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Not Just Playing Around: Infants' Object Behaviors Reflect Ability, Constraints, and Object Properties

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Abstract

This study describes infants' behaviors with objects in relation to age, body position, and object properties. Object behaviors were assessed longitudinally in 22 healthy infants supine, prone, and sitting from birth through 2 years. Results reveal: (1) infants learn to become intense and sophisticated explorers within the first 6 months of life; (2) young infants dynamically and rapidly shift among a variety of behavioral combinations to gather information; (3) behaviors on objects develop along different trajectories so that behavioral profiles vary across time; (4) object behaviors are generally similar in supine and sitting but diminished in prone; and (5) infants begin matching certain behaviors to object properties as newborns. These data demonstrate how infants learn to match their emerging behaviors with changing positional constraints and object affordances.

Keywords

object; exploration; perceptual-motor development; infant

This study aimed to describe the ontogeny of the behaviors infants perform with objects throughout the first two years of life using a systematic yet naturalistic assessment. Infants were seen in their homes and were handed objects to grasp in a manner reminiscent of typical play. The first objective was to quantify the behaviors infants performed on objects in relation to infants' changing abilities, or with increasing age. The second objective was to

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determine whether infants' behaviors on objects were influenced when task demands were altered. To this end, we tracked infants' behaviors in three positions typically experienced during infancy: (1) supine, or lying on the back, (2) prone, or lying on the stomach, and (3) sitting supported in a seat. The third objective was to determine when infants begin to behave selectively on objects with different properties, matching their behaviors with the affordances of objects. These objectives are based on dynamic systems theory's tenet that behavioral performance emerges from the complex interplay of an individual's experience and ability and characteristics of the task and environment (L. B. Smith, 2005; Thelen, 2005). This study describes how infants adapt their emerging abilities to changing constraints and object affordances (J. J. Gibson, 1979; Newell, Scully, McDonald, & Baillargeon, 1989).

The existing object exploration literature suggests that cyclical grasp is an early exploratory tool for neonates (Molina & Jouen, 2004). Mouthing, looking, fingering, and multimodal behaviors then increase through 5 months (P. Rochat, 1989). Then through 12 months, infants increase performance of a greater variety of finer behaviors, such as rotating, transferring, and manipulating, with objects (Palmer, 1989; Ruff, 1984). This study builds upon the existing literature in important ways. First, object exploration studies have typically focused on either cross-sectional data or data collected over periods of weeks to a few months (P. Rochat, 1989; Ruff, 1984). Thus, despite great interest in the development of object exploration, there are few longitudinal studies on how infants' changing abilities affect the ways they interact with objects. Second, studies have typically focused on infants older than 6-9 months of age although data suggest the origins of object exploration behaviors are much earlier. For example, many of the behaviors measured in studies with older infants, including looking, fingering, mouthing, rotating, and transferring, were already present by 6 months when the studies began (Palmer, 1989; Ruff, 1984). In addition, recent studies suggest that infants begin to adapt and utilize their existing abilities, such as cyclical grasping, touching the face with objects, and mouthing, to explore objects even in the first days and months of life (Molina & Jouen, 2004; P. Rochat, 1987). Research like the present study assessing behaviors early and longitudinally can best inform us about the *emergence* of object exploration behaviors. Third, studies have typically focused on a limited set of behaviors providing a relatively narrow view of infants' behaviors with objects. For instance, in object exploration studies with infants younger than 6 months, researchers have generally quantified performance of a limited number of variables, such as holding, mouthing, looking, and fingering (Molina & Jouen, 2004; P. Rochat, 1989). These studies with younger infants have shown increases in these behaviors and combinations of these behaviors across time and after the onset of reaching but they have not provided a comprehensive view of object exploration in infancy (M. A. Lobo & Galloway, 2013b; P. Rochat, 1989). We aimed to fill the gaps in the literature by studying object exploration *longitudinally* from *early* infancy through toddlerhood measuring a *broad* range of behaviors.

