data with count outcomes.

Although every attempt was made to give the infants a full set of toys, there were occasions where pieces would be missing from the data. Missing data occurred when item(s) were immediately scattered or thrown off of the table by the infant, when an infant refused a toy, or when a presenter made an error. Therefore, a small number of infants had a differing number of opportunities to construct. To correct for the differences in constructing opportunities, the model allowed for variable exposure, by adding an additional variable marking the number of presented items at each visit.

Poisson regression transforms the dependent variable into a rate parameter (λ_i), which is linear to the predictors. A Poisson regression model tests the rate of constructions occurring; thus, this exposure variable incorporates the differences in opportunity at each visit into the model. The rate parameter can be conceptualized as the rate by which constructing increased, relative to the total number of constructing opportunities, at each visit.

A standard Poisson distribution has a variance equal to its mean. Since count data frequently violate this assumption, a modified version of Poisson models have been developed called over- or underdispersed Poisson models. Overdispersion implies that there is more variability than expected under a standard Poisson model; while underdispersion means there is less variability than expected. In the case of standard multilevel longitudinal Poisson models, HLM constrains the level 1 (σ_{ε}^{2}) variance parameter to 1. In HLM, longitudinal Poisson models allow for over/underdispersion by estimating the level 1 variance parameter. If the model's Level 1 variance is <1, it is underdispersed; whereas if it is >1, it is overdispersed. Underdispersion is typically expected in datasets with a large number of zeroes as with the current study's younger infants.

Exploratory Analyses

Exploratory analyses were performed using JMP 10 (© 2012, SAS Institute, Inc.) in order to understand distributional properties of the data at each assessment point. The distribution of constructing skill appears right-skewed, especially at the younger ages (see Figure 2). As age increases, the mean of the distribution increases, until by 14 months, it appears roughly symmetrical. The variability also increases across the ages. Thus, both the mean and variability of constructing skill are increasing across the age period, which is typical of Poisson models (Long, 1997). The constructing skills of infants from each Sex by Handedness groups were graphed across age in order to see how infants individually change across the 10-14 month period (see Figure 3). Both the number of constructed items and their variability at the individual level appear to increase as infants age.

Figure 2. Distribution of the Overall Proportion of Constructed Items by Infant Age.

