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The Development of Object Construction From Infancy Through Toddlerhood

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Early in development, children explore and combine objects in increasingly complex ways. One manual skill, object construction, represents a major shift in how objects are explored relative to other objects. Despite recent connections with cognitive functioning such as spatial skills, the development of object construction ability has rarely been studied and its trajectory has not been adequately described. The purpose of this study was to describe the development of three types of object construction (stacking, nesting, and affixing) across 5 monthly infant visits and 7 monthly toddler visits using a longitudinal design and a large sample size. Infants (10–14 months, n = 131) and toddlers drawn from the infant sample (18–24 months, n = 65) were given sets of age-appropriate toys each of which elicited at least one type of constructive play. We described success at different construction tasks and identified trends for construction skill for infant and toddler development using multilevel modeling. We found that each of the three construction actions developed in unique ways across the 10- to 24-month period. Infant construction skill predicted the development of toddler skill, but toddler construction skill diverged from infant trajectories. We discuss the role of combination strategies in the development of object construction skill and how object construction could be related to other domains of development.

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Throughout the first 2 years of life, infants explore objects in their environments in increasingly complex ways. Initially, infants explore single objects and properties (e.g., Bushnell & Boudreau, 1993; Ruff, 1980). Later infants explore objects in relation to other objects and surfaces (e.g., Bourgeois, Khawar, Neal, & Lockman, 2005) and can draw inferences about object properties through exploration (e.g., Baldwin, Markman, & Melartin, 1993; Pieraut-Le Bonniec, 1985). As infants explore objects more, they gain sensory information about object relations and increasingly specialize their object exploration (e.g., Barret, Davis, & Needham, 2007; Bourgeois et al., 2005; Morgante & Johnson, 2011). Manual exploration of objects gives rise to more advanced object cognition, which is defined here as reasoning about the relations between objects, such as in tool use (Keen, 2011; Lockman, 2000) and object construction (Lifter & Bloom, 1989; Marcinowski & Campbell, 2017). Object construction (i.e., the ability to successfully stack, nest, or adhere) is uniquely different from object manipulations like banging, shaking, or mouthing because it requires a more complex integration of object locations and relations. These more complex engagements with objects represent a pivotal change in causal understanding (Tomasello, 1998); however, the development of object construction has not been studied as extensively as other domains of development, particularly within the first 2 years of life (Casasola, Bhagwat, Doan, & Love, 2017). The goal of this project was to chart the development of three construction skills: stacking, nesting, and affixing. Described below, these actions represent distinctly different kinds of spatial object relations from one another.

Stacking involves placing an individual object on top of another object. Only 15% of infants can stack one block on top of another block at 10 months of age (Marcinowski, Campbell, Faldowski, & Michel, 2016). By 15 months, more than 75% of toddlers can build a two-block tower with over 50% of toddlers building five-block and eight-block towers by 18 and 25 months, respectively (Hayashi & Matsuzawa, 2003). When stacking blocks, the flat side of one block must be set on the flat top of the other block, rather than placing a block's corner onto the other block. Then, once an infant has stacked a block, the next action must be tailored to fit the new structure. To illustrate this point, Hayashi and Takeshita (2009) used a clever task to test whether children could stack cubic blocks that had been modified to prevent stacking on some sides of the blocks. Some blocks had a large bump on one of the sides, which prevents that side of the block from being stacked upon, or that block to be stacked with the bump side facing downwards. Two-year-olds made errors 5–15% of the time in which they failed to reorient the location of the bump side before attempting to stack (Hayashi & Takeshita, 2009). These findings show how construction skill requires multiple frames of reference: The child must hold in mind both the orientation of the block his/she is adding to the tower and the orientation of the top block on the tower to accommodate a successful construction action. Though stacking has received some attention in the literature as a challenging motor and cognitive task, the development of stacking skill has not been studied comprehensively in young children using a longitudinal design.

Understanding the properties of objects and their affordances is also a key feature of nesting where one object is placed inside of another object. Infants begin to explore insertion and containers toward the end of their first year (e.g., Casasola et al., 2017; Iverson, 2010; Lifter & Bloom, 1989). Eight-month-old infants rarely produce spatial relations of nested cups, while 13- and 18-month-olds are relating objects together an average of one and four times, respectively (Casasola et al., 2017). Greenfield, Nelson, and Saltzman (1972) observed children from 11 to 36 months of age in a cross-sectional design and described three action strategies for interacting with seriated nesting cups. The youngest infants predominantly used the pairing method, which involved a simple combination of two items (i.e., placing a smaller cup inside of a larger cup). At 16 months, the dominant strategy was the "pot method," where there are multiple acting objects used in succession and a single acted upon object (i.e., a medium cup is inserted into a large cup, and then, a small cup is inserted into the medium cup, which is within the large cup). The linear strategy of the pot method means that cups can be paired multiple times with one acting cup to achieve a full structure. At 20 months, the third and most complex strategy called the subassembly method appears in some children, and this method is increasingly used in the oldest children examined. The subassembly method is a nonlinear strategy in which an actor and an acted upon object are combined to form a structure, which then becomes the next actor-object. The new actor-object can then be placed into another object. Instead of placing cups one at a time into the largest cup as in the pot method, here sub-structures are created *en route* and moved as units into the final structure. When three or more objects start to be used for nesting, errors can arise in ordination (DeLoache, Sugarman, & Brown, 1985; Greenfield et al., 1972). 18-month-old children will attempt to correct an error by changing a single object (e.g., trying to push a nonfitting cup into a structure); these early corrections are based on two object relations (e.g., after placing a nonfitting cup into a base cup, the base cup is then nested in a different base) while older children can correct relations between multiple objects (e.g., reversing two incorrectly placed cups within a structure) (DeLoache et al., 1985). Despite the wide literature on seriation in older children and its probable connection to early nesting ability, few studies have examined nesting in infants and toddlers, particularly in a longitudinal design.

Affixing is the final construction skill examined in this project. Affixing is defined as joining or attaching an individual object to another object through adherence properties. Compared to "on" for stacking and "in" for nesting, affixing represents a different spatial orientation (e.g., "next to"). Moreover, affixing does not depend on gravity to combine objects, but rather uses object materials (e.g., magnets, Velcro) or shape (e.g., puzzle pieces) to create complex structures. By exploring objects with adherence properties, infants can learn the unique characteristics of these materials and adapt their combination strategies in the future. Such exploration is valuable because interacting with objects changes infants' understanding of objects (Needham, 2000), and infants adapt their future exploration actions as a consequence of experience with unique materials or novel objects (Morgante & Johnson, 2011). By 11 months, after experience with a novel object, infants can transfer their exploration skills to objects with the same novel properties (Hauf & Paulus, 2011). There is a knowledge gap in our understanding of how the ability to affix objects develops, as few studies have examined this construction skill in a cross-sectional or longitudinal design in young children.

The emergence of object construction skill is a particularly unique aspect of development for two reasons. *First, object construction is the initial instance of creating something new from different objects, which may have unique properties from one another*. A newly created structure has unique characteristics and properties that, while reflecting some of the properties of its individual components, also can reveal new properties that are the result of the combination of the individual components. For example, cubic blocks can be stacked to create a new structure or a "tower." The individual components in the tower are hard, durable, and easily transported in the hands.

The newly created block tower is tall and thin, delicately assembled, difficult to transport, and readily destroyed. Also, the properties of the components used to create the new structure can contribute to the kind of structure created. For example, the shape of wooden cubic blocks precludes their containing other objects; however, these blocks can be placed on other objects and they can serve as a base on which other objects can be placed. In contrast, a cup can contain other objects, serve as a base, or be placed upon other objects, depending on the cup's orientation. Therefore, infants gain a different understanding of object properties by constructing or attempting to construct a variety of objects. Infants experience changes in the type of sensory information provided by exploration with objects of differing property types.

Second, constructed objects may reveal new object information through creation or demolition of structures. Success and failure at construction demonstrates the importance of object orientation and location in space. For instance, when stacking a cubic block into a tower, an infant garners information about the location of the block in space in relation to the tower, whether the block is stacked successfully or the tower falls. Adhering magnets reveals their unique quality of magnetism, which is afforded through adhering or repulsion of other magnets and metals, but not afforded on wood or cloth. Puzzle pieces, Legos, or rings can be fitted onto certain other objects (other puzzle pieces, Legos, rods, respectively), if the object is fitted appropriately. Also, an infant can create a different structure based on the orientation and placement of seriated cups. Inserting seriated cups creates a small, layered structure, while stacking cups on one another creates a larger, tower structure. In a similar way that infants experience the differential consequence of banging soft versus hard blocks (Lockman, 2000; Lockman & Wright, 1989) or drawing in sand versus on paper (Morgante & Johnson, 2011), infants learn to detect object affordances and experience how objects relate to other objects in complex ways through object construction.