We wanted this study to provide an example of how infants learn to use their evolving perceptual-motor abilities to interact with objects in relation to time, body position, and object properties. This is important information developmentally because object exploration

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behaviors are facilitators for cognitive, social, language, and perceptual-motor development (Barsalou, 2008; Goldin-Meadow & Beilock, 2010; M.A. Lobo, Harbourne, Dusing, & McCoy, 2013). By understanding how these behaviors emerge and evolve, we gain understanding of how infants use their everyday play to form and shape cognition. It also has important implications for early intervention since we understand very little about the amount and variability of activities infants should be engaging in with objects. This lack of understanding of typical upper extremity behavioral performance in infancy limits our ability to identify and treat delays in infants when most measures of upper extremity function focus on behaviors like dressing, feeding, or other activities expected of older children and adults but not relevant for infants. In addition, infant motor assessments typically determine whether an infant can perform a behavior once in an isolated context rather than observing how often and how variably the infant uses the behavior across contexts to explore and learn (Bayley, 2006; M. A. Lobo & Galloway, 2013a). The data provided in this study inform us about the typical activity patterns infants should be capable of engaging in with objects.

We assessed object exploration behaviors in supine, prone, and sitting because these positions are ones naturally experienced by infants and because they provide unique challenges to infants' exploration behaviors (Dudek-Shriber & Zelazn, 2007; Fetters & Huang, 2007). Body position affects infants' ability to reach for and contact objects. For instance, infants may find it easier to initiate reaches but harder to sustain object contact when objects are offered in front of the chest in supported sitting compared to supine (Carvalho, Tudella, & Savelsbergh, 2007; Savelsbergh & Vanderkamp, 1994). In contrast, they may find it harder to initiate reaches but easier to sustain contact with objects in this same relative object location in supine. Some have proposed that supine is a more challenging position than sitting for infants to explore objects (Bly, 1994; K. C. Soska, Galea, & Adolph, 2011). However, there has been only one study manipulating body position and assessing its effects on object exploration. This study involved one assessment session with infants between 5 and 7 months of age and found infants performed more manual, oral, visual, and multimodal exploration in sitting relative to prone and supine (K.C. Soska & Adolph, 2013). Interestingly, although young infants spend much of their time playing on the floor, all of the other studies we reviewed, even studies with neonates, assessed object exploration in sitting or reclined sitting (M. A. Lobo & Galloway, 2013b; Molina & Jouen, 2004; P. Rochat, 1989). This study is the first to our knowledge to longitudinally assess object exploration behaviors outside of sitting in other positions infants commonly assume. The assessment of object exploration across positions provides a picture of how infants learn to adapt their behaviors when the demands of the task and effects of environmental forces are altered (Carvalho, Tudella, Caljouw, & Savelsbergh, 2008).

Although the prone position may be uniquely challenging because one or both of an infant's arms are typically used for support, assessing behavioral performance with objects in this position is also important. It provides insight into whether infants fundamentally change their behaviors on objects in this challenging position or if they perform the same behaviors as in supine and sitting but to a lesser degree. It also informs us of the state of prone play abilities in typically developing infants after the "Back to Sleep Campaign" evolved into the "Back to Sleep, Prone to Play Campaign". The latter campaign emerged in response to

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research suggesting that infants had less play time in prone and later crawling onset in response to the "Back to Sleep Campaign" aimed at reducing the frequency of sudden infant death syndrome (Davis, Moon, Sachs, & Ottolini, 1998).

Finally, we assessed when infants selectively adapted their behaviors on objects based on the properties of those objects. Adults perform specific exploratory procedures to gather information about object properties. For instance, they move objects to learn about their weight and they finger objects to learn about their texture (S. Lederman, 1993). Similarly, 9-12 month olds perform more banging when exploring objects that vary in weight and more rotating and transferring when exploring objects that vary in shape (Ruff, 1984). Two to five month olds alter their scratching, mouthing, and looking behaviors when exploring objects varying in size (P. Rochat, 1989). There is even evidence that newborns oscillate their grip pressure when holding objects of varying textures (Molina & Jouen, 2004). The ability to behave selectively on objects relative to their properties suggests that infants are increasing their knowledge about their bodies and objects and learning how to interrelate the two to behave in ways that allow them to selectively extract information about objects (E. J. Gibson, 1988). It also suggests that infants are learning to discriminate among objects based on their specific properties (Overman, Bachevalier, Turner, & Peuster, 1992). This study broadens our knowledge by being the first to longitudinally capture the *emergence* of selective performance of exploratory behaviors on objects in relation to object properties. Altogether, the purpose of this study was to demonstrate how behaviors on objects change across time, whether they are performed differentially across body positions, and when infants begin to match their behaviors with the affordances of objects.