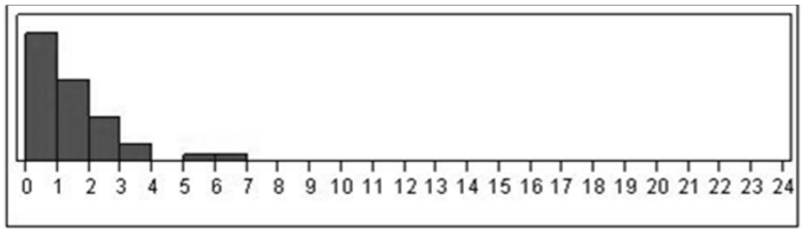
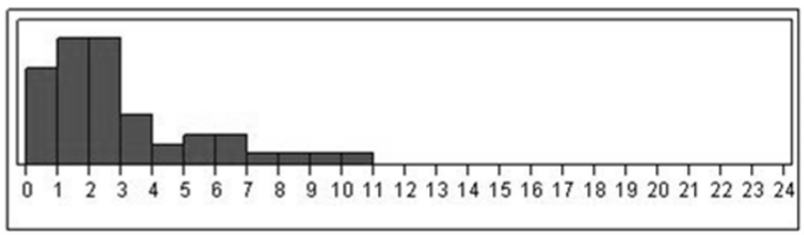
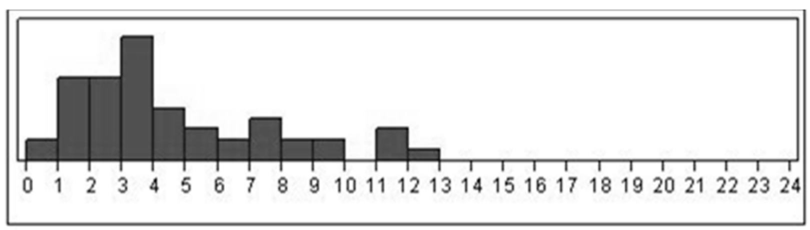
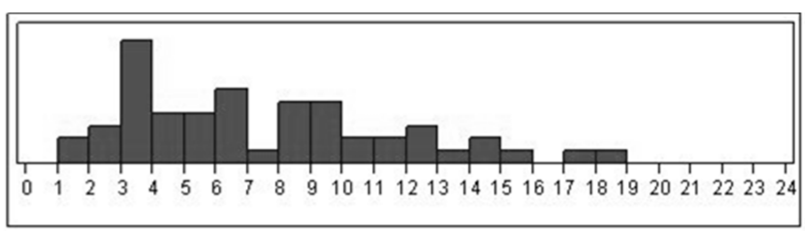
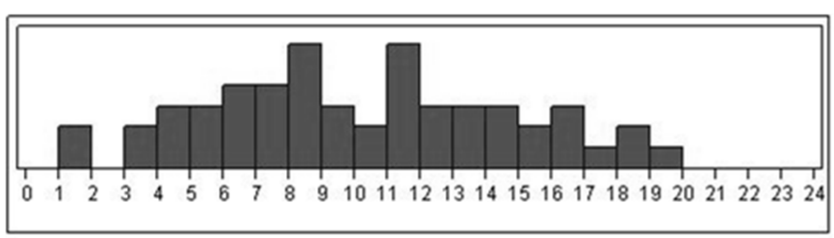
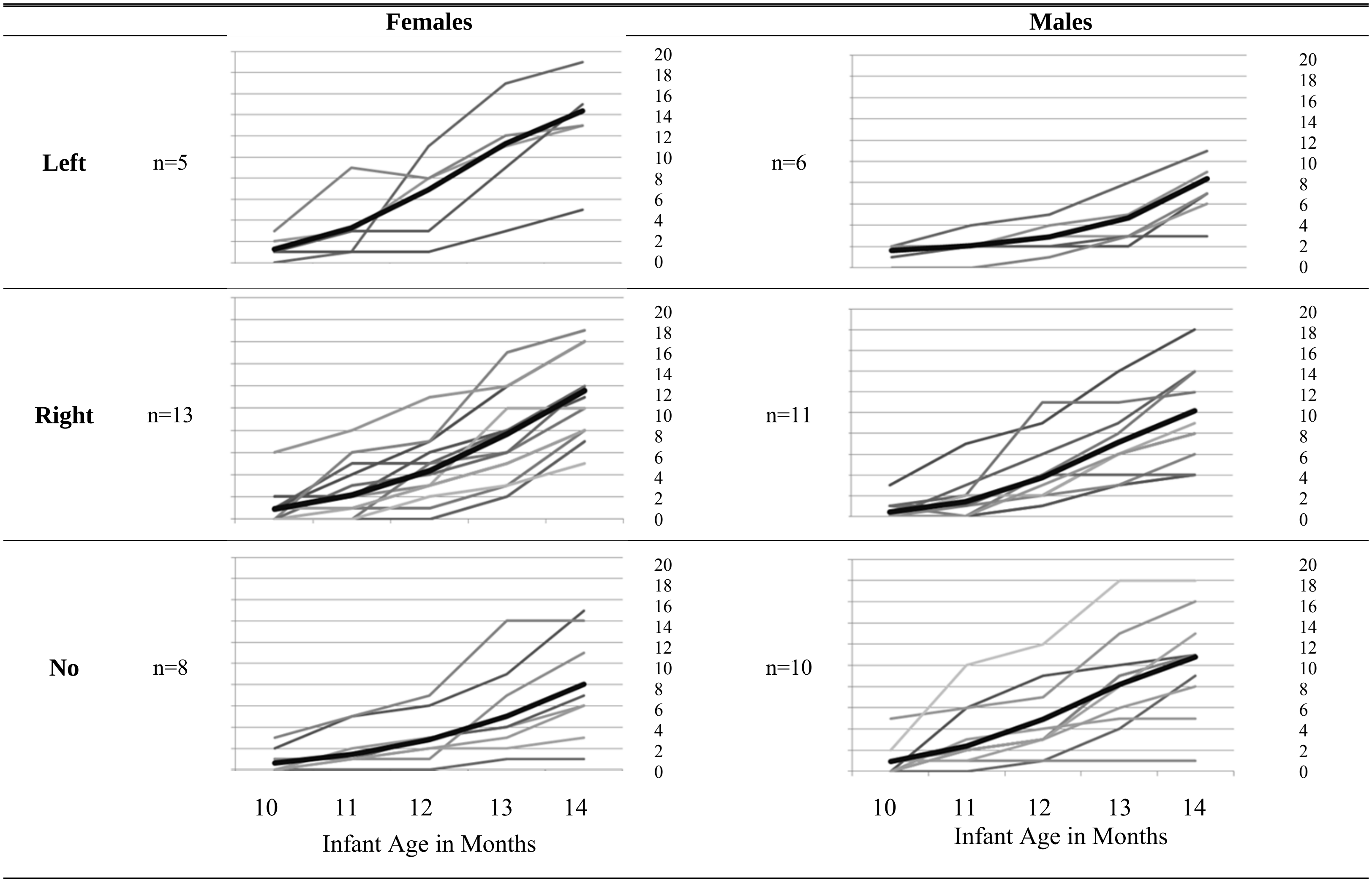
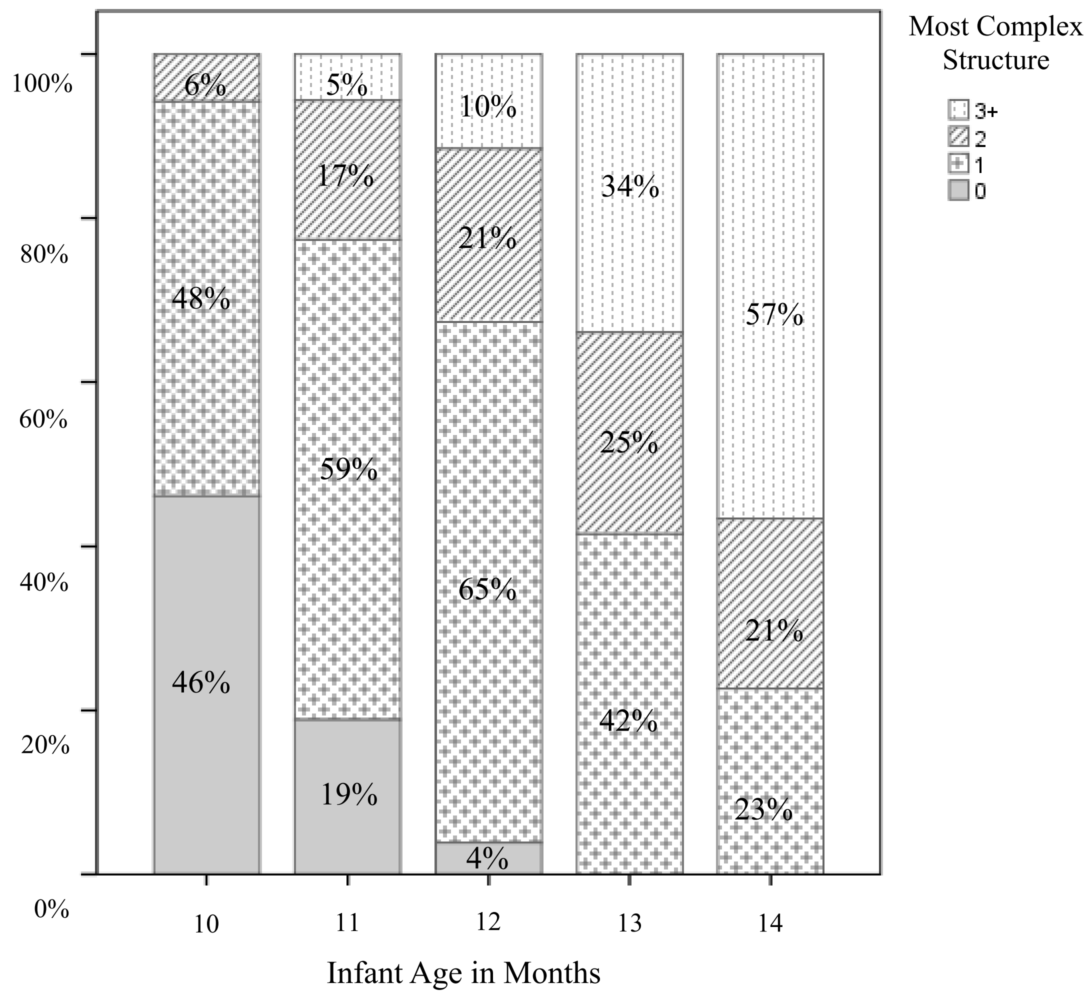
Infant Age	**Distribution**
10 months	
11 months	
12 months	
13 months	
14 months	

Figure 3. Lattice Plot Depicting Infants from Sex*Handedness Groups Increasing Their Constructing Skill over Infant Age.



