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Developmental Changes in Children's Object Insertions during Play

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ABSTRACT

Spatial play in early childhood is associated with a variety of spatial and cognitive skills. However, these associations are often derived from studies in which different tasks are used across different age ranges, leaving open the question of how children's natural behaviors during spatial play develop from infancy into the early preschool years. We used an open-ended spatial play task to establish typically developing children's behaviors from 12 to 48 months ($N = 66$, 36 girls). Specifically, we observed young children's insertions into a commercially available shape sorter that included six geometric solids with corresponding apertures. Approaches to this task changed with age. Younger children primarily inserted solids into the large top opening, a strategy that did not require spatial alignment for success. Between 24 and 30 months, children shifted to inserting solids into their corresponding side openings, a more spatially and motorically difficult strategy that required aligning solids to their appropriate apertures. This pattern suggests that at 24 months, children begin to adopt more sophisticated strategies for this motor problem-solving task. Older children also completed a higher proportion of successful insertions compared to younger participants, and children successfully inserted rotationally symmetrical shapes (e.g., circle) at younger ages than rotationally asymmetrical shapes (e.g., triangle). This study represents an important first step in providing a detailed baseline of children's natural play behaviors over a wide developmental period that can be used to inform how spatial and cognitive systems contribute to spatial play.

Visually examining and manipulating objects is a fruitful avenue for children's learning. Children's manual object exploration is associated with the simultaneous development of advanced cognitive skills such as mental rotation, spatial assembly, 3D object completion (children's ability to perceive the unseen components of three-dimensional objects), and language (Jirout & Newcombe, 2015; Möhring & Frick, 2013; Soska, Adolph, & Johnson, 2010; Walle & Campos, 2014). Moreover, object exploration in early childhood appears to be part of a developmental cascade. For example, infant object exploration predicts achievements at 14 years in both quantitative and reading and writing-focused domains (Bornstein, Hahn, & Suwalsky, 2013). Finally, enhancing infants' manual manipulation of objects results in significant gains in their object exploration, attention, and spatial skills (e.g.,

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Frick & Wang, 2014; Möhring & Frick, 2013; Needham, Wiesen, Hejazi, Libertus, & Christopher, 2017; Schröder, Gredebäck, Gunnarsson, & Lindskog, 2020; Slone, Moore, & Johnson, 2018), with benefits remaining evident after one year (Libertus, Joh, & Needham, 2016). These studies highlight how children's object play contributes to the developmental cascade of cognitive skills.

Understanding children's developing object interactions will help us further understand the cascading effects of those interactions. Although a large body of research has shown relations between children's object interactions and other aspects of development, much less is understood about how and why children's object interactions themselves develop. A complete understanding of how object interactions contribute to and are influenced by other aspects of development requires a deeper understanding of the factors that underlie these object interactions. Consider children's object insertions, such as placing a puzzle piece in an opening or a shape in a corresponding aperture on a shape sorter. Successful insertion of an object into an aperture requires dynamic and flexible coordination of fine motor skills, mental rotation, and planning. Thus, age-related changes in children's object insertions can provide insight into how the multiple skills required for success at this task develop, as well as how children become able to coordinate these skills.

Successful insertion involves several motor and cognitive skills. First, children must have sufficient fine motor *coordination* to successfully execute insertions. At 9 months infants can shape their hands into anticipatory grasps that align with the shape and orientation of objects, but it is not until between 18 and 22 months that infants actually fit objects into apertures, even in scenarios in which there is only a single object and a single aperture (Örnkloo & von Hofsten, 2007). However, fine motor precision continues to refine over childhood as children develop the ability to alter their grip based on additional characteristics of objects such as weight (Gordon, Forssberg, Johansson, Eliasson, & Westling, 1992; Lockman, Ashmead, & Bushnell, 1984).

Second, inserting a shape into an opening requires mental rotation. Correctly inserting a shape requires that children envision the correct orientation of the object and subsequently plan and execute the corresponding motor manipulations (Ossmy, Han, Cheng, Kaplan, & Adolph, 2020). Although some studies have suggested that infants are capable of mental rotation (Lauer & Lourenco, 2016; Lauer, Udelson, Jeon, & Lourenco, 2015; Moore & Johnson, 2008, 2011; Quinn & Liben, 2008), other studies show that this ability develops through the preschool years (Levine, Huttenlocher, Taylor, & Langrock, 1999; Uttal et al., 2013). Children succeed with object insertion most often with rotationally symmetrical solids such as cylinders. These shapes have the same spatial attributes at every rotation and fit into apertures in many possible orientations (Örnkloo & Von Hofsten, 2007). Thus, early successes may not involve mental rotation, and developing mental rotation abilities may contribute to children's later success with object insertions, especially for solids that are not rotationally symmetrical.

Third, successfully inserting an object into an opening requires attention and working memory. Children must orient their attention efficiently between the target and goal, hold a visual representation of the goal opening's shape in their working memory as they make an object selection, and activate motor systems to complete manual adjustments (Ossmy et al., 2020; Shutts, Örnkloo, Von Hofsten, Keen, & Spelke, 2009). Attention and working memory skills develop during early childhood and coincide with children's development of more sophisticated methods for engaging, disengaging, encoding, and recalling relevant visual stimuli (Hendry, Johnson, & Holmboe, 2019; Oakes & Amso, 2018).

Fourth, successfully inserting solids into apertures also depends on children's understanding of how objects relate to each other and of the functional relation between objects and openings. For example, in instances in which they are presented with an array of solids of different shapes and sizes to choose from, children must efficiently attend to both the relevant features of the three-dimensional solid in positive space and to the features of the two-dimensional aperture in negative space that they are selecting as their goal as they are making a decision about which solid to insert (Örnkloo & Von Hofsten, 2007; Shutts et al., 2009). They must then evaluate each of the pairings separately until they find the correct match – a process that is greatly aided by their ability to construct mental representations of how the solid and apertures would relate to each other, and by their working memory for the outcomes of their previous choices (Shutts et al., 2009). Children's developing attention and working memory also contribute to their success with object insertions. Children do not correctly choose between two objects of the same shape but different sizes until 20 months of age and do not correctly choose between two objects with different shapes until 30 months of age, reflecting the development of children's ability to recognize and track object features that are informative about particular insertion combinations (Örnkloo & Von Hofsten, 2007; Shutts et al., 2009). In general, the existing literature suggests that although young children can anticipate spatial relations such as the degree of rotation when presented with only a single object and one to three openings, coordinating the selection of multiple objects and anticipating their rotation proves to be a more challenging task.