The interrelation between object knowledge, object location, and structural organization may be why constructive activities have been connected with a number of spatial skills at older ages, including mental rotation (Brosnan, 1998), spatial visualization (Caldera et al., 1999; Jirout & Newcombe, 2015), spatial transformation (Levine, Ratliff, Huttenlocher, & Cannon, 2011; Verdine et al., 2014), mathematics and visuospatial memory (Nath & Szucs, 2014; Wolfgang, Stannard, & Jones, 2003), and spatial language (Marcinowski & Campbell, 2017). Greater experience building structures and a better understanding of object relations could be one reason why greater ability for object construction predicts spatial skills later in development. The connection between constructive activities and spatial skills may lie in greater environmental experience with spatial relations during object construction at young ages. However, to date no study has systematically characterized children's experiences with stacking, nesting, and affixing over the first 2 years of life. Detailed study of how these skills emergence in infancy and change across toddlerhood is needed to lay the groundwork for future study on the development of cognitive strategies, spatial skills, and language later in life (e.g., DeLoache et al., 1985; Marcinowski & Campbell, 2017; Marcinowski et al., 2016). Good descriptions of development are important to making predictions about *what* affects the development of a skill or *how* the development of that skill may influence the development of other abilities (Kagan, 2013; Michel, Marcinowski, Babik, Campbell, & Nelson, 2015; Tinbergen, 1963).

The goal of the current project was to describe the development of object construction as measured by stacking, nesting, and affixing using a longitudinal design across two age bands: 10–14 months (infant visits) and 18–24 months (toddler visits). Infants and toddlers are capable of performing these construction skills and will do so spontaneously. In pilot work for an earlier project, we found that 9-month-old infants were not performing any successful combinations (Marcinowski et al., 2016), suggesting that 10 months was the appropriate age to start examining construction abilities in infants. We selected the toddler time points because children have been shown to increase the number of constructions across this period (Lifter & Bloom, 1989), and we expected to capture a wider range of construction skills and strategies in the older age band. The age bands were not continuous because data were drawn from a larger project with a gap in funding. We predicted that different object construction skills will increase across age, and that infant construction skill will predict toddler construction skill. We also predicted that success with the different construction actions (stacking, nesting, affixing) would correlate with one another. We then examined the trajectories of each construction skill to provide descriptions for future hypothesis-driven research.

METHOD

Participants

The sample was drawn from a larger longitudinal project investigating the development of handedness (n = 380). Recruitment used a rolling cohort design. Infants used in these analyses (n = 131) represent the later cohorts for whom we have object construction data. Infants were recruited from Guilford County birth records to come to the Infant Development Center at UNCG for 5 monthly visits during the age period from 10 to 14 months. Birth records of infants born in Guilford County between February 2010 and May 2012 were purchased from the Guilford County courthouse, and letters describing the study were mailed to the addresses of the parent(s) listed on the birth record. Families interested in participation contacted study staff through phone or email. All infants were born full term (≥37 weeks of gestational age) without birth complications. The current study was conducted according to guidelines laid down in the Declaration of Helsinki with written informed consent obtained prior to data collection; all study procedures 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. All visits occurred within a week of the infant's birth date, corresponding to each month of testing (e.g., an infant born on the 14th of the month would have a date range from the 7th to the 21st of the month). Participants for this project were tested during the 10- to 14-month age period with mean ages of 9.8 (SD = 0.12), 10.8 (SD = 0.12), 11.8 (SD = 0.14), 12.8 (SD = 0.16), and 13.8 months (SD = 0.15), respectively. To be included in analyses, infants could miss no more than two visits across the 10- to 14-month ages. During these 10–14 month visits, infants were administered an object construction assessment task (Table 1), as well as other play-based manual assessments during the same visit and a gross motor assessment.

A subsample of these 131 infants was observed for object construction skill from 18 to 24 months (n = 65; 35 males). The subsample represents the last two cohorts of the larger infant project when the laboratory received additional funding to conduct toddler visits. The participants were tested at mean ages of 17.7 (SD = 0.19), 18.7 (SD = 0.15), 19.7 (SD = 0.14), 20.7 (SD = 0.14), 21.6 (SD = 0.15), 22.7, and 23.6 months (SD = 0.16), respectively. As before, parents were given a $10 Target gift card for each

TABLE 1
Description of the Infant and Toddler Construction Assessments

Construction object	*Afforded action*	*# Pieces*	*Largest possible structure*[a]
Infant visits			
Round blocks	Stack	4	3
ABC blocks	Stack	5	4
Stacking/Nesting cakes[b]	Stack/Nest	4	3
(presented twice)	Stack/Nest	4	3
Stand with rings	Affix	3+ stand	3
Magnet spheresb	Affix	5	4
Magnet sticks	Affix	3	2
Toddler visits			
Small blocks	Stack	10	9
Large blocks	Stack	10	9
Stacking/Nesting cakes[b]	Stack/Nest	9	8
(presented twice)	Stack/Nest	9	8
Sombreros	Nest	8	7
Bowls	Nest	11	10
Wood rings	Affix	8+ stand	8
Magnet spheresb	Affix	10	9
Porcupine blocks	Affix	11	10
Cauliflower	Affix	4	3
Orange	Affix	8	7

Note. [a]The largest possible structure in Table 1 value is usually one item less than the total number of items. A structure cannot have one piece, only two or more items. We do not count the base toy in our sums (Figure 1c), so that "0" means "no building" in our analysis. This rule is true, except for the Stand with rings and the Wood rings, which both have a stand that serves as the base.
[b]Presented at both infant and toddler visits.

completed visit, all visits occurred within a week of the toddler's birthday, and toddlers could miss no more than two visits across the 18- to 24-month visits to be included in analyses. Demographic information on the infant and toddler samples is reported in Table S1. No systematic differences were found between the infant-only and infant–toddler participants for sex ($\chi^2 = 0.030$, $p = .862$), maternal race (Caucasian, African American, or Other; $\chi^2 = 3.140$, $p = .154$), paternal race ($\chi^2 = 2.857$, $p = .154$), or infant race ($\chi^2 = 4.597$, $p = .132$).

The participants in this study were not assessed for cognitive or physical disorders throughout study participation, although parents were asked at enrollment if the mother had any complications during birth, or if their infants had any significant health concerns or diagnoses that might affect participating in research. At follow-up visits after their participation in the current study had ended, two children had received diagnoses of autism at 3 and 4 years of age. Therefore, the infant and toddler sample analyzed did not include these children.

Infant procedure (10–14 months)

All participants were assessed for a variety of manual activities during a visit that lasted no more than 1 h (range: 35–50 min). A researcher sat directly across from the infant at a crescent-shaped table. The infant sat on the parent's lap and the parent supported the infant's torso during testing. Each visit was video-recorded in its entirety for later behavioral coding. Two cameras (Panasonic WV-CP240, Secaucus, NJ, USA) were positioned to capture a top and side view of the table top and focused on the infant's hands.

The infant construction task was composed of seven sets of toys that afforded at least one of three construction actions (Table 1, Figure 1a). Before presenting the task to the infant, the presenter demonstrated how the task could be assembled and disassembled. Then, all items in the set were presented simultaneously to the infant. Toys were presented in no particular order. The cakes were presented to infants in two ways: once to demonstrate stacking and once to demonstrate nesting; thus, infants had two independent opportunities to demonstrate construction with the cakes. Infants played with each of these toys for 20 sec, and the entire assessment took approximately 6 min.

Toddler procedure (18–24 months)

All participants were assessed for a variety of manual activities during a visit that lasted no more than 1 h. The configuration of the testing site and presentation method for toddlers was the same as for the infant visits. The toddler construction task was composed of 10 sets of toys (Table 1, Figure 1b). Again, toys afforded stacking, nesting, or affixing, with the cakes affording both stacking and nesting. Two sets of construction objects were used at both the infant and toddler visits (cakes, magnet spheres); however, additional pieces were added to these objects sets during toddler visits, because it was expected they would construct more. Toddlers were given 20 sec to interact with the toy or until they finished building a structure, since building with the number of pieces presented during toddlerhood sometimes took longer than 20 sec. The entire toddler assessment of construction took approximately 12 min.

Infant and toddler construction coding

Three actions were coded from videos of infant and toddler object construction tasks: stacking, affixing, and nesting (Marcinowski, 2015). These actions represent a range of construction skills that infants and toddlers can perform and activities in which these children demonstrated interest. Selected tasks were chosen which represented different manual actions with differing levels of manual precision required to complete and requiring different cognitive skills to complete. Only successful constructions were coded; a "successful action" was defined as when an object in a child's hand was connected with another object and the child removed his/her hand without the object(s) immediately losing its placement.