Infants are not only increasing the number of items constructed across toys, but they are increasing the number of items constructed within toys. Figure 4 describes the estimated percentages of infants' most complex structure achieved across the 10-14 month period. The 10-month-old infants are primarily constructing 1 or no items (94%); whereas 57% of 14-month-olds can build 3 or more items.

Figure 4. Percentage of Infants' Most Complex Structure at Each Possibility at Each Month.

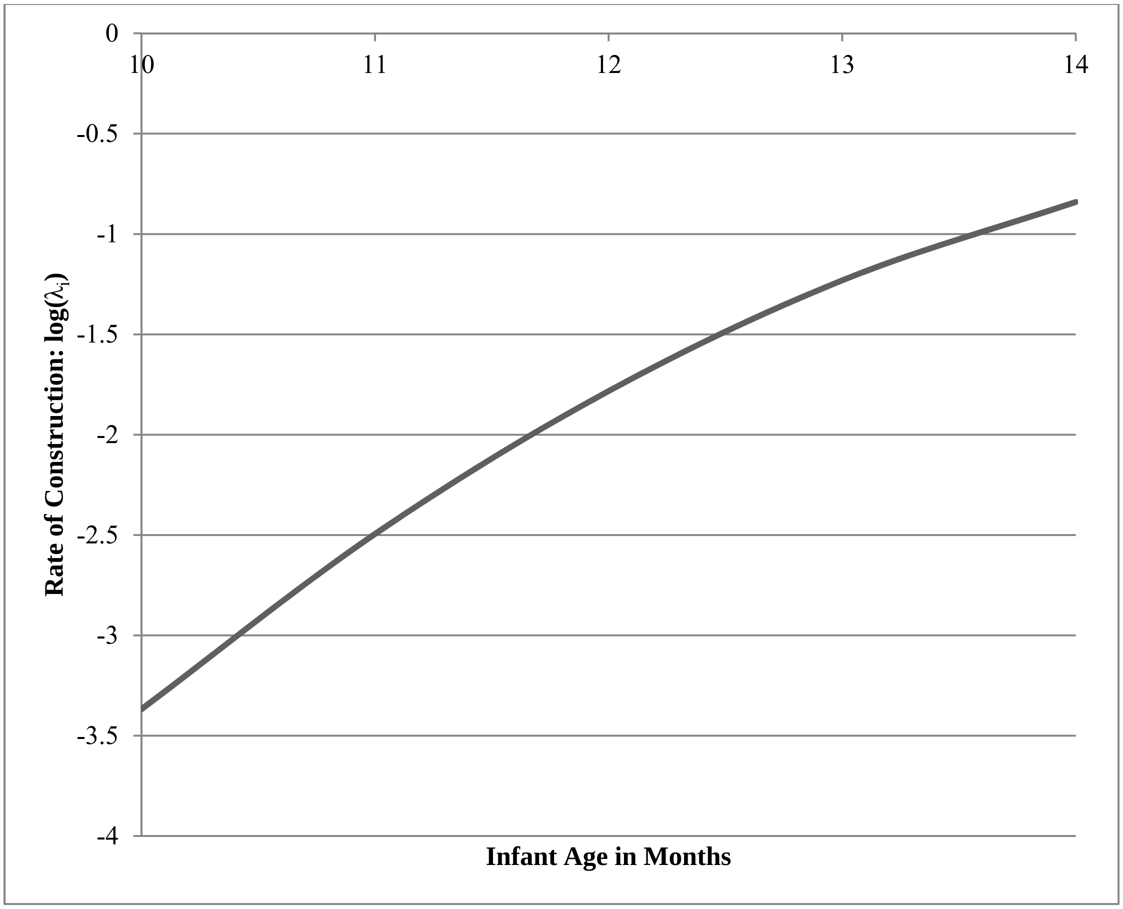


Model Testing

For all analyses, a conventional alpha level of 0.05 was the criterion for gauging statistical significance. The model-building strategies recommended by Raudenbush, Bryk, Cheong, Congdon, & du Toit, 2004 and Singer & Willett, 2003 were employed in developing the models. This means that the analyses started with the unconditional and then the conditional growth models with predictors, followed by model reduction. The unconditional growth model only includes time-varying independent variables (like Age and Age^2). Although Age^3 and Age^4 were tested, neither their fixed effects nor variance components were significant. Only Age (γ_{10} = 0.632, ρ < 0.000) and Age^2 (γ_{20} = -0.080, ρ < 0.000) were significant predictors in their fixed effects and variance components. The significant components were retained for the subsequent conditional growth models. Based on the unconditional growth model (i.e., collapsing across sex and handedness groups), constructing skill generally changed quadratically over the 10-14 month period (Figure 5).

Next, the full conditional growth model was tested, which incorporates both Age and time-stable (Handedness, Sex) variables, and their interactions. A conditional growth model containing a lateralized/not lateralized handedness grouping along with sex was tested first. No group effects were significant (see Table 2a). Although Lateralized*Age is significant in the full model, this term is not interpretable while higher order terms are still in the model, in accordance with Nelder's (1977) principle of marginality. Once higher order terms are removed, Lateralized*Age is no longer significant.

Figure 5. The Rate of Items Constructed Over Time.



Next, the conditional growth model which differentiated between right- and left-handed infants was tested. The Sex*Left handedness interaction variable was significant (γ_{23} = -0.244, p < 0.000) for the quadratic slope, suggesting that left-handed females differed from one or more groups (Table 2b, Figure 6). Constituent effects (such as, π_{0i} or π_{1i}) were still retained in the model, despite not reaching significance, since more complicated elements (e.g, γ_{23}) in the formula are composed of the simpler elements (e.g., γ_{21}).