Finally, when faced with contexts in which there are multiple objects or multiple openings, success depends on children's ability to *plan* and *execute* their motor actions according to one of several options. A large literature on children's executive function suggests that these abilities develop late in the preschool years (Zelazo et al., 2003). In fact, even children between 36 and 60 months of age were less efficient than adults when attempting to insert three objects into their three corresponding openings in a shape sorter box (Ossmy et al., 2020). Specifically, compared to adults, the preschoolers took longer to transport the object to the opening and to make manual adjustments that facilitated insertion (Örnkloo & Von Hofsten, 2007; Ossmy et al., 2020). These differences reflected the fact that the preschoolers did not look between the object and its opening as early or as long as did the adults.

Clearly, children's object insertions are multiply determined, and development of this ability reflects changes in many domains. Thus, beyond providing a descriptive account of children's motor behaviors, examination of how children engage with problem-solving tasks, such as inserting solids into apertures, can provide insight into how, across development, children dynamically adapt and coordinate many skills *across domains* as they manipulate objects. One limitation in the existing literature is that standard laboratory tasks involve highly constrained sets of objects and apertures, typically designed to examine one aspect of development (e.g., motor development, planning). As a result, no study has systematically examined how children across the infant, toddler, and preschool periods engage with precisely the same task and experimental materials from the same set. This was the goal of the present work.

We examined insertion behavior in children between 12 to 48 months of age. We gave children a commercially available shape sorter with multiple openings and multiple objects to choose from. We anticipated age-related changes in children's behavior that reflected multiple underlying skills, as well as the developing ability to coordinate those underlying skills. Specifically, because all children were offered the same shape sorter, with six possible apertures, and multiple solids to insert, all children were required to choose among multiple shapes and multiple openings. However, we varied the number of shapes presented (from two to six shapes) as a function of child age. We presented younger children with fewer shapes because previous literature suggests that children will succeed at earlier ages when there are fewer possible object and aperture combinations (Chen, Keen, Rosander, & Von Hofsten, 2010; Lockman, Fears, & Jung, 2018; Örnkloo & Von Hofsten, 2007; Shutts et al., 2009). Thus, we assessed children's insertions when they had to select among multiple objects while also controlling for developmental changes in how well children manage multiple objects. Doing so allowed us to better unmask the role of additional factors in this development.

All children were also given rotationally symmetrical and rotationally asymmetrical shapes. This combination of shape types allowed us to test the prediction that children would successfully and reliably insert rotationally symmetrical shapes at earlier ages. We reasoned that if children's developing mental rotation abilities contribute significantly to developmental change in this task, children should succeed with rotationally symmetrical shapes at younger ages compared to rotationally asymmetrical shapes. However, if success in this task relies more heavily on skills such as motor coordination and planning than on mental rotation, we should see that children begin to successfully insert both rotationally symmetrical and rotationally asymmetrical shapes at similar ages. Thus, we predicted different levels of success for the two types of shapes, and that the extent that the developmental trajectories for the two types of shapes diverged would provide insight into the role of mental rotation in this development. Specifically, increasing mental rotation abilities would contribute to the development of success in inserting the asymmetrical shape but not the symmetrical shapes.

Although we anticipated change over the entire age range, we predicted a shift in children's success on this task between the ages of two and three years. The results of previous research suggest that development in processing visual spatial cues and planning and carrying out manual insertions occur at this age (Örnkloo & Von Hofsten, 2007; Pedrett, Kaspar, & Frick, 2020; Shutts et al., 2009). However, our task allowed us to examine more than simply whether or not there was a shift from failure to success. First, because we adapted the task to be age-appropriate (i.e., by giving different numbers of objects to children of different ages), we could examine children's success at choosing among an age-appropriate number of objects. Second, because our shape sorter toy had a large opening at the top (in which any shape could fit but was not intended by the manufacturer to be the goal of the task), we could ask whether children's success when engaging with this task varied with age. Specifically, children may "succeed" by inserting the shapes in the large top opening, a strategy that would not require the motor coordination, mental rotation, attention, memory, and planning required when inserting the shapes in the appropriately shaped openings.

Two aspects of this study are particularly novel. First, we presented children across a wide age range (12 to 48 months) with the same shape sorter. Thus, our study will establish a uniform baseline assessment about typically developing infants' and young children's behaviors in an open-ended scenario in which they are given a wider variety of objects and openings to choose from. Conclusions about development from existing work require comparing performance of different aged children tested in different studies using different materials. Our study will therefore allow conclusions across this wide age range when children were given the same kind of materials.

Second, we employed a more naturalistic task than many previous studies. We used a commercially available shape sorter, providing us insight into how children play with the kinds of toys they encounter in their everyday life. In addition, although conducted in a lab, our task was open-ended and unstructured. Thus, this study takes a step toward applying children's performance in the lab to their typical interactions with objects outside of the lab. The current work focuses on observing infants' and young children's interactions with a shape sorter toy and therefore can situate and evaluate the conclusions previous studies have made about children's actions with object-fitting toys in a less rigid setting.

Method

Participants

Our final sample included 66 healthy, full-term children (36 girls) with no known history of neurological, vision, or hearing problems. Children were tested between 3/25/2019 and 9/13/2019. To ensure an even distribution of participants from 12 to 48 months, we recruited children to fall into seven age brackets: 12 months (M = 372 days, range = 371–374 days, N = 3, 1 girl), 18 months (M = 552 days, range = 537–560 days, N = 13, 7 girls), 24 months (M = 728 days, range = 721–741 days, N = 8, 6 girls), 30 months (M = 919 days, range = 903–926 days, N = 10, 7 girls), 36 months (M = 1103 days, range = 1091–1109 days, N = 9, 6 girls), 42 months (M = 1284 days, range = 1280–1289 days, N = 10, 4 girls), and 48 months (M = 1469 days, range = 1456–1475 days, N = 13, 5 girls).