Methods

Participants

Twenty-two healthy infants were recruited from the community using public birth information. Parents signed consent forms that had been approved by The University of Delaware's Institutional Review Board. All infants were born full-term between 37 and 42 weeks of gestational age (39.4±1.1 weeks) and had no significant medical history. One family was below poverty level. Twelve infants were male. Four families reported their infants were African-American, two reported Asian, and sixteen reported Caucasian. Participating families received videos of their infants across the span of the study as well as certificates of completion in gratitude for their participation.

Procedures

Infants were visited in their homes for 10 visits starting in the first month of life and ending at 2 years of age. Visits occurred at 0.6±0.1, 1.6±.2, 3.0±0.1, 4.0±0.2, 4.9±0.1, 6.0±0.2, 9.0±0.1, 12.1±0.3, 18.1±0.4, and 24.1±0.2 months of age.

At each visit, we provided infants opportunities to explore seven objects (Figure 1). The objects varied in size, shape, texture, hardness, color, and existence of moving parts. For all visits through 6 months, infants were provided opportunities to explore each of the objects in supine, prone, and sitting. After 6 months, it is not typical for healthy infants to remain

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stationary in supine or prone for extended periods because they have begun rolling and possibly crawling. Therefore, for the visits after 6 months, infants were only provided the objects in sitting. During the supine and prone assessments, infants were positioned on clean blankets on the floor. For the sitting assessment, infants 6 months and younger were seated in an infant seat that provided trunk support but did not hinder arm movement (Figure 1C). Infants become better able to sit independently after 6 months, so the remaining sitting assessments were performed on a typical booster seat (Fisher-Price Healthy Care Deluxe Booster Seat) with the tray removed. All assessments began with infants in a positive or neutral behavioral state. If infants entered a negative behavioral state marked by 2 minutes of continuous crying, we stopped the assessment and returned the next day.

In supine, prone, and sitting, infants were provided up to 30 seconds to interact with each of the seven objects, for a total of 21 potential trials spanning a total of 10.5 minutes. The order of object presentation was counterbalanced across positions and at each visit. For young infants who could not reach, the experimenter placed the object in the infant's grasp, alternating hands with each object's presentation. For older infants who could reach, the experimenter presented the object within reach in midline. If the infant did not actively reach for and grasp the toy, the experimenter placed it in the infant's hand. The trial began when the infant was independently grasping the object. It ended after 30 seconds or after the infant released the object 3 times while needing assistance to retrieve it. Each visit was recorded using two standard video cameras to provide frontal and lateral views of the infant.

Behavioral Coding and Outcome Variables

Coders were trained and practiced until they met an inter-rater reliability of greater than 80% with a primary coder using the equation [Agreed / (Agreed+Disagreed)] * 100. Then they coded usable data while re-coding 20% of their visits for reliability. The average inter-rater reliability was 84.0±1.5% across coders. The average intra-rater reliability was 87.7±3.3%. Coding was performed using MacSHAPA coding software and programs were run within a relational database (Filemaker, Inc.) to combine overlapping occurrences of behaviors as well as to summarize the data in order to calculate the variables listed in Table 1.

To assess for behavioral changes *across time*, we collapsed data across all positions and objects to look for general trends across development. Before 9 months, objects were presented in supine, prone, and sitting, while from 9 months onward, objects were only presented in sitting. Thus, the combined assessment time varied across visits, decreasing at 9 months after the supine and prone assessments ceased, so we normalized the data in relation to holding time for comparison of performance across time.

To assess for behavioral changes *across position*, we collapsed data across all objects within each position to compare performance in supine, prone, and sitting. This comparison runs only through 6 months since infants did not perform in supine or prone after that point. Because infants had the potential to explore all seven objects up to 30 seconds each in every position, we compared these data without normalizing them.