Table 2a. Conditional Growth Model from 10-14 months (Unit Specific Model) (Lateralized/Not lateralized Handedness Grouping)

	Constructing Ability
	Full Conditional Growth
Fixed Effects†	*Coefficient*
Intercept (γ_{00})	-3.749***
Age (γ_{10})	0.796***
Age^2 (γ_{20})	-0.147*
Lateralized (γ_{01})	0.814
Lateralized*Age (γ_{11})	-0.263*
Lateralized*Age^2 (γ_{21})	0.100
Female (γ_{02})	0.616
Female*Age (γ_{12})	-0.157
Female*Age^2 (γ_{22})	0.073
Female*Lateralized (γ_{03})	-0.876
Female*Lateralized*Age (γ_{13})	0.245
Female*Lateralized*Age^2 (γ_{23})	-0.103
Random Effects†	*Variance Component*
Intercept (δ_{0i})	1.124***
Age (δ_{1i})	0.049***
Age^2 (δ_{2i})	0.008***
Level-1 (σ_{ε}^2)	0.384

† For all fixed and random effects, *df* = 49

* $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$

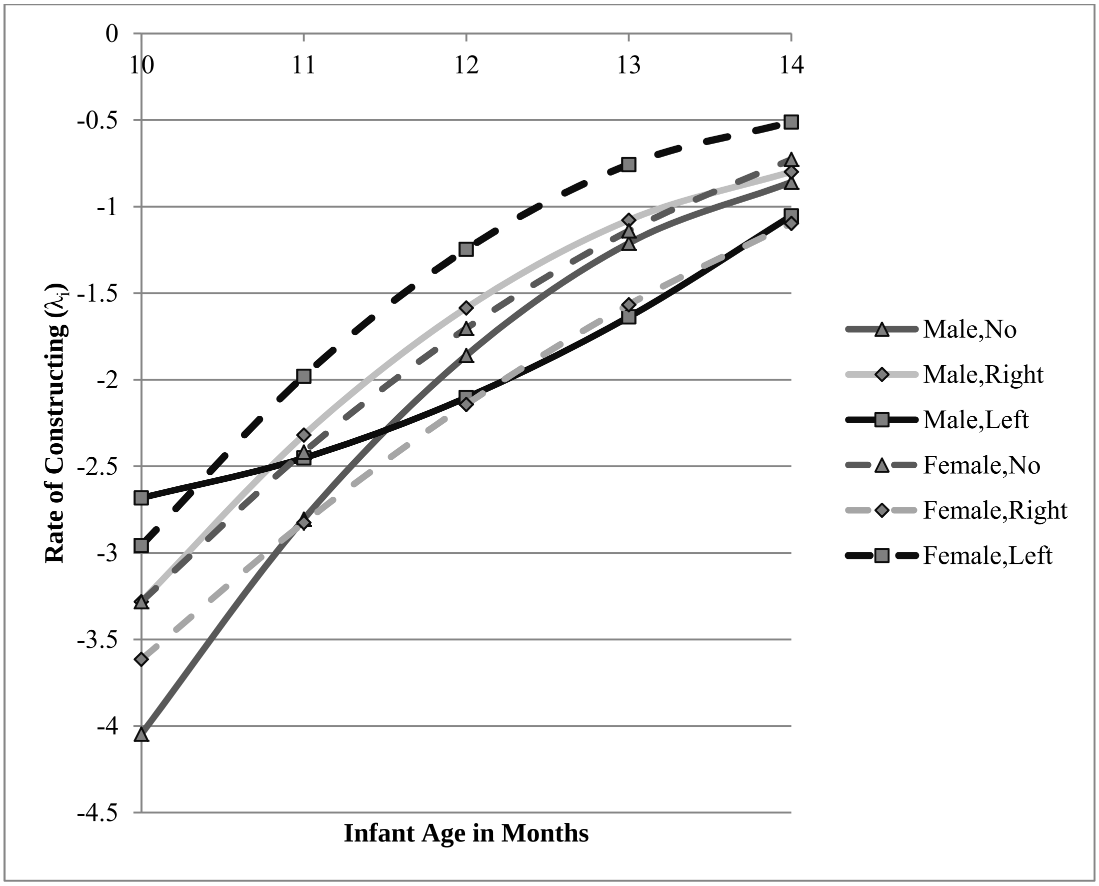
Table 2b. Conditional Growth Model from 10-14 months (Unit Specific Model) (Right/Left/No Handedness Grouping)

	Constructing Ability		
	Unconditional Growth	Full Conditional Growth	Final Conditional Model
Fixed Effects†	*Coefficient*	*Coefficient*	*Coefficient*
Intercept (γ_{00})	-3.208***	-3.750***	-3.398***
Age (γ_{10})	0.632***	0.797***	0.706***
Age^2 (γ_{20})	-0.080***	-0.148**	-0.130***
Right (γ_{01})	-	0.696	-
Right*Age (γ_{11})	-	-0.176	-
Right*Age^2 (γ_{21})	-	0.035	-
Left (γ_{01})	-	0.950	0.595
Left*Age (γ_{11})	-	-0.390**	-0.298*
Left*Age^2 (γ_{21})	-	0.207**	0.188**
Female (γ_{02})	-	0.619	0.117
Female*Age (γ_{12})	-	-0.158	-0.068
Female*Age^2 (γ_{22})	-	0.073	0.063
Female*Right (γ_{03})	-	-1.073	-
Female*Right*Age (γ_{13})	-	0.167	-
Female*Right*Age^2 (γ_{23})	-	-0.013	-
Female*Left (γ_{03})	-	-0.531	-0.029
Female*Left*Age (γ_{13})	-	0.362	0.272
Female*Left*Age^2 (γ_{23})	-	-0.254**	**-0.244****
Random Effects†	*Variance Component*	*Variance Component*	*Variance Component*
Intercept (δ_{0i})	1.185***	1.098***	1.146***
Age (δ_{1i})	0.056***	0.044***	0.046***
Age^2 (δ_{2i})	0.009***	0.005**	0.005**
Level-1 (σ_ε^2)	0.384	0.390	0.394