Parents reported the racial and ethnic identities of the children. Our sample was racially diverse, including children identified as White (n = 36), mixed race (n = 16), American Indian or Alaska Native (n = 2), Black or African American (n = 1), Asian or Asian American (n = 6), and Native Hawaiian or other Pacific Islander (n = 1). Race information was not provided for four participants. Across racial categories, 17 were reported as Hispanic or Latino (7 were White, 2 were Asian American, 1 was American Indian or Alaska Native, 5 were mixed race, and 2 did not report race). Of the 64 families who reported maternal education, 1 mother's highest level of education was 8th grade completion, 14 mothers' highest level of education was high school graduation, and 49 mothers' highest level of education was at least a 4-year degree.

We tested an additional 23 children but omitted them from the final sample because they never touched the toys or never attempted to put any shapes in the shape sorter, (n = 3), became too fussy to continue (n = 2), or the experimenter made an error (e.g., presenting the wrong set of shapes, n = 18). The full demographics for both the children who were and were not included in the final sample can be found in the supplementary materials on the Open Science Framework (OSF) website: https://osf.io/n2769/?view_only=20ccc90803fd4a4b9e5592dfc78abe15.

Written informed consent was obtained from a parent or guardian before data collection. All procedures involving human subjects were approved by the Committee for the Protection of Human Subjects and the Institutional Review Board (IRB). Children were recruited from the Sacramento Valley of California, a region that included a large metropolitan area, a mid-sized college town, and several small agriculturally based cities. We identified potential participants using one of two methods. First, children's names were identified from a pool of potential participants. We obtained from the State Office of Vital

Records information about new parents, and we send information about our program of research and how to participate was sent to all parents who lived within a 30-minute drive of the laboratory. Parents volunteer to be in studies by responding to the mailing by returning a postage-paid card, e-mail, phone, or filling out a webform. When children approached the appropriate age for the present study, we contacted the parents who volunteered. Second, we placed ads on social media about the present study and enrolled any eligible children whose parents responded to those ads. Children received a book and families were given a $25 gift card for participating.

Materials and apparatus

The shape sorter toy was a commercially available toy – Hape Shake and Match Wooden Shape Sorter (see Figure 1A). It had six apertures and six corresponding three-dimensional shape blocks: a purple trapezoid (4.0 cm tall × 4.5 cm wide), an orange semicircle (2.79 cm tall × 5.89 cm sides on base), a red triangle (4.19 cm tall × 4.90 cm sides on base), a green circle (4.50 cm diameter × 4.09 cm tall), a blue hexagon (4.09 cm tall × 4.09 cm wide), and a yellow rectangular prism (4.09 cm tall × 3.70 cm sides on base). The shape sorter apertures were the same size and color as their corresponding shape block. The shape sorter toy also had a 7.00 cm diameter circular opening on its top. The shape blocks fit only into their corresponding apertures (with the exception that the cylinder (i.e., circle shape) also fit into the hexagon opening) and only when placed at the correct orientation. All the blocks fit through the large top opening at any orientation.

The sessions were video recorded using two video cameras that captured a front and side view of the participant, to ensure the actions of interest were captured. These views were combined into a single video file using VMix to simplify later coding (see Figure 1B).

Procedure

Children in this study were recruited as part of a larger project and were tested in a number of perception and play tasks. The shape sorter task was administered in the context of other play tasks. For this part of the session, children sat either on the floor (12-month-old children) or at a child-sized table (18- to 48-month-old children) with an experimenter. A parent sat nearby but was instructed to interact as little as possible. The experimenter presented the shape sorter toy on the floor for the youngest children (12-month-old children) and on the

Figure 1. A. The shape sorter and geometric solids used in this study. Note that children of different ages were presented with different numbers of shapes (see text), B. The video of a child participating in the task.

table for all other age groups (18 to 48-month-old children). Pilot testing confirmed that we maximized the number of children at each age who completed our tasks by varying the seating by age in this way. It was not possible to seat the 12-month-old children at the table and seating the older children on the floor made it difficult to keep them on-task. Thus, although it is not ideal to have the youngest children seated on the floor and the others at a child-sized table, this approach yielded the most data from our wide age range.

The shape sorter was placed in front of the child with the shapes offered in front of the shape sorter (see Figure 1A). Children were presented with a different subset of shapes to play with depending on their age bracket. We adapted the number of shapes to alleviate burdens placed on children's motor planning cascade while still providing challenge and choice: 12-month-old children received the triangle and circle, 18-month-old children received the triangle, square, and circle, 24- and 30- month-old children received the triangle, square, hexagon, and circle, and 36-, 42-, and 48-month-old children received all six shapes. Importantly, all children received at least one rotationally symmetrical shape (circle, square, hexagon) and at least one rotationally asymmetrical shape (triangle, trapezoid, semicircle). Another strategy would have been to present all children with all six shapes. However, based on previous literature we expected that our youngest children would be overwhelmed by the number of shapes, and we therefore minimized the number of items presented while maintaining choice.

Younger children (12 to 30 months) first watched the experimenter insert the semicircle piece into its corresponding aperture in the shape sorter. This demonstration was included to ensure that the youngest participants understood that the goal was to insert the objects through their matching apertures. The experimenter then gestured to the openings on the shape sorter and asked the children to play with the toy. If the child did not touch any of the components of the toy after 20 seconds, the experimenter gestured to the shapes and asked the child to play with them. No further instruction or demonstration was given. Older children (36 to 48 months) were not shown the initial demonstration with the semicircle piece. It was expected that children were familiar with inserting shapes into corresponding apertures. Instead, the experimenter simply gestured to the openings on the shape sorter and told them that they were going to play a speed game and that the child should try to put as many shapes as they could into the openings. The play sessions ended when all children had successfully inserted all the shapes into the shape sorter or until two minutes had elapsed. Examples of the sessions can be found on the OSF: https://osf.io/n2769/?view_only=20ccc90803fd4a4b9e5592dfc78abe15.

Data coding

A primary coder used the open-source program Datavyu (www.datavyu.org) to code the play session videos frame by frame and timestamp behaviors of interest. First, each insertion attempt was identified. This included attempts to the top as well as attempts to any of the apertures, whether they were the corresponding aperture or not. This coder then divided these insertion attempts into two sequential phases, the *transport phase* and the *insertion phase*, based on the classifications in Ossmy et al. (2020). Next, the coder indicated which *piece* the child was attempting to insert into the shape sorter, which *opening* they were attempting to insert the piece into, and whether this attempt was *successful or not*. The *hand* the child used for the insertion was also coded but not included in the analyses. To ensure reliability among coders, a second coder independently coded 100% of each play session for the number of attempted insertions, piece and space chosen, success of the attempt, and handedness. Reliabilities will be reported for each relevant measure below. Disagreements between coders were resolved through discussion and the resolved data was used in the analysis.