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To assess for behavioral changes *across objects*, we focused on behaviors with objects in sitting. We eliminated prone data from these analyses because we found restricted behavioral performance in this position as discussed in the results. We focused on sitting performance because we did not see systematic differences in supine and sitting (see results). Assessment durations were equal across time so we compared these data without normalizing them.

Statistical Analyses

All data were analyzed using MPlus hierarchical linear modeling (HLM) software (Muthén and Muthén). For each analysis, the model of best fit is presented. To model changes in behaviors with objects *across time*, we performed 2-level growth curve modeling with time as the level 1 factor and participants as the level 2 factor. Data for all visits were included in these analyses. For each variable, two experimenters independently visually inspected charts of the individual data and noted if there was an age where there was a change in slope (direction or amount) or amount of variability. If perceived to vary, experimenters noted where the data should be splined for piecewise analyses. Piecewise analyses involve breaking the data into shorter time periods to estimate intercepts and slopes for each period. The percent agreement of visual inspection between experimenters was 95%. For the few cases where experimenters differed in their visual analyses, we ran both models but reported the model with the lower Bayesian value, or the model that best fit the data.

To model changes in behaviors on objects *across position*, we performed 2-level growth curve modeling with multiple outcomes (supine, prone, sitting). Data for visits through 6 months of age were included in these analyses. We did not try to model infrequent behaviors that did not occur often until later visits because they did not generate enough non-zero values for the model's estimates. T tests were performed to test for differences in the model's estimated means at 0 and 6 months and in the model estimated slopes of change across positions. A p value of $\leq .05$ with Bonferroni correction for multiple tests was considered significant.

To model changes in behaviors *across objects* in relation to their properties, we performed 2-level growth curve modeling with multiple outcomes (high and low behavior object groups). Data for all visits were included in these analyses. For each behavior, we grouped our 7 objects into 2 groups, one group of objects with properties expected to elicit high levels of the behavior and one group of objects with properties expected to elicit low levels of the behavior (Table 2). We hypothesized that more holding would be performed for objects with small diameter sections because they would be easier for infants to grasp with their small hands (Newell, McDonald, & Baillargeon, 1993; P. Rochat, 1989). We hypothesized that infants would perform more bilateral holding, transferring, and touching the body with objects of greater overall size because even when grasped by one hand, these objects would afford extra area for contact with the opposite hand and other parts of the body (P. Rochat, 1989; van Hof, van der Kamp, & Savelsbergh, 2002). We hypothesized infants would perform more cyclical movement for objects that produced sound when moved (Bourgeois, Khawar, Neal, & Lockman, 2005). We hypothesized infants would perform more fingering and picking for objects with textured surfaces (Bourgeois et al.,

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2005; Ruff, 1984). We hypothesized that infants would perform combinations of behaviors and looking more with objects that exhibit a variety of properties, because different behaviors would provide unique information about each of those properties and variations in properties like surface texture and color have been shown to enhance visual attention (S. J. Lederman & Klatzky, 1993; Ruff, 1984). Only behaviors with support for the grouping of objects by a specific property were included in these analyses. T tests were performed to test for differences in the model's estimated means at 0 months for the 2 groups. When the estimated means at 0 months were not different, we tested the means at each subsequent visit until a difference was identified. This allowed us to determine the first age at which participants performed each behavior selectively with the objects based on their properties. Again, a p value of $\leq .05$ with Bonferroni correction for multiple tests was considered significant.

Results

Results are presented consistently across time and body position. First, we present holding results to demonstrate ability to maintain objects since this is the first requirement for independent object exploration. Second, we present aggregated findings that give a general view of behavioral performance during holding times. Then we present findings for individual behaviors for a more specific view of change.

Estimated growth curves generated by the growth curve modeling are presented in Figures 2 through 8. In addition, raw (observed) data are presented for the across time and across position analyses in Table 3. Table 4 reports the variance of the estimated growth modeling results.

Results in relation to object properties are presented in the order of their emergence.