† For all fixed and random effects, *df* = 49

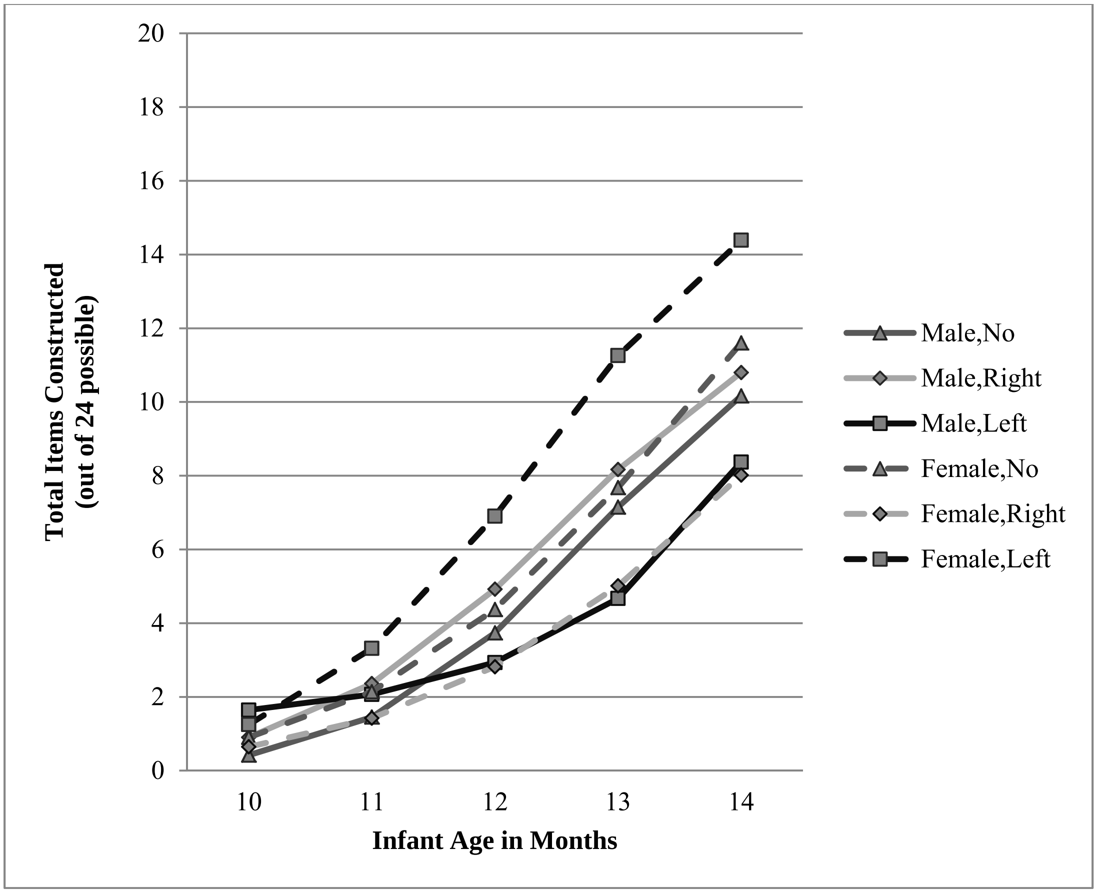
* $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$

Figure 6. Full Conditional Growth Model: Rate of Items Constructed Increase Over Infant Age by Sex*Handedness.



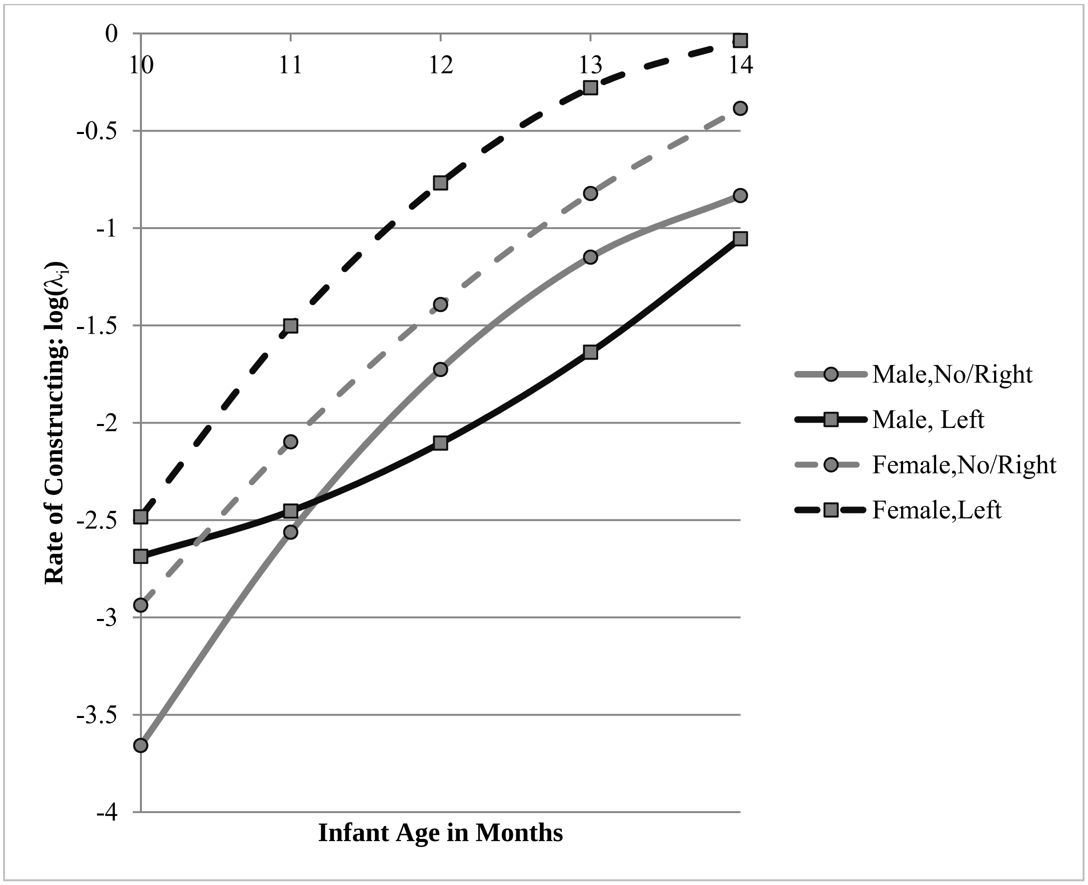
Left-handed females are performing consistently above all other groups, although this group is only significantly above left-handed males (see Figures 6 and 8). Females and males without a hand preference or a right hand preference seem to develop construction skill similarly to each other, and below left-handed females.