Stacking[1] was defined as "placing an individual object on top of another." A successfully stacked object occurred when the weight of one object was placed completely on another object. If the item immediately fell or the structure immediately destabilized after the infant's hand was removed (e.g., the infant stacks a block, releases it,

[1]Originally, stacking for the stacking rings was coded (i.e., placed the rings on each other and not on the stand). Very few infants ever stacked the rings during early testing during infancy (Marcinowski, 2013). Because the mean difference including or excluding stacking the rings was very small (0.09 pieces) and this type of construction occurred very infrequently, it was excluded from the infant analysis and only affixing was coded for the stacking rings. Since construction with the Wood rings presented during toddlerhood is very similar to the stacking rings presented during infancy, we chose to code only affixing for this toy during toddlerhood for continuity. Although infants continually have the capacity to surprise us in the way they interact with toys, no other alternative forms of building were noted with these toys.

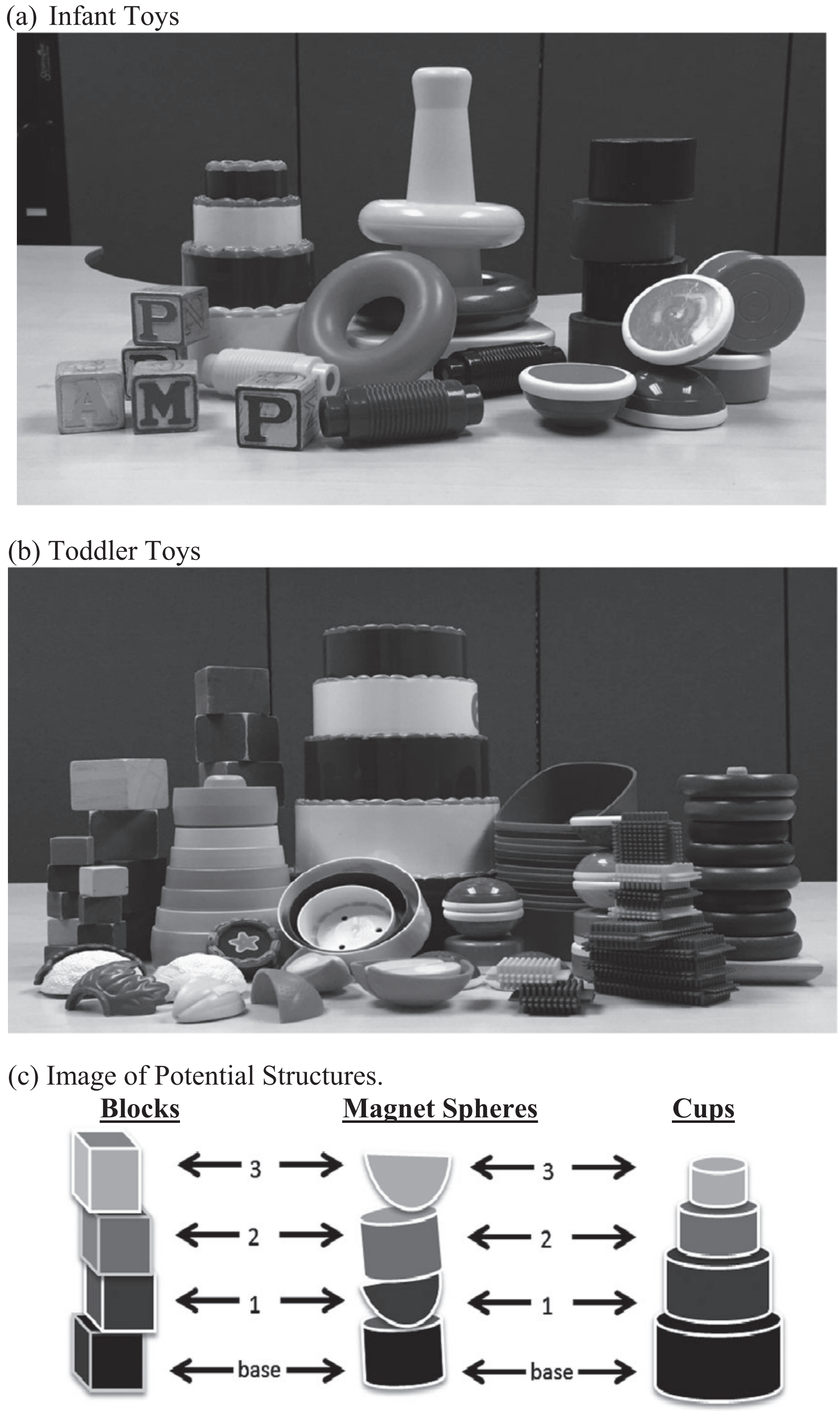

Figure 1 Pictures of construction toys. (a) Infant toys, (b) toddler toys (c) image of potential structures.

and the block falls), then this action was considered unsuccessful. We often observed infants stacking items and then immediately knocking the structure over in a separate action (e.g., stack the final block and then swipe the tower). This structure would still count, because a separate action destabilized the tower and not the stack itself. For the cakes, stacking could only be observed when the base cup had a solid side facing up and was larger than any other cup that was placed on top. Therefore, upside down stacking (a larger cup (open side facing upwards) placed on a smaller cake (open side upwards)) was not considered a successful stack.

Nesting was defined as "placing or settling an individual object inside another object" (Stacking/Nesting cake cups). Nesting was considered successful when the nested cup was inserted through the open side of the base cup and was completely settled within the base cup. Cups must be nested in the correct order based on descending size, and cups could only be contained within larger cups. Cups did not need to be seriated correctly for nesting to be successful, only that a smaller cup was completely settled within a larger cup. For the cakes, nesting could only be observed when the base cup had its open side facing up and only smaller cups were nested into it. Therefore, covering (placing a larger cake over a smaller cake) was not considered a successful nest.

Affixing was defined as "joining or attaching an individual object to another." Successfully affixed objects were defined in three ways. First, the infant could adhere two magnets or Velcro pieces using both hands. Second, an infant could hold one magnet or Velcro piece in one hand and adhere it to a magnet or Velcro piece on the table. If a magnet rolled toward an infant's stationary hand and adhered, this action was not considered a successful affix. Third, an object could be "fitted" to another piece or base object (e.g., a ring placed on a stick stand, porcupine block fitted correctly onto another porcupine block).

Zero toddlers and only two infants ever reached a ceiling (0.31% of infant visits) for any action (a 13-month-old for affixing, a 14-month-old for nesting). In both cases, the infants had a missing toy and had fewer items than designed for the task. All toys had <3% of participants reaching a ceiling for any visit, with the exception of the wood rings toy which had a large number of toddlers reaching a ceiling for at least one visit (86%).

Videos of the infant and toddler construction tasks were coded using Noldus© Observer XT 10.1 (Wageningen, The Netherlands). On 20% of randomly selected videos stratified by age, infant visits had an inter-rater reliability of 96.6% and an intrarater reliability of 97.9%. On 20% of randomly selected videos stratified by age, toddler visits had an overall agreement of 98.1% and an intrarater reliability of 97.4%.

Ordered versus nonordered construction in toddlerhood

More complex structures and methods for construction were created by toddlers, than by infants. Therefore, nonordered and ordered construction tasks were delineated in descriptive analyses, since these tasks were acquired at a different rate from one another in toddlerhood. This differentiation is meant to describe objects where there is no detriment to using a linear strategy to complete (e.g., "pot" strategy) or a nonlinear strategy (e.g., "subassembly"). Toys which have no consequences based on the order of placement (e.g., nonseriated cups) would not affect success differentially for children using either linear or nonlinear strategies. In contrast, toys with consequences for each placement (e.g., puzzles) might be more challenging for children and using a hierarchically structured or flexible strategy could be more advantageous to successful completion (e.g., "subassembly").

"Nonordered" affixing means that the same act can be repeated multiple times to create a more complex structure and the placement of items only minimally affected future placement of other items (porcupine blocks, magnetic spheres). No matter the order of placement of porcupine blocks or magnetic spheres, children could always affix more items onto the structure. "Ordered "affixing meant that the task was dependent on the location or order of items (orange, cauliflower[2]). For example, if one orange slice was placed in line with its neighboring slice, then more slices could be placed similarly and create a sphere. However, if one orange slice was placed on the rounded side of its neighboring slice (i.e., where a peel is meant to be adhered), then this placement affected the placement of other items (i.e., a peel) in the future.

Like nonordered affixing, nonordered nesting means that the same act can be repeated multiple times to create a more complex structure and the placement of items only minimally affected future placement of other items (sombreros, bowls). The bowls were all the same size, so any bowl could be placed within any other bowl. Similarly, the sombreros were shaped such that any of the pieces could be nested within the shape of any other item, even though these items have different sizes. "Ordered" nesting meant that the task was dependent on the location or order of items (stacking cakes, nesting cakes). The stacking and nesting cakes were seriated cups; therefore, larger cups could not be placed within smaller cups. For example, if the smallest cup (cup 1) was placed within the largest cup (cup 9), then that would inhibit cups 2–8 from being nested within cup 9.