Transport phase

The transport phase of each attempt was defined as the time from the frame in which the child either picked up a piece from the table or began to move it from the opening of the previous attempt to the frame in which the child made contact with an opening on the shape sorter toy with the piece. For each transport phase, coders marked: 1) the *onset* of the transport phase, 2) which *piece* the child was holding, 3) the *opening* they were moving the piece toward, and 4) the *offset* of the transport phase as the first frame in which the piece came into contact with the opening on the shape sorter. Reliability was calculated for the pieces the children were transporting, *kappa* = 0.89, and the openings they were transporting the piece to, *kappa* = 0.89.

Insertion phase

The insertion phase of an attempt was the phase from the moment a child made contact with an opening on the shape sorter to the moment in which the attempt was either completed or abandoned. The *onset* of the insertion phase was the same frame as the *offset* of the preceding transport phase. Each time the piece the child was holding came into contact with an opening was considered an *attempt*. The onset of an insertion attempt was defined as the frame in which the child touched the piece to an opening, and the offset of the attempt was defined as the frame in which the piece was halfway into the correct opening (successful attempt) or the first frame where the piece was clearly lifted away from the opening or was halfway into the incorrect opening (failed attempt). It was possible for the child to attempt multiple insertions with the same piece in either the same opening or in different openings. Such insertions were coded as separate attempts.

For this phase, coders once again indicated which *piece* the child was attempting to insert and the *opening* they were inserting into (these would be the same as in the preceding transport phase). In addition, the coders indicated whether the insertion was *successful*; a successful attempt occurred only when the child completely fit the correct shape through the correct opening. In this case, the *offset* of the insertion phase was marked as the frame in which the piece was halfway into the corresponding aperture. A failed attempt was indicated when one of two conditions were met: 1) the child was unable to fit the shape into the opening at all, regardless of which aperture they were attempting to insert into, or 2) an insertion in which the child managed to insert the shape through either an incorrect opening or through the top opening of the shape sorter. An insertion in which the child did not completely insert the shape into the opening was classified as the first type of failed insertion regardless of whether the child was attempting to insert at the correct or incorrect location. The offset of the first type of failed insertion was marked as the first frame in which the shape was clearly lifted away from the opening. The offset of the second type was marked at the moment in which the piece was halfway into the corresponding aperture, similar to the offset coding for successful insertions. Reliability was calculated for the pieces the children were inserting, *kappa* = 0.90, the openings they were inserting the pieces into, *kappa* = 0.90, and the classification of the insertion as successful or not, *kappa* = 0.89.

Statistical analysis

All analysis was conducted using the statistical package R (version 4.0.2). To test children's success on each attempt, we used a logistic mixed effects model (also known as a generalized linear mixed model – GLMM) and logistic regression framework using the lme4() function (Bates, Maechler, Bolker, & Walker, 2015). The logistic mixed effects framework accounted for the nested structure of the data (e.g., attempts nested within participants). A binomial error distribution was assumed. Two models were fit to the data, a logistic mixed effects model with top attempts as the outcome variable and a logistic mixed effects model with successful insertion into the correct side aperture of the shape sorter as the outcome variable. Each attempt was treated as an observation that was accounted for individually in the model and a random intercept was calculated for each participant. The generic model expression for participant i at their jth attempt was logit $(\pi_{ij}) = \log(\pi_{ij}/1 - \pi_{ij}) = X_{ij}\ \beta + u_i$, where π_i represents the probability of the outcome variable of interest and X encompasses all predictors of interest. The fixed effects are contained within the vector β and u_i is the random effect associated with participant i. The random effects were assumed to be independent and normally distributed, $u_i \sim N(0, \sigma^2)$, with the variance of the random effect defined as $\sigma_u{}^2$.

Relations between predictors and between predictors and the outcome variables were computed on the logit scale under Laplace maximum likelihood approximation. Significance of fixed effects was assessed with the Wald test. Age was treated as a continuous variable in both logistic mixed effects models. The logit values were then converted to probabilities and assessed with pairwise comparisons at discrete timepoints along the continuous age variable (12-, 18-, 24-, 30-, 36-, 42-, 48-months) using Tukey's HSD under the emmeans() and multcomp() packages (Hothorn, Bretz, & Westfall, 2008; Lenth, 2020). Model assumptions were evaluated using the performance() package (Lüdecke, Makowski, Waggoner, & Patil, 2020). When applicable, the correlation and interaction of the covariates was assessed. A 95% confidence interval (CI) and statistical significance of alpha < .05 were applied.

To examine the duration of children's transport and insertion phases, a linear mixed effects framework was used with scaled age as the continuous numeric predictor. Two separate linear mixed effect frameworks were fit using the lmer() function to determine how the duration of each phase varied at each of the seven discrete age groups. The degrees of freedom associated with the models were determined using Satterthwaite's method. A normal error distribution was assumed and 95% confidence intervals (CIs) and statistical significance of alpha < .05 were applied.

Results

The data and the scripts used to clean and process the data and to conduct the analyses can be found in the supplemental materials on the OSF: https://osf.io/n2769/?view_only=20ccc90803fd4a4b9e5592dfc78abe15. Gender effects were not present in preliminary analyses, so this variable was collapsed in all subsequent analysis, all *p*'s > .05. Although we recruited children from distinct age categories (e.g., 12-month-old children, 18-month-old children), to account for variation within our age categories, the models included age in months as a continuous variable except as noted.