Behaviors with Objects Across Time

Infants were already able to hold and behave with objects in some basic ways shortly after birth. The first 6 months of life were characterized by a host of behavioral changes with objects. For instance, infants already held objects placed in their grasp for about 30% of the potential holding time around birth (Figure 2A). Their ability to hold objects increased to about 80% of the potential holding time by 6 months, where it plateaued through 24 months. The greatest changes in bilateral holding were also observed in the first 6 months of life (Figure 2B). Infants showed practically no bilateral holding in the first months of life but did this about 40% of the time by 6 months and close to 50% of the time thereafter.

While they were holding the objects, newborns spent about 40% of that time performing behaviors with them at a rate of about 5 bouts/minute, changing behaviors about once every 12 seconds (Figure 2C-D). They increased time spent behaving with objects to about 65% by 5 months of age and remained around this level through 24 months. By 6 months and through 24 months, infants were performing about 33 bouts of behaviors with objects per minute, changing behaviors about once every 1.8 seconds.

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In addition to learning to switch among behaviors with objects more frequently, infants also had the largest increases in variability of the behaviors they used over the first 6 months of life. Newborns performed only about 25% of the 14 potential individual behaviors on objects and only 1% of the 155 combined behaviors (Figure 2E). By 6 months they performed around 60% of the individual behaviors and 11% of the combined behaviors with objects. The number of individual behaviors used remained steady through 24 months while the number of combined behaviors decreased slightly. The time infants performed combination behaviors on objects followed a similar trend, increasing through the first 6 months and then decreasing slightly through 24 months (Figure 2C).

The specific behaviors that showed the largest slopes, or change, between birth and 6 months were transferring, mouthing, and banging. Object transfers increased from about 0 around birth to about 2/minute by 6 months though 24 months (Figure 2F). Mouthing increased from about 4% to 30% of the time in the first 6 months then decreased through 12 months of age and was barely performed in the second year (Figure 2G). Banging similarly increased between birth and 6 months and then decreased but was still performed at low levels through 24 months (Figure 2H).

Other behaviors showed their greatest slopes, or change, between birth and 9 to 12 months. The time infants spent touching their bodies with objects sharply decreased through 9 months and then leveled (Figure 3A). Both the time spent fingering objects and the number of times rotating objects increased through nine months and then declined through 24 months (Figure 3B,C). The number of times infants threw objects increased through 9 months then remained steady (Figure 3D). Looking increased substantially from 3 through 12 months, after which it continued to increase at a slower rate for the next 12 months (Figure 3E). This pattern was observed for times infants were looking at objects regardless of whether they were performing other actions on them. Overall, infants spent more time looking at objects when they were not performing other actions on them.

The remaining behaviors showed more consistent rates of change from about birth through 24 months. The time exploring objects using individual, or separate, behaviors began around 35% and increased throughout (Figure 4A). Use of cyclical arm movements, manipulation, and squeezing all increased steadily through 24 months (Figure 4B-D). Picking remained at about the same level throughout the 24 months (Figure 4E).

Behaviors with Objects in Relation to Body Position

In general, infants behaved similarly with objects in supine and sitting and performance was greater in these positions than in prone based on the tests of differences in their starting or ending intercepts and slopes of change. This was true for general measures of behavioral performance, including time holding objects, time performing any behaviors on objects, number of bouts of behavior, time performing individual or combination behaviors, variability of combination behaviors performed, and time behaving on objects multimodally (looking at objects while performing another behavior; Figure 5A-G). It was also true for the specific behaviors of banging and touching the body with objects (Figure 5H-I).

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For a few behaviors, there were different patterns of performance in relation to position. The variability of individual behaviors performed was higher in sitting (Figure 6A; linear slope prone v sitting $t = -4.01$, $p = .0006$, quadratic slope prone v sitting $t = 3.97$, $p = .0006$). Overall looking performance was also greatest in sitting (Figure 6B; 6 month intercepts supine v sitting $t = -3.94$, $p = .0007$, prone v sitting $t = -4.13$, $p = .0004$). Infants performed more bilateral holding and mouthing of objects in supine (Figure 6C-D; BILATERAL HOLDING: 6 month intercepts supine v sitting $t = 6.31$, $p = .0001$; MOUTHING: linear slopes supine v prone $t = 5.08$, $p < .0001$, prone v sitting $t = -4.89$, $p < .0001$, quadratic slopes supine v prone $t = -4.82$, $p < .0001$, prone v sitting $t = 4.89$, $p < .0001$). There was no difference across positions in the number of object transfers (Figure 6E). The remaining behaviors were not analyzed because they were observed less than 5% of the time from 0-6 months when exploration was performed in all 3 positions.