Figure 7. Total Items Constructed Over Time by Sex*Handedness (average trend lines).



In order to test which groups' trajectories were significantly different, two types of multivariate tests were performed. First, multivariate tests determined whether the groups' slopes were significantly different from other groups, or whether the groups are parallel. Next, multivariate tests determined whether only the groups' intercepts are equal, or whether the groups are equal lines. Left-handed males develop in a significantly different way than males with a right or no preference, and females with a left preference (see Table 3). Left-handed males and females with a right/no preference change similarly to each other (Figure 10).

Figure 8. Final Conditional Growth Model: Rate of Items Constructed Increase Over Infant Age by Sex*Handedness.



Note: The Male, No/Right and Female, No/Right lines are not statistically different from each other.

Figure 9. Final Conditional Growth Model: Total Items Constructed Over Infant Age by Sex*Handedness.

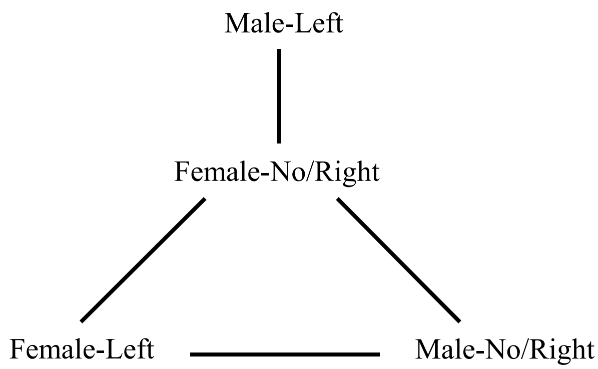
Note: The Male, No/Right and Female, No/Right lines are not statistically different from each other.

Table 3. Significance Tests Between the Interaction Groups. †

	Reference Group							
	MN/R		**ML**		**FN/R**		**FL**	
	χ^2	p	χ^2	p	χ^2	p	χ^2	p
MN/R	**-**	**-**	**11.203**	**0.004**	0.734	>.500	2.619	0.269
ML	**12.984**	**0.005**	-	-	5.503	0.062	**6.646**	**0.035**
FN/R	2.63	>.500	6.915	0.073	-	-	2.087	0.353
FL	1.996	>.500	**10.282**	**0.016**	3.363	0.339	**-**	-

† The top triangle contains tests whether the groups are parallel (df=2), and the bottom triangle contains tests whether the groups are equal lines (df=3).

Figure 10. Graphical Representation of Results from the Multivariate Tests. †



† *Each line represents a group that is equal.*

CHAPTER IV

DISCUSSION

Specific Findings from this Study

Several conclusions can be drawn from these analyses. The 10-14 month ages are an appropriate period to measure the onset of constructing skill. The 10-month-old infants are constructing very few items. In contrast, 14-month-old infants all exhibit constructing behavior, although the skill presents with much more variability. It is important that the investigation of a skill's development begin with measures before it appears, otherwise a part of the developmental trajectory could be missed. Infants begin in this age period with minimal or no constructing actions, and by the end, infants demonstrate a moderate ability to construct. Interestingly, the results demonstrate that constructing skill did not develop linearly over time, but rather exhibited a quadratic trend. Thus, infants did not steadily increase their skill over age; rather they began to change rapidly once the skill began to be manifest.

Nevertheless, additional observations of the development of constructing skill are necessary to continue tracking this skill. Although many infants could consistently construct two or more objects, other infants could not and were still relatively poor at constructing objects. These later-developing infants could change in a uniquely-different way at later ages, which is not yet apparent with these data. The early quadratic trend could potentially continue, asymptote, or change shape at a later age. In addition, the shape of the trend could change fundamentally once children learn to use different strategies to construct or can correct errors more effectively. Future research should examine how constructing skill continues to be manifested at later ages, in order to understand the long-term consequences of the onset on further development of constructing.

The significant Level 1 variances indicate that constructing skill may develop in a variety of ways. Level 1 variance is the variance associated with the individual infant, and so, its significance identifies that the infant's own variability within his/her trajectory is important for understanding construction development. These results demonstrate that only longitudinal investigation can capture such individual differences in development. Single age assessments of construction skill, cross-sectional designs, or studies that group infants with large ranges of ages may, in fact, disguise the character of important developmental trends across the early ages. Future research ought to examine whether the age of the onset of constructing ability relates to the developmental trajectory of constructing ability. For example, an infant who begins constructing at 10 months might develop construction skills differently from an infant who only begins constructing at 14 months. One possibility for future research is to chart development not in terms of age, but time from onset of initial constructing ability. This method could capture whether the age of the onset of constructing ability might affect its trajectory or whether that trajectory is equivalent no matter the age at the beginning of the skill.

Although infants did differ in constructing skill development according to the sex by handedness interaction, this was not as predicted. The slopes of these interaction groups (i.e., their rates of change), were different. The slopes of non-left-handed males and females do not differ whereas left-handed females increased their constructing skill across the 10-14 month period more rapidly than left-handed males. All females and males who were not left handed had a rapid rate of constructing at the earlier months, which slowed somewhat at 13 and 14 months. In contrast, left-handed males increased their rate of constructing at a slower rate from 10-11 months, than all other infants, and only began to increase their rate of constructing from 12-14 months of age. Although the hypothesis that infants with a hand preference would perform better than infants without a hand preference was not supported, the unexpected interaction between sex and handedness may affect how future studies of infant construction skills are conducted.