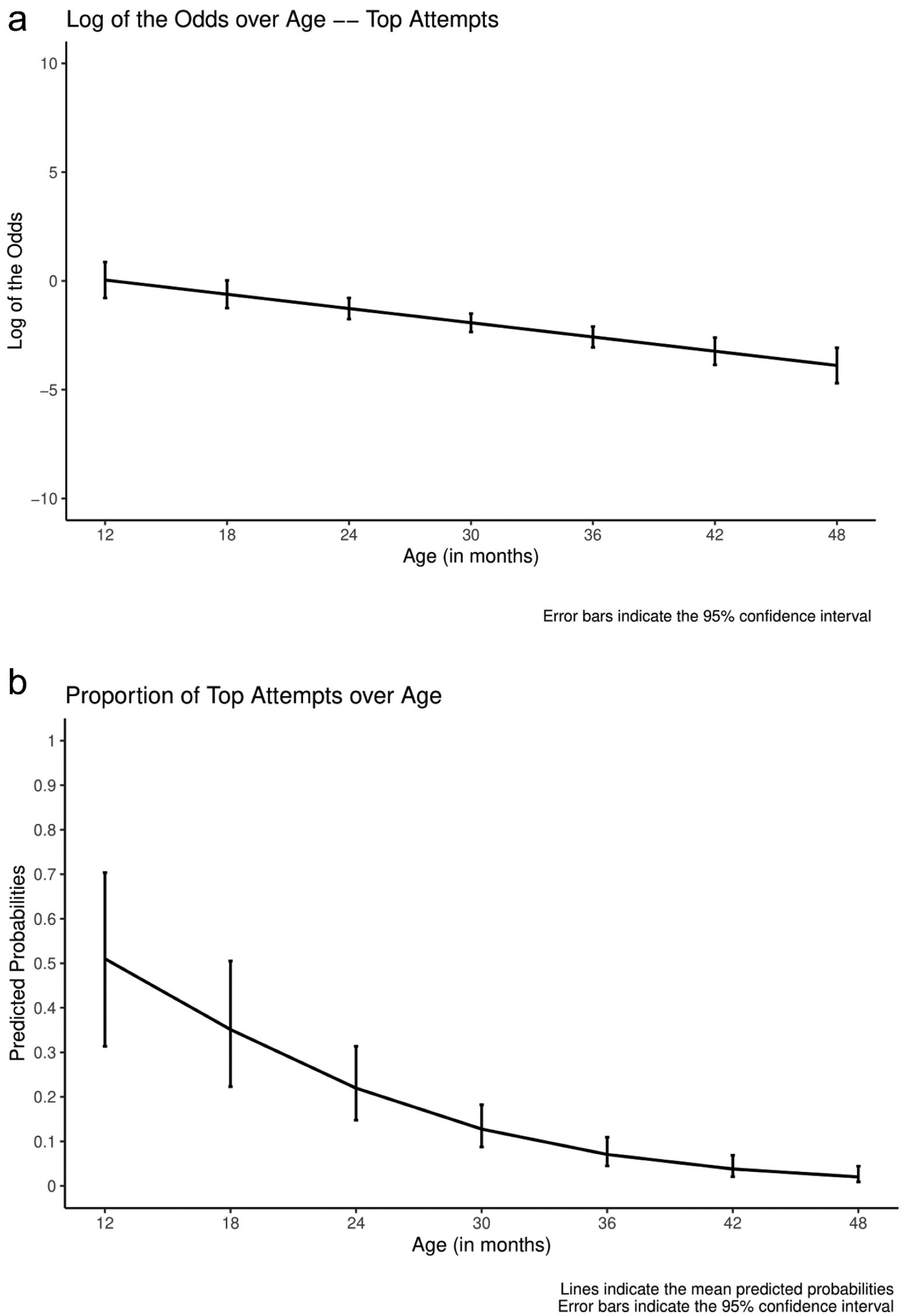

Figure 2. *A*. A significant linear decrease in the log of the odds for top attempts was observed with increasing age. *B*. Probabilities were back-transformed from the logit scale (bound between 0 and 1). Each age bracket had a distinct and statistically different probability of attempting to match a piece to the top of the shape sorter at the alpha < .05 significance level.

Top matches

The developmental trajectory of top insertions was evaluated using transport phase data and accounted for all instances in which children intentionally matched a piece to the top of the shape sorter, regardless of whether they completed a full insertion with the piece or not. This way, all top attempts were included in the analysis regardless of whether they were fully completed. Each attempt was entered into the model and was coded as a 1 if it was an attempt at a top insertion and a 0 if it was an attempt at another opening, yielding the probability that an attempt was made to the top. A logistic mixed effects model was fit with top attempts (0 = non-top insertion, 1 = top insertion) as the dependent variable. The model included age in months (continuous) and an insertion attempt index (e.g., first, second, third; continuous) as predictors. We included a random intercept for participant to account for repeated measures in the data. The analysis revealed only a fixed effect of age, $\beta_1 = -1.1615$, $SE = 0.2120$, $z = -5.480$, $p < .0001$ (Figure 2A). To better understand this decrease, the back-transformed probabilities are shown in Figure 2B. This figure shows about a 2.5% decrease per month increase in age in the proportion of top insertions. As predicted and backed by the transformed probabilities, there was a linear decrease in the proportion of total matches children made to the open top of the shape sorter with increasing child age. As age increased, children became less likely to match pieces to the top of the shape sorter. Insertion attempt index was not a significant predictor in the model, $\beta_2 = -.04929$, $SE = 0.03331$, $z = -1.480$, $p = .139$.

Developmental differences in proportion of successful insertions by age and shape type

The proportion of successful insertions across ages was evaluated using the insertion phase data. Recall, these are the data from the period of time when a child touched the piece to an opening to the time when that item was successfully inserted, or the attempt was abandoned. A logistic mixed effects model was fit with insertion success as the binary outcome variable, age in months as a numeric continuous predictor, and shape type (rotationally symmetrical versus not rotationally symmetrical) as a binary categorical predictor. This model was performed on each insertion into a side opening, coded as a 1 if the insertion was successful (if the child inserted the correct shape into the correct side aperture), and as a 0 if the insertion was not successful (if the child did not fully insert the shape through the correct opening, inserted the shape through the wrong opening, or inserted the shape through the large top opening). Because children of different ages were given a different set of shapes, shape type was collapsed into two categories: rotationally symmetrical (circle, square, hexagon) and rotationally asymmetrical (triangle, trapezoid, semicircle). All children received at least one rotationally symmetrical and one rotationally asymmetrical shape. The fixed effects of age, shape type, and insertion attempt index (e.g., first, second, third) were considered, along with an interaction between age and shape type. A random intercept was also calculated for each participant.