Analytic plan

Two variables were created to represent construction development in the analyses: a "max" and a "sum of" variable. The most complex structure (i.e., with the most items comprising the structure) was identified for each action ("Max stack/nest/affix"). This "max" variable was meant to capture the infant's highest level of achievement, not accounting for the number of constructions performed. These "max" variables were only presented descriptively (Tables 2, 5, and 6) and not analyzed, because they exhibited little variability.

Construction skill was measured by summing all successfully constructed pieces across all construction toys for each action ("Sum of stacking/nesting/affixing"). These "sum of" variables were meant to capture the total number of construction acts the child was performing, regardless of individual toys. These "sum of" variables exhibited right-skewed distributions, and analyses of these variables were analyzed using Poisson regression models. All construction actions fit a Poisson distribution (χ^2s 0.440–49.557, *p*s .230–1.000), using the statistical software program JMP 11 (SAS Institute, Cary, NC, USA). Developmental changes in construction were analyzed using a multilevel Poisson longitudinal model (MPLM), using the software program, hierarchical linear

[2]Although the wood rings could fall under the category of "nonordered" affixing, we did not include it in these estimates for two reasons. First, we wanted the "ordered" and "nonordered" groupings to each have two toy sets, so toddlers would have a similar number of opportunities to achieve nonordered and ordered affixing. Second, the wood rings had a base while none of the other toys had a base, which we thought might make directly comparing to the other toys less applicable.

modeling (HLM v.7 Scientific Software International, Inc., Skokie, IL, USA). Sum of stacking, Sum of Nesting, and Sum of affixing matched an underdispersed Poisson model throughout infancy and most toddler visits (except 23 and 24); therefore, all variables were analyzed using an underdispersed Poisson model. A MPLM describes change over time, as well as how these changes vary separately for individuals and groups (Raudenbush, Bryk, Cheong, Congdon, & du Toit, 2004; Singer & Willett, 2003).

In developmental data such as the current study, a multilevel model is beneficial for three reasons. First, *a multilevel model describes change over time, as well as how these changes vary separately for individuals* (Raudenbush et al., 2004; Singer & Willett, 2003). A multilevel model models a dependent variable on time and/or group characteristics like a typical regression or ANOVA; however, each parameter within a model has fixed effects (e.g., intercepts, slopes) and random effects (e.g., variance components). Fixed effects describe average sample values, while random effects describe the variability that exists within the sample for terms. If a parameter's variance component is significant, this means that the average effects of that parameter do not sufficiently capture the sample's data. Because of these additional variance components, multilevel models do not assume homogeneity of variance; instead, differing levels of variability across visits, groups, or individual change are a core feature of multilevel models. In this way, these added variance components help us understand whether individuals vary in their trajectories or if "average" change captures development adequately. Second, *a child's actual age can be modeled as a continuous variable (e.g., 18.42 months), rather than an age category* (e.g., "18 months"). This makes for more accurate model estimates, because some variability, which otherwise would have been error variance, is accounted for in the model. Finally, *a multilevel model handles missing visits well*, as an infant's trajectory is modeled using all available data rather than losing an infant's data from a particular age point. The MPLM model used in the current study is to

TABLE 2
Cumulative Percentages of Infants Performing at Each Level by Age/Months (Max Stacks/Nests/Affixes)

	Age				
Action	*10*	*11*	*12*	*13*	*14*
Stacking (%)					
No stacking	84	73	55	34	13
Stack 1 item	16	22	35	39	46
Stack 2 items	0	4	6	17	24
Stack 3+ items	0	1	3	8	14
Nesting (%)					
No nesting	72	55	51	41	33
Nest 1 item	24	36	40	41	42
Nest 2 items	3	6	7	13	21
Nest 3+ items	0	2	2	5	4
Affixing (%)					
No affixing	74	55	34	22	16
Affix 1 item	24	36	45	45	43
Affix 2 items	4	6	18	16	21
Affix 3+ items	0	2	3	17	20

accommodate for the aforementioned factors, as well as for Poisson-distributed data (see Marcinowski, 2015 or Avant, Gazelle, & Faldowski, 2011 for a more detailed description of MPLM.)

Items were occasionally missing from tasks (e.g., researcher error, infant refusal); however, available pieces did not correlate with any sum of construction variables (ρs $-.004$ to .052, *p*s .116–.913). A variable exposure parameter was included into the model in an effort to accommodate differing opportunities to stack. The trajectory of the dependent variable can be conceptualized as the rate by which construction increased, relative to the total number of opportunities, at each visit.

A standard model-building procedure was used to test an unconditional growth model for each construction action with model reduction (Raudenbush et al., 2004; Singer & Willett, 2003). The child's actual age was modeled (e.g., "12.34 months"), and infant age was centered on 10 months (InfAge = Age–10) to create a linear age variable. Quadratic ($\text{InfAge}^2 = [\text{Age-Mean Age}]^2$) and Cubic age ($\text{InfAge}^3 = [\text{Age-Mean Age}]^3$) were both coded orthogonally to Age to decrease multicollinearity (Bock, 1975). The infant model included InfAge, InfAge^2, and InfAge^3 predicting the sum of stacking, nesting, or affixing in three separate models. The toddler's actual age was modeled with linear age centered on 18 months (TodAge = Age–18). The toddler model included TodAge, TodAge^2, and TodAge^3 predicting the sum of stacking, nesting, or affixing in three separate models.

There are three sections of our analyses: (1) Infant construction development (10–14 months), (2) toddler construction development (18–24 months), and (3) bridging the "gap" from infancy through toddlerhood (10–24 months). The section on infant construction development (10–14 months) provides descriptive information and analyses on the developmental trajectories during the infant period, models trajectories for each construction action during infancy, and correlates the construction actions to one another at each infant age. The section on toddler construction development (18–24 months) provides descriptive information and analyses on the developmental trajectories during the toddler period, specifically describes ordered/nonordered construction, models trajectories for each construction action during toddlerhood, and correlates the actions to one another at each toddler age. The third section bridges the gap between the two periods (10–24 months) by relating 10, 12, and 14-month data to 18 and 24-month toddler ability for each action.

RESULTS

Infant construction development (10–14 months)

Description of infant construction

The mean number of items available to infants during presentations included 11.39 items (*SD* = 1.40, 9–13 items) that could be stacked (out of 13 possible), 8.99 items (*SD* = 0.16, range: 5–9 items) that could be affixed (out of nine possible), and 5.99 items (*SD* = 0.17, range: 3–6 items) that could be nested (out of six possible).

All three actions increased across infancy. Most infants did not stack from 10–12 months (55–84%), but over half of infants could stack at least one item by 13 (64%) or 14 months (84%) (Table 2). At 10 (72%) and 11 months (55%), the majority of infants were not nesting any items; however, after 12 months, most infants could nest at least one item (66–84%) (Table 2). The majority of infants could affix at least one item by 13 months (59%) compared to the nearly equal proportions at 12 months (49% affix versus 51% not affix, Table 2). A higher percentage of infants could stack (38%) or nest (41%) 2+ items at 14 months, than could affix 2+ items (25%).

Infant developmental trajectory analyses (10–14 months)

For all infant models, the entire infant sample (n = 131) was used to estimate trajectories. On average, the sum of *stacking* increased linearly (γ_{11} = 1.043, p < .001) and had a significant intercept (γ_{01} = 5.334, p < .001) during infancy (see Fixed Effects in Table 3). The variance components for the intercept and linear slope were also significant (see Random Effects in Table 3). Significant variance components indicate that individuals exhibited variability in their scores at the model component (intercept, slopes) and the average effects by themselves are not sufficient to explain the data, meaning that infants varied in their 10-month scores (intercept) and their initial rate of change (linear slope). The quadratic and cubic slopes were not significant, but the random effects for these slopes were (see Fixed Effects and Random Effects in Table 3). This means that the sample *on average* did not exhibit quadratic or cubic change; however, significant variability in the quadratic and cubic slopes suggests that *some* infants within the sample do exhibit a quadratic and/or cubic slope. Therefore, the addition of random effects to the model allows us to capture this variability and create a more accurate model of stacking.

On average, the sum of *nesting* increased quadratically during infancy (γ_{21} = −0.051, p = .037). Infants were significantly variable to warrant a variance component for their respective intercepts. Infants were variable enough to warrant a variance component for the linear slope for nesting, but not for the quadratic slope. On average, the sum of *affixing* increased quadratically across infancy (γ_{21} = −0.116, p < .001). Infants were significantly variable to warrant a variance component for their respective intercepts and linear slopes, but not for any higher order slopes.

Correlations across infant object construction

The individual construction actions also correlated with each other across infancy (Table 4). Using a Spearman rank-order correlation formula and using a Bonferroni correction for multiple correlations, the sum of affixing and sum of nesting correlated at each month from 10 to 13 (rs .28–.37, ps <0.001), but not at 14 months (r = .160, p = .074). Affixing correlated with the sum of stacking at each month from 11 to 14 (rs .400–.515, ps <.001), but not at 10 months (r = .133, p = .139). Stacking correlated with nesting at all ages during infancy (rs .289–.426, ps <.001).