The majority of infant studies for manual skills do not include a left-handed group, and so we have virtually no information as to whether left-handed females or males perform better or worse than each other on other aspects of motor skill development. Kotwica, Ferre, and Michel (2008) did include left-handers in their object-managing study; however the number of left-handers (n=6) was so small that it was pooled with the right-handers (n=14) to create the "stable hand use preference" group. Thus, no conclusions on object management skills could be drawn from the small group of left-handers, especially in relation to sex. Since left-handers are relatively rare in the population of infants (about 12-15%), most studies fail to include left-handers as a separate group, and so left-handed infants are often grouped with right-handed infants into a "lateralized" group or they are excluded from the results. Since too few infants are expected to be left-handed in any sample, little is known about the effects of left handedness on other forms of development. The results of this study indicate that left-handed infants may show patterns of development different from right handed infants, and so grouping left- and right-handed infants into a single "lateralized" group may be inappropriate for some manual skills, as with construction. Future research ought to have samples large enough to investigate the effects of left-handed infants on constructing skills, object managing skills, or object pairing skills. Comparing left-handed infants to other infants (whether with or without a handedness) could be an illuminating endeavor.

Is there a Link between Constructing Skill and Spatial Abilities?

There is some evidence that left-handed females and males show differences in spatial abilities in later childhood. Benoit-Dubrocard and Touche (1993) tested 8-9 year old females on identifying 3-dimensional letters and non-linguistic shapes non-visually, by feeling the figures with their hands. In comparison to right-handed females, left-handed females more correctly matched letters and shapes with their dominant hand. Left-handed females also performed better on visuospatial tasks than left-handed males and right-handed females, although they performed equally well as right-handed males (Gordon & Kravetz, 1991). Such results support the results of the present study that the differentiation of visuospatial skills develops differently according to sex and handedness of infants. Kraft (1984) also tested children aged 2.5 – 5.5 years for their lateralization on a variety of tasks (hand preference for a manual actions task, dichotic listening, parental handedness, etc.) and spatial ability and found that right-handed females outperformed non-right-handed males on spatial ability. Females (irrespective of their handedness) with familial left handedness achieved the highest spatial scores of all groups, including males with familial left handedness. Unfortunately this study collapsed children with a left or indefinable hand preference into a single group (i.e., "non-right-handedness"), so it is unknown whether left-handedness was related to spatial abilities differentially between females and males.

It may be tentatively hypothesized that knowledge of the spatial relations of objects in the environment and how they can be manipulated, obtained during infancy, may concatenate into spatial concepts at older ages. An infant who constructs may use existing spatial understanding to build and may subsequently learn about the unique consequences associated with the placement of an object relative to other objects. An infant may learn about spatial relations while constructing objects, since it is, in essence, placing objects in different spatial locations relative to one another. For example, if a cup is placed "on" another cup, then the bottom cup must be oriented so the closed side is facing upwards. In contrast, if a cup is to be placed "in" another cup, then the bottom cup must be oriented so the open side is facing upwards. Both the structures produced from placing a cup "in" versus "on" another cup and their perceptual characters are distinct. An infant who constructs learns about the unique consequences associated with placement of an object relative to other objects. Thus, learning to construct might facilitate some of the differences in spatial abilities observed at these later ages. Additional research is needed to determine whether the development of spatial skills relates to differences in the development of handedness or construction during infancy.

Constructing Ability and Later Cognitive Abilities

Why is construction skill important to study in early development? Infants learn about novel object properties through manual and visual exploration of unique or previously unfamiliar objects (Baldwin, Markman, & Melartin, 1993; Morgante & Johnson, 2011). During late infancy, simple object-on-object interactions develop into to making unique structures (Gesell & Amatruda, 1941; Greenfield, Nelson, & Saltzman, 1972; Keen, 2011). Combining toys into structures leads to a different understanding of the properties of the individual objects and the resulting structures reveal emergent properties. For example, if four blocks are scattered across a table, perturbing one block will not necessarily perturb the other blocks. However if these same four blocks are stacked into a single tower, then perturbing a bottom block is much more likely to perturb the rest of the blocks. As a result, infants learn that the properties of the new structures can create a unique result.

In addition, the properties of the items themselves affect the actual construction of the structure. Hayashi and Takeshita (2009) found that even though 2-3 year old children could easily build a tower of more than 4 plain blocks, they struggled with its construction when the blocks had large bumps on some of the sides. Using these "bumpy blocks," the height of the tower was either constrained or unaffected by the bumps on the blocks' sides. Placing a block on a tower with the bump facing downward will be unsuccessful, and placing a block on a tower with the bump upward will prevent any further block placement. However, placing a block on a tower with the bump facing to the side will not constrain the tower's height. Children would re-orient a block to attempt building the tower; but their re-orientations were often inappropriate and failed to enable the building of the tower (although invalid re-orientations did decrease across these ages: Hayashi & Takeshita, 2009). The constructing ability demonstrated by infants aged 10-14 months is simple in comparison with this more complicated constructing ability. Nevertheless, understanding the initial constructing ability may provide insight into the cognitive mechanisms which drive the development of constructing from simple to complicated construction.

Studying constructing ability could inform researchers about the development of seriation, as well. Seriation is organizing objects in ascending/descending order of a property, such as length, or size (Piaget & Inhelder, 1969). One challenge of seriating objects is inserting an object into a structure which has already been composed. Children can appear to successfully seriate objects by categorizing each object as either "smaller" or "larger" (Breslow, 1981; Inhelder & Piaget, 1964). However, if the researcher provides the child an additional object to be placed within the finished seriation, then the child demonstrates a failure to understand seriation by not successfully inserting the object correctly into the seriated structure. A child who truly comprehends seriation can identify an object as simultaneously being "smaller" than some objects and concurrently "larger" than other objects. The progression of nesting strategies Greenfield, Nelson, & Saltzman (1972) observed were not unlike Piaget's ideas about the development of seriation. First, children placed all cups into a single, larger cup (the "pot" method); children at later ages would nest the smallest cup into the next largest cup, then move both cups into the next largest, and so on (the “subassembly” method). The pot method only requires a general understanding of a “larger” or “smaller” cup size, whereas subassembly requires a transitive understanding of cups. Children who can transitively understand cups in comparison to all the other cups are better at inserting a cup into a completed structure (Fragaszy et al., 2002).

Interestingly, Fragaszy et al. (2002) suggested that successfully adding in an additional cup (non-sequential seriating) is like subassembling a structure. When the child removes a component of the structure, adds a cup, and recomposes the structure, the child is assembling a part of the structure before recomposing the deconstructed parts. Many researchers have identified seriating, particularly skilled non-sequential seriating, as an important transition into abstract thinking, particularly transitive reasoning (Breslow, 1981; Inhelder & Piaget, 1964; Kidd, Pasnak, Gadzichowski, Ferral-Like, & Gallington, 2008; Largo & Howard, 1979). Non-sequential seriating may develop from the ability to build seriated structures during late infancy, and thus, represent an early indicator for the development of transitive reasoning.