The model revealed significant fixed effects of age ($\beta_1 = 1.2361$, $SE = 0.2476$, $z = -9.842$, $p < .0001$), shape type ($\beta_2 = 2.2740$, $SE = 0.2809$, $z = 8.094$, $p < .0001$), and insertion attempt index ($\beta_3 = -.7139$, $SE = 0.1642$, $z = -4.347$, $p < .0001$). The interaction between age and shape type was not significant ($\beta_4 = 0.3511$, $SE = 0.2836$, $z = 1.238$, $p = .216$). These results are visualized in Figure 3A. The proportion of children's total insertions that were successful significantly increased with child age, lending support for our hypothesis that age effects would be observed in the proportion of successful insertions. In addition, children were more successful with rotationally symmetrical shapes than with rotationally asymmetrical shapes. Finally, children were more successful when they made fewer overall insertion attempts. That is, children who successfully inserted shapes required few attempts to do so, succeeding on their initial attempt to insert a shape. Examining the interaction between age and insertion index revealed that older children required fewer attempts than younger children, $\beta = -0.60669$, $SE = 0.1266$, $z = -4.792$, $p < .0001$.

As seen in Figure 3B, children also achieved significantly higher proportions of success at earlier ages when inserting rotationally symmetrical shapes compared to rotationally asymmetrical shapes, as we predicted. Specifically, the *y*-intercept (corresponding to a log-odds of zero and a probability of 50%), occurred around 36 months for rotationally symmetrical shapes, but was not reached even by 48 months, the oldest age in our sample, for rotationally asymmetrical shapes. However, the non-significant interaction between age and shape type in the model suggests that although children were able to succeed with rotationally symmetrical shapes at *earlier* ages compared to rotationally asymmetrical shapes, the *rate* of this increase over age was not statistically different between the two shape types.

Transport and insertion phases

To evaluate whether older children exhibit shorter and more efficient transport and insertion phases, as has been suggested in the literature by studies such as Ossmy et al. (2020), two separate linear mixed effects models were applied to ascertain whether the timing of these two phases differed across age. The duration of each phase was treated as an individual observation and a random intercept was calculated for each participant to account for the fact that there were multiple observations per participant. The number of insertions was included as an additional predictor in the model. To correct for a right-skew in the distribution of residuals for both the transport and insertion phases, a log transformation was applied to both sets of duration data before their respective models were fitted. The fixed effect of age was not significant for either the transport ($\beta_1 = 0.0346$, $SE = 0.0572$, $t = -0.605$, $p = .5473$) or insertion phases ($\beta_1 = -0.0395$, $SE = 0.0472$, $t = -0.8336$, $p = .406$). In contrast to our prediction, based on these analyses there is no evidence to claim that the duration of the transport and insertion phases significantly decrease with age.

Discussion

We observed our predicted developmental shift in children's behavior while inserting shapes into a shape sorter at about two years of age. Specifically, younger children were more likely to make top insertions than were older children, suggesting a *qualitative* shift in how children approach this task and complementing previous findings that older children make fewer alignment errors and are more strategic at manipulating objects and correcting the errors they do make (DeLoache, Sugarman, & Brown, 1985; Fenson, Kagan, Kearsley, & Zelazo, 1976; Örnkloo & Von Hofsten, 2007; Taffoni, Focaroli, Keller, & Iverson, 2019). In addition, with increasing age, children also made more correct insertions, *quantifying* the shift in their success with the task and supporting past studies that have found children that become more accurate and efficient at object insertion tasks at around 24 months (Marcinowski, Nelson, Campbell, & Michel, 2019; Örnkloo & Von Hofsten, 2007; Ossmy