Behaviors with Objects in Relation to Object Properties

Infants already behaved differently with objects based on their characteristics in many ways in the first month of life. There were intercept differences for the high and low object groups at the 0 month visit for time holding and time performing any behaviors (Figure 7A-B; Holding $t = 10.29$, $p < .0001$, Overall Behavioral Performance $t = 4.03$, $p = .0003$). Infants also cyclically moved and picked at objects selectively based on object properties at 0 months of age (Figure 7C-D; Cyclical Movement $t = 4.00$, $p = .0003$; Picking $t = 4.09$, $p = .0003$).

Infants' other behaviors did not become selectively tailored to object characteristics until later in the study. For instance, the time infants spent touching their bodies with objects was different for the object groups by 1.5 months (Figure 8A; $t = 4.00$, $p = .0003$). The variety and duration of combination behaviors performed on objects was different for the 2 groups of objects by 4 months (Figure 8B-C; Variability $t = 4.46$, $p = .0001$, Duration $t = 3.36$, $p = .001$). Time looking at objects varied for the 2 object groups by 9 months (Figure 8D; $t = 3.45$, $p = .001$). Time spent holding objects with two hands was different by 12 months (Figure 8E; $t = 3.45$, $p = .001$). Trends for differences were found for time spent fingering or rotating objects and these began by 12 months (Figure 8F-G; FINGERING $t = 2.33$, $p = .01$; ROTATING $t = 2.81$, $p = .005$). The number of transfers was never different for objects as we grouped them (Figure 8H).

Discussion

The goal of this study was to use the development of object exploration as an example demonstrating how infants learn to coordinate their emerging abilities with changing constraints and object affordances. We reported data on infants' behaviors with objects in relation to changing abilities from birth through 24 months. We reported on how infants' behaviors on objects were influenced when constraints were altered among supine, prone, and sitting. And we reported on when infants began to behave selectively on objects with different properties, matching their behaviors with the affordances of the objects. Below we discuss the findings, their significance, and their implications.

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Behaviors with Objects Across Development: Infants' Behaviors on Objects Emerge Early and Develop in a Fast and Furious Manner

The results of this study provide an interesting and novel picture of the emergence and development of behaviors on objects through two years. To start, they suggest the ability and drive to act on objects is present very early postnatally and undergoes significant changes in the first 6 months (M. A. Lobo & Galloway, 2013b; Molina & Jouen, 2004; P. Rochat, 1989). Even as newborns, infants had extended opportunities to gather information about objects, their bodies, and their interrelations via grasping and touching their bodies with objects. This likely emerged from months of experience in utero, where exploration of one's own body and the immediate environment through touch is common (Abo-Yaqoub, Kurjak, Mohammed, Shadad, & Abdel-Maaboud, 2012; Athanasiadis et al., 2013). The ability to hold objects and the drive to explore was present early and was not extinguished throughout the first two years of life. In fact, infants progressed from lower levels of activity to quite high levels of activity with objects in terms of variability, amount, and complexity over just the first 6 months of life. By 6 months and beyond, infants were performing a new behavior on objects *about every 2 seconds* and were linking their behaviors together in a variety of combinations. This intensity of behavioral performance mirrors that observed for other important exploratory behaviors such as crawling and walking in older infants (Adolph et al., 2012).

Young infants were also adept at interacting with objects using both hands and at banging, mouthing, and transferring objects. These findings suggest that very young infants have better exploratory abilities with objects than we may have thought in the past (Jouen & Molina, 2005). Rather than selecting from a few basic behaviors, young infants dynamically and rapidly shift among a wide variety of combinations of behaviors to intensely gather information about objects. These findings suggest that studying *very* early object exploration provides an interesting methodology for the comprehensive understanding of the origins of cognition, language, social, and perceptual-motor abilities (L. Smith & Gasser, 2005; Thelen, 2000).