Toddler construction development (18–24 months)

Description of toddler construction

The mean number of items available to toddlers during the presentations included 33.46 items (SD = 5.80, 20–34 items) that could be stacked (out of 34 possible), 36.27 items (SD = 4.37, range: 28–37 items) that could be affixed (out of 37 possible), and 30.49 items (SD = 5.84, range: 23–33 items) that could be nested (out of 33 possible).

TABLE 3
Estimated Fixed and Random Effects for Sum of Items Constructed by Action at Infancy. (Unconditional Growth Models)

	Construction		
Fixed effects	*Stacking Coefficient*	*Nesting Coefficient*	*Affixing Coefficient*
Inf Intercept	−5.334***	−2.886***	−3.049***
InfAge	1.043***	.361***	.524***
$InfAge^2$	−.086	−.051*	−.116***
$InfAge^3$	−.015	–	–
Random effects	*Variance component*	*Variance component*	*Variance component*
Intercept	9.465***	0.849***	0.859***
InfAge	1.263***	0.045*	0.033*
$InfAge^2$	0.240***	–	–
$InfAge^3$	0.084***	–	–
Level-1 (σ^2_ε)	0.273	0.657	0.702

Note. $^*p < .05$, $^{***}p < .001$.

TABLE 4
Correlations Between the Sum of Each Construction Action During Infancy

	Stacking (months)					Nesting (months)				
	10	*11*	*12*	*13*	*14*	*10*	*11*	*12*	*13*	*14*
Stacking	–	–	–	–	–	.33*	.34*	.43*	.29*	.32*
Affixing	.13	.40*	.47*	.52*	.40*	.28*	.37*	.33*	.32*	.16

Note. $^*p < .01$.

All three actions increased during toddlerhood in different ways (Table 5). Toddlers had a wide range of skill for stacking with 52% of toddlers stacking 0–2 items, 28% stacking 3–4 items, and 20% stacking 6+ items at 18 months. However, by 24 months, 55% of toddlers stacked 6+ items, and very few toddlers are stacking <2 items (24%). Thirty-eight percent of toddlers affixed 7+ items at 18 months and ≥79% of toddlers after 19 months. Early on, toddlers had a wide range of skill for nesting with roughly a third of toddlers able to nest 7+ items at 18–19 months (33–36%), but after 21 months, more than half of toddlers nested 7+ items (54–76%).

Nonordered versus ordered construction in toddlerhood

Toddlers exhibited a wide range of variability for both types of affixing at 18 months (Tables 5 and 6); most toddlers were capable of affixing at least 1 item in the nonordered (86%) and ordered (66%) tasks. Over half of toddlers were able to affix 4 or more items in nonordered affixing tasks after 20 months (52–74%). Indeed, 26% of toddlers used all pieces for the porcupine blocks or the magnetic spheres at

TABLE 5
Cumulative Percentages of Toddlers Performing at Each Level by Age/Months (Max Stacks/Nests/Affixes)

	Age						
Action	*18*	*19*	*20*	*21*	*22*	*23*	*24*
Stacking (%)							
No stacking	2	4	2	2	0	2	0
Stack 1 item	24	13	11	11	2	5	7
Stack 2 items	26	15	18	9	11	5	7
Stack 3 items	12	17	21	18	14	7	10
Stack 4 items	16	17	25	16	18	12	8
Stack 5 items	10	22	12	16	18	16	13
Stack 6+ items	0	13	12	30	39	53	55
Nesting (%)							
No nesting	5	9	8	0	3	3	0
Nest 1 item	10	5	13	5	3	6	3
Nest 2 items	10	11	3	7	0	3	3
Nest 3 items	18	11	13	5	9	8	0
Nest 4 items	5	0	5	7	3	0	3
Nest 5 items	3	5	0	2	0	0	3
Nest 6+ items	48	59	59	74	81	81	89
Affixing (%)							
No affixing	0	0	0	0	0	0	0
Affix 1 item	10	6	0	0	0	0	0
Affix 2 items	17	0	4	2	2	2	2
Affix 3 items	12	4	2	4	4	0	0
Affix 4 items	10	6	2	7	0	0	0
Affix 5 items	7	2	9	2	0	0	0
Affix 6+ items	45	82	83	86	95	97	98

24 months, while only 19% used all pieces for the cauliflower or orange, despite the cauliflower and orange having fewer items than the porcupine blocks and magnetic spheres.

As with affixing, toddlers exhibited a range of variability in ordered and nonordered nesting (Tables 5 and 6); most toddlers were capable of nesting at least one item in the nonordered (82%) and ordered (88%) tasks. A majority of children were able to nest more than five items by 19 months (68%), and 93% could nest more than five items on nonordered nesting tasks by 24 months. In contrast, very few children were able to nest more than five items on ordered nesting tasks by 19 months (7%) and only 20% could by 24 months. In contrast, very few children were able to nest more than five items on ordered nesting tasks by 19 months (7%) and only 20% could by 24 months.

Toddler developmental trajectory analyses (18–24 months)

For all toddler models, the entire toddler sample ($n = 65$) was used to estimate trajectories. *Stacking* increased linearly across toddler ages ($\gamma_{11} = 0.114$, $p < .00$; Table 7). The intercept and quadratic slope, and the variance components were significant. *Nesting* increased linearly across the toddlerhood ($\gamma_{21} = 0.067$, $p < .001$). Toddlers varied in their scores enough to warrant a variance component for their respective intercepts. *Affixing* exhibited cubic change across toddlerhood ($\gamma_{31} = -0.013$, $p < .001$). Toddlers varied in their scores enough to warrant a variance component for their respective intercepts and linear slopes, but not for any higher order slopes. A graph representing the average infant (n = 131) and toddler (n = 65) performance together is shown in Figure 2.

Correlations across toddler object construction

The individual construction actions also correlated with each other for some of toddlerhood. Using a Spearman rank-order correlation formula and using a Bonferroni correction for multiple correlations, stacking correlated with affixing at 22 months (r = .500, p < .001) and 23 months (r = .571, p < .001); however, stacking did not correlate with nesting, or nesting with affixing during toddlerhood.

Bridging the "gap" from infant–toddlerhood (10–24 months)

Individual actions during infant construction predicted toddler skill for that same action. We examined the predictive relation between ability at each infant age with the first (18 months) and last (24 months) toddler assessments using MPLMs. Performance

TABLE 6
Comparing Nonordered Versus Ordered Construction Types in Toddlerhood

		Age						
Action	*Type*	*18*	*19*	*20*	*21*	*22*	*23*	*24*
Nesting	Nonordered: *Toys: bowls, sombreros* (%)							
	No nesting	18	9	9	3	7	4	2
	Nest 1 item	10	9	12	5	0	7	0
	Nest 2 items	4	5	2	3	0	2	5
	Nest 3 items	10	7	2	3	4	0	0
	Nest 4 items	2	0	4	5	2	0	3
	Nest 5 items	0	2	0	0	0	0	0
	Nest 6+ items	54	68	72	80	87	87	90
	Ordered: *Toys: nesting cakes, stacking cakes* (%)							
	No nesting	12	16	14	8	19	16	17
	Nest 1 item	31	23	21	17	14	22	12
	Nest 2 items	27	33	11	19	21	14	25
	Nest 3 items	20	7	36	32	18	21	14
	Nest 4 items	6	14	9	10	14	14	12
	Nest 5 items	4	5	2	8	7	5	12
	Nest 6+ items	0	2	7	5	7	9	8
Affixing	Nonordered: *Toys: magnetic spheres, porcupine blocks* (%)							
	No affixing	14	5	5	3	0	0	2
	Affix 1 item	20	21	17	7	5	5	5
	Affix 2 items	18	20	14	10	16	12	10
	Affix 3 items	20	13	12	22	18	9	10
	Affix 4+ items	28	41	52	58	61	74	74
	Ordered: *Toys: orange, cauliflower* (%)							
	No affixing	34	28	14	12	17	5	11
	Affix 1 item	45	41	53	37	25	31	26
	Affix 2 items	17	16	17	28	32	22	28
	Affix 3 items	4	14	10	10	14	25	18
	Affix 4+ items	0	2	5	13	12	17	16

ability was calculated by creating a proportion of constructed items relative to construction opportunities at 10, 11, 12, 13, and 14 months of age. Only children who had data at both infancy and toddlerhood were included in these analyses ($n = 65$).