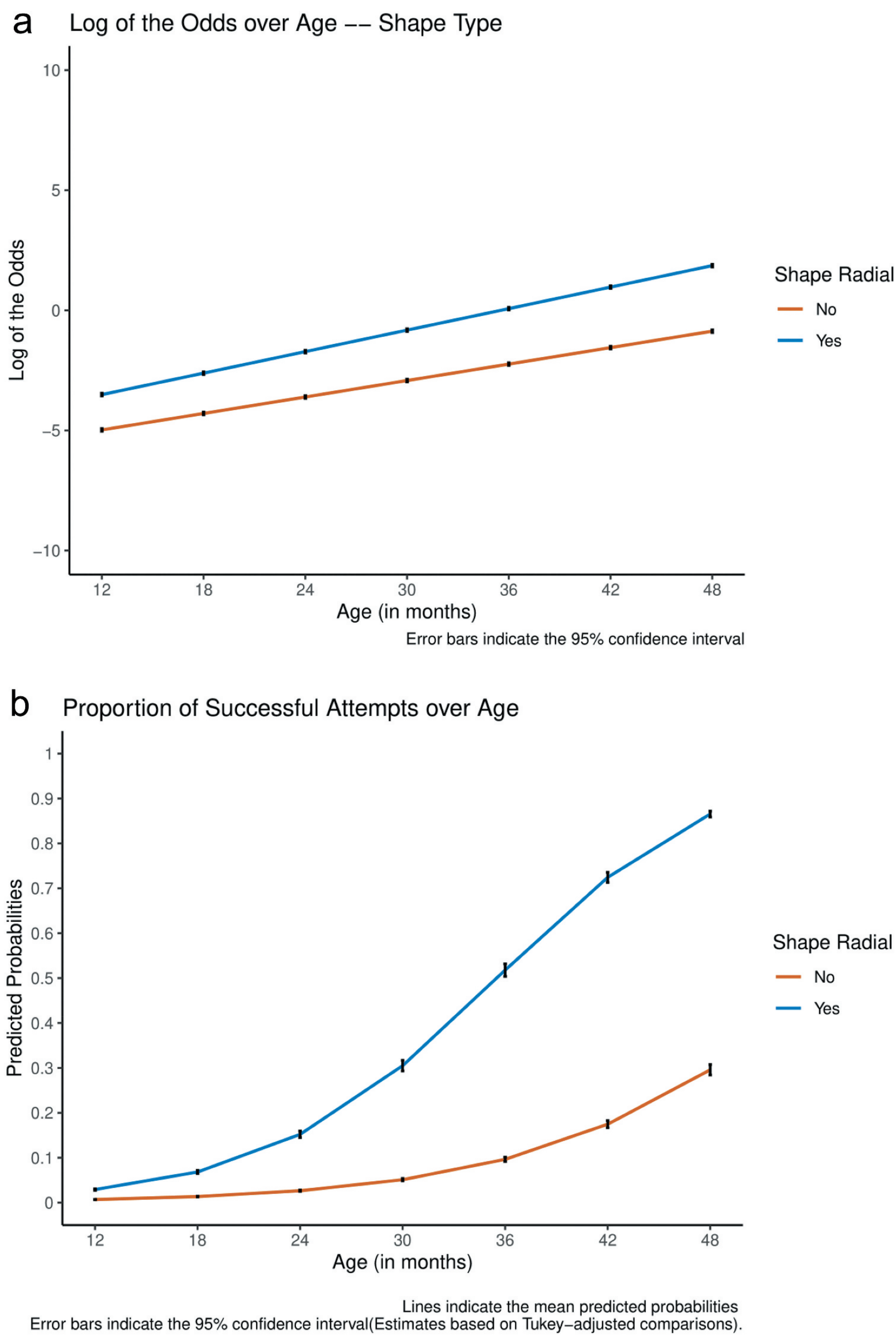

Figure 3. *A*. A significant linear increase in the log of the odds of successful insertion was observed with increasing age for both radial and non-radial shapes when controlling for the number of insertions. The interaction between age and shape type was also significant. *B*. Probabilities were back-transformed from the logit scale (bound between 0 and 1). Again, significant fixed effects of age and shape type were observed at the alpha < .05 level, and the interaction between age and shape type was significant when controlling for the number of insertions.

et al., 2020). We also documented differences in children's insertions of rotationally symmetrical and rotationally asymmetrical shapes, with children of all ages succeeding more often with rotationally symmetrical shapes. This pattern is consistent with findings that younger children tend to encode the overall constancy of an object's shape, which can lead to difficulties when they must consider the shape of an object at different orientations (Lockman et al., 2018).

Moreover, features of our task allows us to speculate about the mechanism of these age-related changes. For example, the fact that our shape sorter offered children the option of using the top opening or the shaped openings on the side gives us some insight into the approach children took in this task. The decrease between 24 and 30 months in children's use of the top opening for insertions suggests a shift in children's approach to this task. Younger children may have favored a strategy involving inserting the shapes into an opening that required little motor planning and minimal manipulation and rotation of the shapes rather than attempting to insert into the side openings, which were the manufacturer's intended target apertures in this toy. We also noted anecdotally that by 18 to 24 months, children often began by making attempts to the side openings that were physically closest to them, even if they were the incorrect side openings. Then, children abandoned those attempts and inserted the shapes through the wide top opening. By 30 months, children rarely used the top opening, and seemed to instead persist in attempting to locate the correct side opening. This difference in behavior between our youngest and older participants could indicate either an increased understanding of the task (i.e., that the goal is to put the shapes in the appropriate apertures), or an increased willingness to attempt to insert the shapes into the more challenging side openings. We believe our observations provide stronger evidence for the second explanation, and that our observed age differences primarily reflect changes in spatial cognition. Although by 18 to 24 months children seemed to better appreciate that the goal of the task was to insert the shapes into the sides and often even initiated the motor movement to do so, they apparently were hindered by the spatial-cognitive aspect of the task (matching the shape to the correct opening), and thus adjusted their goal to be less cognitively challenging by opting for the top opening once they were thwarted by a failed attempt into a side aperture. Again, this interpretation aligns with prior research indicating that younger children struggle with certain aspects of shape perception and are thus less adept at planning required rotations but can succeed in tasks at younger ages when they require less precise object manipulations (Chen et al., 2010; Lockman et al., 2018).

The shift in approach that we observed at 30 months suggests a change in the effectiveness of young children's problem-solving strategies. When unable to insert a shape into the incorrect aperture, children who were 30 months and older were more likely to search for the correct opening on the shape sorter, as evidenced by the fact that at this age children were more accurate than younger children and had more attempts than older children. In some cases, children even walked around the toy to find the correct opening, suggesting that these children were actively seeking a side opening with the correct spatial alignment and were actively attending to the spatial-cognitive aspects of the task. The change we observed likely reflects at least two aspects of children's development. By this age, children's shape perception and spatial planning are more fully developed, and they can better differentiate and attend to shape features and plan object movements (Lockman et al., 2018; Örnkloo & Von Hofsten, 2007; Shutts et al., 2009). In addition, children's problem-solving strategies dramatically improve over this age range. DeLoache et al. (1985) found that when 18-month -old children were unable to insert one nesting cup into another, they used physical force to try to make it fit. However, by 42 months children were more likely to employ complex strategies that involved spatial planning when making their corrections, such as reversing their attempted insertion at an incorrect location and trying again somewhere else or rearranging the cups (DeLoache et al., 1985). Similarly, our youngest participants often attempted to insert the same shape into the incorrect opening by sheer force, and when not successful, resorted to the top opening rather than trying the shape in a different side opening. Future research should be conducted to quantify these observations.

The differences we measured about how effective children were at inserting rotationally symmetrical and rotationally asymmetrical shapes provides additional insight into the mechanisms of developmental change in this task. Recall that we compared children's attempts at inserting rotationally symmetrical shapes, which are the same on all sides and thus require fewer manual adjustments, and rotationally asymmetrical shapes, which require mental rotation and manual adjustment for successful insertion, to evaluate the role that mental rotation played in this task. Our findings are consistent with the observation in Örnkloo and Von Hofsten (2007) that rotationally symmetrical shapes offer more possible orientations that would result in a successful insertion. It is also important to point out that our findings were obtained in a context that provided more naturalistic challenges to these systems than is typical for laboratory experiments examining these behaviors. Recall that although prior research indicated that children do not reliably choose between objects of different shapes when making insertions until they are 30 months of age (Örnkloo & Von Hofsten, 2007; Shutts et al., 2009), those previous studies tended to present children with only a few constrained choices. Here, children were allowed to interact with the toy however they chose and were not prompted to perform particular actions by an experimenter. As a result, although our task was still conducted in a lab setting, our findings allow us to draw conclusions about how children use their spatial-cognitive abilities to solve the kinds of motor problem-solving tasks that are more typical to their everyday experience.