Investigation of construction skills could also inform research on the development of how children come to create and “understand” complex hierarchical structures. For a structure to be arranged “hierarchically” means that each element of the structure is subordinate/superordinate to another element. The organizational strategies reflected in such skill can serve to solve particular problems and controlling conditions of the environment. For example, Bruner and Bruner (1968) posit that very young infants can exhibit a simple hierarchical structure of responses in their simplest motor actions, such as sucking. To test this, the authors created a specialized nipple attached to a lighted picture display, where the picture would illuminate or darken, in response to the infant’s sucking intensity. Infants, as young as 4 weeks old, could adjust their sucking patterns to bring the picture into focus. Bruner and Bruner (1968) concluded that infants could voluntarily change their sucking behavior into a hierarchically-organized response to create a focused picture. For example, if the picture is dark, then the infant should modulate his/her response by increasing sucking intensity; or if the picture is too bright, then the infant should modulate his/her response by decreasing sucking intensity. These responses become dependent on the stimulus and the infant's current rate of sucking. Hence, the infant's strategy for sucking depends on the amount of sucking increase/decrease is needed for altering the picture. An infant might use a burst of sucking intensity to illuminate a darkened picture, whereas the same infant might use a steady sucking pattern to maintain an already-focused picture (e.g., Bruner & Bruner, 1968, p. 249). In this way, infants create a "hierarchical organization" of responses, contingent upon environmental stimuli and patterns of current behavior.

Throughout early childhood, children develop the ability to create increasingly complex object organizations, which are often arranged hierarchically. For example, cups nested within each other are arranged hierarchically, since the first nested cup is subordinate to any cups nested afterwards. When simply arranged on a table, cups are not organized hierarchically, because they do not have subordinate/superordinate cups in relation to other blocks. Over development, children will use different strategies to create hierarchically-organized structures, such as interrupted strategies (e.g., subassembly method). An interrupted strategy is when a child can stop building using a particular action or at a particular location of a structure to build in a different way or in a different location. For example, Greenfield and Schneider (1977) found that 3-6 year-old children develop the ability to create more hierarchically complex branching structures using connecting straws. Additionally, the use of interrupted strategies increased across this age period. Greenfield and Schneider (1977) suggest that children using the subassembly method have a greater understanding of the underlying components of a structure, since they are composing "elements" of a structure *en route* to the final structure. Children using the linear strategies (e.g., "pot" method) are simply repeating the same action with different objects to create the final structure (Fragaszy et al., 2002). Greenfield and Schneider's (1977) results show a progression from perceiving hierarchical structures in terms of elements only (3-year-olds), the whole (5-year-olds), and both elements *and* the whole (6-year-olds and older). Unfortunately, there is still uncertainty about the relation and transition between building complex object structures and organizing hierarchical structures. Do strategies for constructing objects drive the development of hierarchical organization? Does constructing skill simply benefit from a child's newfound ability to organize objects into increasingly complex structures? What mechanisms drive the development of these skills? Further research is needed to discover specifically how constructing actions relate to the development of hierarchical complexity in early childhood.

Conclusions

The structure of the physical world changes the infant's cognitive structure. Since females more quickly than males and stably-handed infants more quickly than those without a stable handedness develop the ability to manage multiple objects (Kotwica, Ferre, & Michel, 2008), then object management skill could reveal differences in the development of abstract representation of objects (Bruner, 1973a; Kotwica, Ferre, & Michel, 2008). Once infants can manage multiple objects, they are capable of merging multiple objects into a single structure with its own set of novel physical properties, which *again* changes the infant's cognitive structures. Once infants can build new compound structures, these complicated actions on the physical environment may form the basis for more complicated cognitive structures (such as seriation, transitive reasoning, etc.). Hence, object constructing skills may be an important step in the development of more abstract cognitive abilities. If so, then differences according to the sex and handedness of the infant might lead to the development of differences in cognition and language. Certainly, how a behavior develops after initial emergence requires descriptions of that development and its interaction with other developmental processes. In conclusion, further research on the development of construction could contribute to the understanding of the development of the more complex phenomena of abstract cognition.

There were two major limitations of the present study. First, there was a very small sample of left-handed infants. Unfortunately, left handedness occurs at relatively low rates in infant (13.7%; Michel et al., 2013a) and adult populations (8-12%; Annett, 1994); thus, 11 left-handers in a sample of 53 infants (20.76%) was a relatively, large proportion. Future research could try oversampling for left-handers or recruiting infants who are more likely to become left-handed (e.g., from two left-handed parents); although this biased recruiting could potentially distort results. Second, the Poisson model adopted in this study is narrowly constrained such that the mean must equal the variance (Long, 1997). Although the addition of over/underdispersion variance terms compensates for this limitation, using a negative binomial model rather than the Poisson could fit the data more elegantly. In addition, the negative binomial model might be more useful in datasets with a large number of zeroes, as in this study, since the likelihood of zero can be slightly underestimated by a Poisson model. One drawback of using a negative binomial model is that software programs only rarely offer longitudinal analysis using a negative binomial model, and so it is often not practical.

This investigation has shown an interesting example of how one form of sensorimotor development (handedness) affects the ontogeny of constructing behaviors; although it was not as predicted. Infants with a right or no preference exhibited very similar rates of change across the 10-14 month ages. Non-left-handed males, left-handed females, and females with no hand preference developed constructing skills much sooner and at a faster rate than left-handed males across the 10-14 month ages. Additionally, right-handed females and left-handed males developed constructing behaviors at similar rates to each other, although right-handed females were not significantly different from the other groups. In fact, the only within-group sex by handedness interaction exists in the left-handed infant group. Future research should focus on replicating these results in a larger sample of left-handed infants to explore any unique consequences of left handedness on the development of construction or other combinatorial abilities. In addition, future research could explore whether these group differences change or persist into later ages. Linking the findings of the current study and the literature on constructing ability at later ages is essential to understanding the development of construction fully. Finally, the observed group differences may be a result of differences in spatial abilities and could potentially extend into more complicated cognitive skills.

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