Infant ability for any action at 10 months did not predict respective ability at 18 or 24 months (*p*s .11–.82). Infant ability from 12 months positively predicted stacking and affixing at 18 and 24 months (*p*s < .01–.04), but not nesting. Nesting ability at 14 months positively predicted 18 and 24 months (*p*s < .03) nesting ability. Stacking ability at 14 months positively predicted 18 and 24 months (*p*s < .040) stacking ability. Affixing ability at 14 months predicted 18 and 24 months (*p*s < .01) affixing ability. Thus, infant skill at 12 and 14 months predicted construction skill at the beginning and end of the toddler age period.

DISCUSSION

A general discussion of findings

This study described the pattern of development for three distinct types of object construction skill (stacking, nesting, affixing) during infant (10–14 months) and toddler (18–24 months) age periods. We wanted to determine whether object constructions increased across age and whether infant skill predicted toddler skill. Object construction skills did increase across time, but the shape of change varied. While some infants increased stacking at a constant rate in a linear pattern, others developed stacking slowly initially and then rapidly increased from 13 to 14 months in a quadratic or cubic pattern. In contrast, nesting and affixing both exhibited cubic change, but had significant variability in their initial rate of change and at 10 months (i.e., their linear slopes and intercepts, respectively). The overall increase for stacking was linear, significant variability exists at the quadratic and cubic slopes, indicating that some infants may also exhibit quadratic or cubic change across 10–14 months.

TABLE 7
Estimated Fixed and Random Effects for Sum of Items Constructed by Action During Toddlerhood. (Unconditional Growth Models)

	Construction		
Fixed effects	*Stacking Coefficient*	*Nesting Coefficient*	*Affixing Coefficient*
Tod intercept	−1.639***	−1.268***	−1.123***
TodAge	0.108***	0.067***	0.086***
$TodAge^2$	−0.016*	–	−0.023***
$TodAge^3$	–	–	0.005*
Random effects	*Variance component*	*Variance component*	*Variance component*
Tod intercept	0.138***	0.085***	0.060***
$TodAge^2$	–	–	0.000*
$TodAge^3$	–	–	0.000**
Level-1 (σ_ε^2)	1.713	1.612	0.897

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

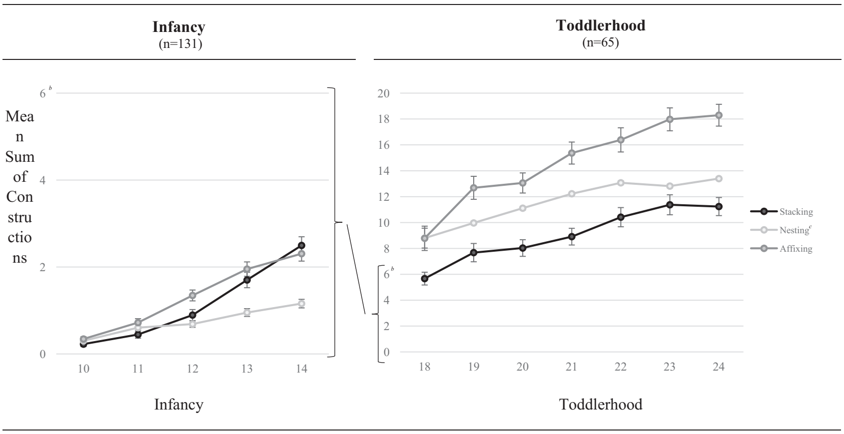

Figure 2 Mean sum of construction skill across infancy and toddlerhood by action.[a]
[a]Bars are standard errors. [b]Note that these graphs were presented side-by-side for comparison, but are not on the same scale. [c]The nesting lines do have standard errors on them; but they are small. The maximum number of objects that could be constructed was 13 infant stacks, six infant nests, nine infant affixes, 34 toddler stacks, 33 toddler nests, and 37 toddler affixes.

Overall, these findings suggest that there were not a one size fits all pattern for the development of infant construction. Rather, the development of infant construction skills can be characterized by variability within infants' trajectories and between action types.

The way in which infants develop object construction skill sheds light on bidirectional factors influenced or being influenced by its emergence (i.e., developmental timing: Michel & Tyler, 2007; Adolph, Robinson, Young, & Gill-Alvarez, 2008). Quadratic and cubic change, rather than constant linear change, could occur if this construction skill is connected to an important shift in a relevant factor during development. For example, infants become able to detect motion differences between objects after 13 months. Ten- to 12-month-old infants are not capable of discerning object motion in the presence of spatial cues, while 13- to 15-month-old infants are (Pruden, Göksun, Roseberry, Hirsh-Pasek, & Golinkoff, 2012). Perhaps, the ability to detect relative motion differences between objects affects the emergence of object construction; conversely, the emergence of object construction may change how infants perceive relative motion differences. Through this mechanism, the spatial and object construction domains of development may be connected (Marcinowski & Campbell, 2017).

Additionally, differences among infants in their construction skill during their older ages predicted their toddler skill. Toddlers are combining more objects together and creating more complex structures; however, the skills acquired during late infancy may shape object construction skills during toddlerhood. Infants gain knowledge of object properties and creation of new structures through manipulation and experience. By building upon their experiences during infancy, toddlers may adapt their behavior more readily and develop strategies for object combination that yield more complex structures.

We also predicted connections among different construction actions. There were correlations across actions within infant ages, although correlations across different actions diminished as toddlers got older. Object construction developed differently within each of the age periods examined (infant versus toddler) and skill for these actions also differed in the way they developed (linear versus quadratic versus cubic change). Nesting skill increased more slowly than other actions during infancy, perhaps because greater success requires some ability with seriation; however, toddlers nested more items than they stacked. Stacking had a consistent rate of change (i.e., linearly) across toddlerhood, yet infants showed a wide range of variability in how they developed stacking skill from 10 to 14 months. Finally, affixing is highly variable across participants during infancy and toddlerhood. Perhaps, affixing is more variable as defined by the current study, because the skills and materials associated with this ability are more heterogeneous than those for stacking or nesting. The affixing toys included materials such as magnets, Velcro, and specially shaped pieces, for which successful adherence is reliant on different properties of these materials. In contrast, stacking and nesting toys included roughly similar materials and shapes, for which successful stacking or nesting relied on an understanding of roughly similar object properties (e.g., stacking blocks on the flat top of another block, nesting a cup in another cup).

Unique skills and shifts in environmental characteristics occurring after 18 months may affect how toddlers combine objects. Eighteen-month-olds are more likely to make containment actions (e.g., nest), than support actions (e.g., stack; Casasola et al., 2017). Toddlers are consistently more successful at nesting, than stacking, perhaps because of an increased interest in containments relative to supports. Additionally, caregivers are more likely to demonstrate a support action and are more likely to label containment during play (Casasola et al., 2017). Therefore, the differences in trajectory between stacking and nesting could be explained, in part, by toddlers' and caregivers' differential play patterns and verbalizations regarding nesting and stacking.

Finally, although object construction trajectories were connected between the infant and toddler periods, toddlers exhibited markedly higher rates of ability than infants. Some infants were building structures at 10 months, and all infants could construct by 14 months, making the end of the first year the initial emergence of this skill. Toddler skill increased after 18 months with the majority of 18-month-olds building structures with three or more items for any action (64–91%). By 24 months, the majority of children could build structures with six or more items for any action (55–98%). Toddlerhood could represent a unique time of change for the development of object construction, because new kinds of cognitive abilities appear and may contribute to the development of object construction ability. For example, greater insight into error correction strategies (e.g., DeLoache et al., 1985; Hayashi & Takeshita, 2009) and understanding of hierarchical structures (e.g., Greenfield et al., 1972) change within the 18- to 24-month period and both likely affect the development of object construction.

The improvement in construction skills is also likely to be influenced by general improvement in motor skills over the ages tested here given the bidirectional relationship between postural control and fine manual control (for discussion, see Rosenblum & Josman, 2003). For example, reach kinematics change rapidly over the first 2 years of life, including an overall slowing in average hand speed (for a review, see Berthier, 2011). Reach kinematics have been linked to individual differences in construction ability. Chen, Keen, Rosander, and von Hofsten (2010) reported that toddlers (18–

21 months) who could build taller block towers slowed their arm near the tower, allowing the block to be placed more precisely. By contrast, toddlers who built smaller block towers did not exhibit the same kinematic patterns, which may explain why those children were less successful at building tall towers. More broadly, several investigators have reported links between motor abilities and gains in other domains including perceptual skills (Soska, Adolph, & Johnson, 2010), cognitive skills (Campos et al., 2000; Schwarzer, Freitag, Buckel, & Lofruthe, 2012), and language skills (Libertus & Violi, 2016; Walle & Campos, 2014; Wang, Lekhal, Aaro, & Schjolberg, 2014).