In addition, our conclusions about age-related changes are based on observing children from 12 to 48 months in essentially the same motor problem-solving task. All children in our study were presented with multiple shapes to insert in the same seven-opening shape sorter (the top plus six shaped openings on the side). Previous research has shown that spatial play during infancy and the preschool years, such as play with shape sorters and puzzles, is positively associated with object processing, spatial development (particularly mental rotation, spatial assembly, and 3D object completion), and language development, and that they create more spatially complex relations with these toys as they age (Casasola, Bhagwat, Doan, & Love, 2017; Jirout & Newcombe, 2015; Lifter & Bloom, 1989; Möhring & Frick, 2013; Schröder et al., 2020; Soska et al., 2010; Walle & Campos, 2014). However, those previous findings have not typically examined the nature of this spatial play in an age range that spans both infancy and preschool using the same methods. By including a broader age range than is usually included in these studies, the current study provides a deeper understanding of how children's play with such toys changes over time. We observed that our youngest age groups relied on the most visually salient and accessible opening for insertion, curtailing assertions that these toys will promote the same type of spatial problem-solving at the younger end of our tested age range (e.g., 12–18 months) as at other ages. Rather, it is during their third year that children begin to insert geometric shapes into their corresponding apertures, suggesting that at this age children would gain relevant experience with more complex spatial problem-solving while playing with a shape sorter. Thus, it is not clear from our findings that the kind of play children engage in with shape sorters promotes development of spatial abilities in the same way across this broad age range. This is not to say that spatial toys such as shape sorters provide no benefit to younger children, only that these benefits may be different than the ones provided to older children. In line with previous research showing that exploratory play helps infants as young as nine months discover the features and functions of objects (see Baldwin, Markman, & Melartin, 1993; Bornstein et al., 2013), playing with shape sorters may help young children become more familiar with the properties of three-dimensional shapes. Spatial play also has the potential to encourage parents to demonstrate object constructions and label shape and spatial relations for their young children, which would have important implications for word learning and how these children understand and reproduce spatial properties (Casasola et al., 2017; Lifter & Bloom, 1989; Tamis-lemonda, Kuchirko, & Song, 2014; West & Iverson, 2017). For example, 18-month-old children's increased likelihood of constructing containment relations (i.e., a construction in which one object is inserted into another) during play corresponds to their caregivers' tendency to label containment relations more than support relations (Casasola et al., 2017). Future research is needed to determine how the physical manipulations children perform on objects at different ages relate to the skills they are able to acquire from different kinds of object play (Tamis-LeMonda & Lockman, 2020).

It is noteworthy that our findings are consistent with previous work that used more constrained and structured tests, lending support that their findings are generalizable and applicable to more open-ended tasks. Taken together, therefore, the literature as a whole supports the conclusion from the existing literature that over the second and third years of life children develop a more nuanced understanding of the spatial attributes of geometric solids and how these attributes relate to insertion, such as recognizing how the positive form of the solid relates to the negative form of the aperture (Shutts et al., 2009).

Despite the strength of the current approach, questions remain about children's problem-solving strategies that were not able to be addressed in the current study. For example, because not all children received every shape, it was not possible to compare children's insertions with each shape individually. Instead, we classified the shapes into the broader categories of rotationally symmetrical and rotationally asymmetrical, which allowed us to understand differences in performance as a function of the type of shape *in general* but did not allow us to conduct more nuanced comparisons that might reveal more specific differences in children's performance with particular shapes. This is an interesting avenue of future work in a higher-powered study in which all children receive exactly the same shapes. In addition, although we put in place controls to test for motor ability, it could be that younger children still made some decisions about where to insert based on motoric factors, such as selecting the large top opening because it offered easy access for their less developed motor ability, rather than cognitive factors. Although our observations of children as young as 18 months making initial side attempts seems to lessen this argument, more work is needed to more precisely discern the individual contributions of motor and cognitive ability.

It should be mentioned that we did not find that the duration of the transport (length of time it takes child to move piece to opening) and insertion (length of time from contact with opening to completion or abandonment of insertion) phases varied with age, contradicting our prediction that the duration of both would decrease significantly with age. We predicted changes based on Ossmy et al.'s (2020) demonstration that adults completed insertions more quickly than preschoolers, apparently because they performed all necessary manual adjustments during the transport phase. There are at least three possibilities for why we did not find our expected age-related changes. First, aspects of our more open-ended task may be responsible. Older children may have been inhibited from immediately fixating on the goal and beginning the necessary manual adjustments as soon and as efficiently as possible. Instead, in our task, older children may have taken their time manipulating the shapes and moving them toward their target or actually rotating the shape sorter until they found the correct opening. Younger children, in contrast, may have immediately attempted to insert shapes into the openings that were closest to them.

Second, Ossmy et al. (2020) observed that younger children waited until they made contact with the opening to make adjustments and therefore performed all of them during the insertion phase. In our task, because our younger children tended to put the objects in the top opening, it is possible that they simply did not perform many adjustments at all and thus their insertion phases were not significantly longer than those of the older children. Thus, the large opening at the top may have masked developmental differences in the transport phase. Without the option of putting shapes into the more accessible top opening, younger children might take longer to transport pieces and make insertions.

Finally, the differences in the ages tested in the present study and by Ossmy et al. (2020) may be responsible for the different findings. It is possible that the developmental difference observed by Ossmy et al. does not originate in the preschool period, and we would need to test even older children to see a difference in timing.

This study was the first of its kind to examine how children's natural interactions with a commercially available spatial toy develop between the ages of one and four. By situating children in an open-ended play scenario, it was possible to observe at what age children began to use the toy for its intended purpose and what sorts of behaviors they employed independently when presented with it. We found that children understood that object insertion was the intended purpose of the toy at as young as 12 months and that across age they progressively completed more sophisticated and successful insertions. These patterns can be contextualized within a broader theoretical framework that views motor development as an embodied and enabling system that is both scaffolded by the physical capabilities of the developing body and enables exploration and learning (Adolph & Hoch, 2019). In our study we also witnessed children perform increasingly complex insertions along a trajectory that coincided with the development of their fine motor skills and mental rotation (LeBarton & Iverson, 2013; Möhring & Frick, 2013; Pedrett et al., 2020). Our results underscore the importance of considering how children's motor and spatial skills differentially enable the potential benefits of this type of play. In line with these theoretical views, our results highlight the interwoven relationships across domains of development.

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Data availability statement

The data described in this article are openly available in the Open Science Framework at https://osf.io/n2769/?view_only=20ccc90803fd4a4b9e5592dfc78abe15.

Open scholarship

This article has earned the Center for Open Science badge for Open Data. The data are openly accessible at https://osf.io/n2769/?view_only=20ccc90803fd4a4b9e5592dfc78abe15.

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