Unfortunately, one limitation of the current study is that it lacked monthly visit data between 14- and 18-month visits. The notable shift in ability from low infant rates to higher toddler rates of construction and similar changes in cognition (e.g., DeLoache et al., 1985) and fine motor ability (Chen, Keen, Rosander, & von Hofsten, 2010) highlights the importance of investigating the 14- to 18-month period in the future. Future work should explore these links between motor, cognitive, and language skills within the context of the development of object construction abilities, particularly between 14 and 18 months of age. Although we chose monthly intervals based on prior research, additional work in this research area may benefit from a microgenetic method to examine developmental change in construction using smaller sampling intervals such as days or weeks (e.g., Adolph et al., 2008).

Why does object construction skill change from infancy and toddlerhood?

Shifts in cognition and combination strategies may be responsible for change in construction skill from infancy through toddlerhood. Object construction skill at young ages may be highly variable and random (Smith & Gasser, 2005). Infants and toddlers both may initially exhibit a skill for combining or pairing objects (e.g., a block inserted into a cup, a Velcro ball attached to cloth.), but perhaps infants inadvertently combine more objects through multi-object exploration. These combinations may not be "planned" (i.e., involving goal-directed activities to create specific structures) which may not become manifest until later ages (Smith & Gasser, 2005). Infants who are haphazardly combining objects are actually exploring multi-object properties, which, in turn, might increase the amount of their multi-object combinations and ultimately make them successful at construction later in development (Oudgenoeg-Paz, Volman, & Leseman, 2016). Greenfield et al. (1972) describe cases of infants who would successively pair one cup with another, then immediately withdraw and pair it with another cup, repetitively. Also, when nesting, young children (18–42 months) who make many errors in nesting and error corrections were often incorrect (DeLoache et al., 1985). It is unknown whether greater experience with combination activities permits the discovery of better combination strategies or promotes changes in cognition.

These apparent "trial-and-error" strategies might be why toddlers are less successful in ordered construction tasks, as opposed to nonordered tasks. Children can be relatively successful at nonordered construction tasks through haphazard placements or trial-and-error strategies for completion. A child who understands generally how object relations work (place one cup in another cup) can repetitively recreate this action and be successful at creating structures comprising multiple objects when their combination has few constraints (e.g., bowls). The same strategy is less effective for ordered tasks, because the properties of the objects constrain how the child can combine the object and limits success. Nonstrategic combinations or placements are more likely to lead to failure or require error correction when there are more task constraints.

Trial-and-error strategies might also explain why the trajectories for different actions had significant variability in slopes and intercepts. Variability in the development of object construction skill could reflect a "haphazard" pattern of multi-object exploration and combinatory actions. Infant trajectories had a wide range of variability for stacking and infants ranged in the kinds of exhibited change, despite only a main effect of linear change. Once children are capable of performing goal-directed construction activities, they may exhibit less variability in their developmental trajectories. Thereafter, there is a transition from trial-and-error strategies to a higher proportion of correct initial placements (DeLoache et al., 1985). The increased use of "interrupted" strategies in children after 2 years may evidence their beginning to plan their combination strategies (Greenfield, 1991; Greenfield et al., 1972). Through the use of more complex strategies and a greater understanding of construction, object relations, and combination strategies, children then become more successful and efficient at construction after 2 years of age.

Future directions for the study of object construction

The way children develop in the first 2 years of life can have long-lasting implications for their lives. The descriptive information of this study sheds light on how different kinds of object construction change from infancy through toddlerhood. Some have proposed that the development of object construction skills could affect or reflect cognitive and language development (e.g., Greenfield, 1991; Marcinowski et al., 2016; Michel, Campbell, Marcinowski, Nelson, & Babik, 2016). We suggest three avenues of research for future study. First, research should address what information and experience is provided by actively building with objects. For example, constructive play may provide children additional experience with spatial relations and improve spatial skills, which would explain the connection between early construction ability and comprehension of spatial words (Marcinowski & Campbell, 2017). Perhaps, building structures may also "teach" the child about structures and hierarchical structures through play. Therefore, object construction could be one mechanism by which a child comes to understand organization of hierarchical structures, which is an important skill for developing language (Greenfield, 1991). Understanding what a child gains from construction play would shed light on what abilities can be affected by object construction.

Second, research should identify what factors influence the development of object construction. The current study was limited in that no data were collected on home characteristics and toy availability. Presumably, greater access to building toys could influence opportunities for exploring object construction and any skills emerging from building play. Children with greater incidence of puzzle play at home exhibit more advanced spatial transformation (Levine et al., 2011), and children's play with blocks predicted spatial visualization ability (Caldera et al., 1999). Therefore, differing levels of access to certain objects and toys may change how children develop object construction and spatial ability.

Third, research should address what abilities object construction affects and how it affects the development of these abilities. Later in development, construction activities exhibit an apparent connection to spatial cognition (e.g., Brosnan, 1998; Caldera et al., 1999; Jirout & Newcombe, 2015; Levine et al., 2011; Nath & Szucs, 2014; Verdine et al., 2014), even as far as predicting middle and high school mathematics achievement (Wolfgang et al., 2003). However, these studies did not examine construction during infancy and toddlerhood, or how early skills might predict the development of spatial skills at preschool and older ages. Therefore, we suggest careful, developmental study of whether and how object construction may affect the development of language and cognition, particularly in relation to spatial abilities.

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REFERENCES

Adolph, K. E., Robinson, S. R., Young, J. W., & Gill-Alvarez, F. (2008). What is the shape of developmental change? *Psychological Review*, *115*(3), 527–543. https://doi.org/10.1037/0033-295X.115.3.527

Avant, T. S., Gazelle, H., & Faldowski, R. (2011). Classroom emotional climate as a moderator of anxious solitary children's longitudinal risk for peer exclusion: A child x environment model. *Developmental Psychology*, *47*(6), 1711–1727. https://doi.org/10.1037/a0024021

Baldwin, D. A., Markman, E. M., & Melartin, R. L. (1993). Infants' ability to draw inferences about nonobvious object properties: Evidence from exploratory play. *Child Development*, *64*(3), 711–728. https://doi.org/10.2307/1131213

Barret, T. M., Davis, E. F., & Needham, A. (2007). Learning about tools in infancy. *Developmental Psychology*, *43*(2), 352–368. https://doi.org/10.1037/0012-1649.43.2.352

Berthier, N. E. (2011). The syntax of human infant reaching. In H. Sayama, A. A. Minai, D. Braha & Y. Bar-Yam (Eds.), Unifying Themes in Complex Systems Volume VIII: Proceedings of the Eighth International Conference on Complex Systems. New England Complex Systems Institute Series on Complexity, NECSI Knowledge Press, 1477–1487.

Bock, R. D. (1975). *Multivariate statistical methods in behavioral research*. New York, NY: McGraw-Hill.

Bourgeois, K. S., Khawar, A. W., Neal, S. A., & Lockman, J. J. (2005). Infant manual exploration of objects, surfaces and their interrelations. *Infancy*, *8*(3), 233–252. https://doi.org/10.1207/s15327078in0803_3

Brosnan, M. J. (1998). Spatial ability in children's play with Lego blocks. *Perceptual and Motor Skills*, *87*(1), 19–28.

Bushnell, E. W., & Boudreau, J. P. (1993). Motor development and the mind: The potential role of motor abilities as a determinant of aspects of perceptual development. *Child Development*, *64*(4), 1005–1021. https://doi.org/10.2307/1131323

Caldera, Y. M., McCulp, A., O'Brien, M., Truglio, R. T., Alvarez, M., & Huston, A. C. (1999). Children's play preferences, construction play with blocks, and visual-spatial skills: Are they related?. *International Journal of Behavioral Development*, *23*(4), 855–872. https://doi.org/10.1080/016502599383577

Campos, J. J., Anderson, D. I., Barbu-Roth, M. A., Hubbard, E. M., Hertenstein, M. J., & Witherington, D. (2000). Travel broadens the mind. *Infancy*, *1*(2), 149–219. https://doi.org/10.1207/S15327078IN0102_1

Casasola, M., Bhagwat, J., Doan, S. N., & Love, H. (2017). Getting some space: Infants' and caregivers' containment and support spatial constructions during play. *Journal of Experimental Child Psychology*, *159*, 110–128. https://doi.org/10.1016/j.jecp.2017.01.012

Chen, Y.-P., Keen, R., Rosander, K., & von Hofsten, C. (2010). Movement planning reflects skill level and age changes in toddlers. *Child Development*, *81*(6), 1846–1858. https://doi.org/10.1111/j.1467-8624.2010.01514.x

DeLoache, J. S., Sugarman, S., & Brown, A. L. (1985). The development of error correction strategies in young children's manipulative play. *Child Development*, *56*(4), 928–939. https://doi.org/10.2307/1130105

Greenfield, P. M. (1991). Language, tools and brain: The ontogeny and phylogeny of hierarchically organized sequential behavior. *Behavioral and Brain Sciences*, *14*, 531–595. https://doi.org/10.1017/S0140525X00071235

Greenfield, P. M., Nelson, K., & Saltzman, E. (1972). The development of rulebound strategies for manipulating seriated cups. A parallel between action and grammar. *Cognitive Psychology*, *3*, 291–310. https://doi.org/10.1016/0010-0285(72)90009-6

Hauf, P., & Paulus, M. (2011). Experience matters: 11-month-old infants can learn to use material information to predict the weight of novel objects. *Infant Behavior and Development*, *34*(3), 467–471. https://doi.org/10.1016/j.infbeh.2011.05.002

Hayashi, M., & Matsuzawa, T. (2003). Cognitive development in object manipulation by infant chimpanzees. *Animal Cognition*, *6*, 225–233. https://doi.org/10.1007/s10071-003-0185-8

Hayashi, M., & Takeshita, H. (2009). Stacking of irregularly shaped blocks in chimpanzees (*Pan troglodytes*) and young humans (*Homo sapiens*). *Animal Cognition*, *12*(1), 49–58. https://doi.org/10.1007/s10071-009-0273-5

Iverson, J. M. (2010). Developing language in a developing body: The relationship between motor development and language development. *Journal of Child Language*, *37*(2), 229–261. https://doi.org/10.1017/S0305000909990432

Jirout, J. J., & Newcombe, N. S. (2015). Building blocks for developing spatial skills: Evidence from a large representative U. S. sample. *Psychological Science*, *26*(3), 302–310. https://doi.org/10.1177/0956797614563338

Kagan, J. (2013). Equal time for psychological and biological contributions to human variation. *Review of General Psychology*, *17*, 351–357. https://doi.org/10.1037/a0033481

Keen, R. (2011). The development of problem solving in young children: A critical cognitive skill. *Annual Review of Psychology*, *62*, 1–21. https://doi.org/10.1146/annurev.psych.031809.130730

Levine, S. C., Ratliff, K. R., Huttenlocher, J., & Cannon, J. (2011). Early puzzle play: A predictor of preschoolers' spatial transformation skill. *Developmental Psychology*, *48*(2), 530–542.

Libertus, K., & Violi, D. A. (2016). Sit to talk: Relation between motor skills and language development in infancy. *Frontiers in Psychology*, *7*, 1–8. https://doi.org/10.3389/fpsyg.2016.00475.

Lifter, K., & Bloom, L. (1989). Object knowledge and the emergence of language. *Infant Behavior and Development*, *12*(4), 395–423. https://doi.org/10.1016/0163-6383(89)90023-4

Lockman, J. J. (2000). A perception-action perspective on tool use development. *Child Development*, *71*(1), 137–144. https://doi.org/10.1111/1467-8624.00127

Lockman, J. J., & Wright, M. H. (1989). Relating objects and surfaces during infancy: A longitudinal study Poster presented at the biennial meetings of the society for Research in Child Development. MO: Kansas City.

Marcinowski, E. C. (2013). *The influence of sex and handedness on the development of construction skill during infancy*, Unpublished thesis. The University of North Carolina at Greensboro, Greensboro, NC.

Marcinowski, E. C. (2015). *How does handedness affect the development of construction skill from 10–24 months?*, Unpublished dissertation. The University of North Carolina at Greensboro, Greensboro, NC.

Marcinowski, E. C., & Campbell, J. M. (2017). Building on what you have learned: Object construction skill during infancy predicts the comprehension of spatial relations words. *International Journal of Behavioral Development*, *41*(3), 341–349. https://doi.org/10.1177/0165025416635283

Marcinowski, E. C., Campbell, J. M., Faldowski, R. A., & Michel, G. F. (2016). Do hand preferences predict stacking skill during infancy? *Developmental Psychobiology*, *58*(8), 958–967. https://doi.org/10.1002/dev.21426

Michel, G. F., Campbell, J. M., Marcinowski, E. C., Nelson, E. L., & Babik, I. (2016). Infant hand preference and the development of cognitive abilities. *Frontiers in Psychology*, *7*, 1–6. https://doi.org/10.3389/fpsyg.2016.00410

Michel, G. F., Marcinowski, E. C., Babik, I., Campbell, J. M., & Nelson, E. L. (2015). An interdisciplinary biopsychosocial perspective on infant development. In S. D. Calkins (Ed.), *Handbook of infant development* (pp. 427–446). New York, NY: Guilford Publications.

Michel, G. F., & Tyler, A. N. (2007). Developing human nature: "Development to" versus "development from?". *Developmental Psychobiology*, *49*, 788–799. https://doi.org/10.1002/(ISSN)1098-2302

Morgante, J. D., & Johnson, S. P. (2011). Infants' perception of object-surface interplays. *British Journal of Developmental Psychology*, *29*(Part 4), 999–1005. https://doi.org/10.1111/j.2044-835X.2011.02049.x

Nath, S., & Szucs, D. (2014). Construction play and cognitive skills associated with the development of mathematical abilities in 7-year-old children. *Learning and Instruction*, *32*, 73–80. https://doi.org/10.1016/j.learninstruc.2014.01.006

Needham, A. (2000). Improvements in object exploration skills may facilitate the development of object segregation in early infancy. *Journal of Cognition and Development*, *1*(2), 131–156. https://doi.org/10.1207/S15327647JCD010201

Oudgenoeg-Paz, O., Volman, M. J. M., & Leseman, P. P. M. (2016). First steps into language? Examining the specific longitudinal relations between walking exploration and linguistic skills. *Frontiers in Psychology*, *7*, 1–12.

Pieraut-Le Bonniec, G. (1985). From visual-motor anticipation to conceptualization: Reaction to solid and hollow objects and knowledge of the function of containment. *Infant Behavior and Development*, *8*(4), 413–424. https://doi.org/10.1016/0163-6383(85)90005-0

Pruden, S. M., Göksun, T., Roseberry, S., Hirsh-Pasek, K., & Golinkoff, R. M. (2012). Find your manners: How do infants detect the invariant manner of motion in dynamic events? *Child Development*, *83*(3), 977–991. https://doi.org/10.1111/j.1467-8624.2012.01737.x

Raudenbush, S., Bryk, A., Cheong, Y. F., Congdon, R., & du Toit, M. (2004). *HLM 6: Hierarchical linear & nonlinear modeling*. Lincolnwood, IL: Scientific Software International Inc.

Rosenblum, S., & Josman, N. (2003). The relationship between postural control and fine manual dexterity. *Physical & Occupational Therapy in Pediatrics*, *23*(4), 47–60. https://doi.org/10.1080/J006v23n04_04

Ruff, H. A. (1980). The development of perception and recognition of objects. *Child Development*, *51*, 981–992. https://doi.org/10.2307/1129536

Schwarzer, G., Freitag, C., Buckel, R., & Lofruthe, A. (2012). Crawling is associated with mental rotation ability by 9-month-old infants. *Infancy*, *18*, 432–441.

Singer, J. D., & Willett, J. B. (2003). *Applied longitudinal data analysis: Modeling change and event occurrence*. New York, NY: Oxford University Press. https://doi.org/10.1093/acprof:oso/9780195152968.001.0001

Smith, L., & Gasser, M. (2005). The development of embodied cognition: Six lessons from babies. *Artificial Life*, *11*(1–2), 13–29. https://doi.org/10.1162/1064546053278973

Soska, K. C., Adolph, K. E., & Johnson, S. P. (2010). Systems in development: Motor skill acquisition facilitates three-dimensional object completion. *Developmental Psychology*, *46*, 129–138. https://doi.org/10.1037/a0014618

Tinbergen, N. (1963). On aims and methods of ethology. *Zeitschrift fur Tierpsychologie*, *20*(4), 410–433.

Tomasello, M. (1998). Uniquely primate, uniquely human. *Developmental Science*, *1*(1), 1–16. https://doi.org/10.1111/1467-7687.00002

Verdine, B. N., Golinkoff, R. M., Hirsh-Pasek, K., Newcombe, N. S., Filipowicz, A. T., & Change, A. (2014). Deconstructing building blocks: Preschoolers' spatial assembly performance relates to early mathematical skills. *Child Development*, *85*(3), 1062–1076. https://doi.org/10.1111/cdev.12165

Walle, E. A., & Campos, J. J. (2014). Infant language development is related to the acquisition of walking. *Developmental Psychology*, *50*, 336–348. https://doi.org/10.1037/a0033238.

Wang, M. V., Lekhal, R., Aaro, L. E., & Schjolberg, S. (2014). Co-occurring development of early childhood communication and motor skills: Results from a population-based longitudinal study. *Child: Care, Health, and Development*, *40*, 77–84. https://doi.org/10.1111/cch.12003.

Wolfgang, C. H., Stannard, L. L., & Jones, I. (2003). Advanced constructional play with LEGOs among preschoolers as a predictor of later school achievement in mathematics. *Early Child Development and Care*, *173*(5), 467–475. https://doi.org/10.1080/0300443032000088212

SUPPORTING INFORMATION

Additional Supporting Information may be found online in the supporting information section at the end of the article:

Table S1. Characteristics of infant and toddler samples.