Besides providing novel insight into the rapid emergence of early behaviors on objects, our data provide a unique picture of the complexity of the developmental process (Gottlieb, 1983; Thelen, 1992). Different behaviors evolved along distinct developmental trajectories so that the behaviors infants used to explore objects varied at each time point. For example, touching the body with objects peaked early and decreased with development. Mouthing was rare around birth, peaked at 6 months, and became rare again in the second year. Looking was rare before 3 months then continually increased.

Dynamic systems theory suggests the variability of behavioral performance across development observed in these data reflect the dynamic interaction among infants' increasing knowledge about objects, their existing behavioral repertoire, and their prior and ongoing daily experiences (Newell, Liu, & Mayer-Kress, 2003; Thelen, 1998). For instance, newborn infants' abilities to hold and touch their bodies with objects likely emerges from their in utero experiences feeling and holding their bodies and parts of the surrounding environment, such as the umbilical cord (Abo-Yaqoub et al., 2012; Athanasiadis et al.,

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2013). Increases in mouthing, banging objects on surfaces, and moving objects within the field of vision from 3-6 months likely reflects infants' improving arm control and ability to reach and move their hands toward desired locations (P. Rochat, 1987; P. Rochat, 1989; Thelen et al., 1993). Infants' increased fingering, rotating, manipulation, and squeezing of objects in the 2^{nd} half-year likely emerges from their improved abilities to grasp, handle, and play with objects and to match these behaviors to their expanding knowledge of objects' properties for optimal information gathering (Palmer, 1989; Ruff, 1984). Therefore, infants' behaviors on objects across development provide a glimpse of how they use their evolving abilities and knowledge about objects to interact with and gather information about objects in their world (E. J. Gibson, 1988). Future studies should test specific hypotheses about the developmental significance of these distinct trajectories and whether they vary in infants at risk for developmental delays.

Behaviors with Objects in Relation to Body Position: Changing Constraints Affect the Behaviors Infants Perform With Objects in Prone But Not Between Supine and Sitting

This study is the first testing object exploration across body positions longitudinally and the results suggest that contrary to previous assumptions, infants perform most behaviors similarly in supine and sitting (Bly, 1994; K. C. Soska et al., 2011). Furthermore, despite the Prone to Play Campaign, infants perform most behaviors significantly less in prone. There were only a few exceptions to these rules. Taken together, these findings suggest that when infants' hands are free from supporting functions in supine and sitting they tend to use them similarly to explore objects regardless of the altered biomechanical demands (Carvalho et al., 2007). In cases where there are differences in behavioral performance in supine and sitting, it is not the case that one position consistently facilitates behaviors above the other. Because initiating reaches has been shown to be more challenging for young infants in supine than in sitting due to the effects of gravity, it has been theorized that manual actions with objects are also more difficult to perform in supine (Bly, 1994; K. C. Soska et al., 2011). In addition, previous research on object exploration has emphasized object exploration in sitting, noting that independent sitting allows the hands to be free for exploration (M. A. Lobo & Galloway, 2013b; P. Rochat, 1989; K. C. Soska, Adolph, & Johnson, 2010). However, infants have their hands free for object interaction in supine as well. And infants spend much of the first 6 months of their lives in the supine position, so it is likely that most very early object exploration happens in this position. Our data suggest that researchers and clinicians should not overlook object exploration in supine because it is as intense as it is in sitting and because this position may best reflect how very young infants spend much of their day.

Infants had poorer performance of most behaviors in prone. They performed a lower number of behaviors and performed them less often in prone. At first glance, this might be expected since the prone position often involves weight bearing on one or both arms. Yet, if infants gain experience in prone, they can become able to shift their weight, lift their heads, and utilize one or both hands to perform many of the behaviors measured in this study by 3-4 months (Piper & Darrah, 1994). Infants performed so differently in prone relative to supine and sitting across almost all behaviors, even those that did not require the use of both hands or even require the head to be upright. Thus, our findings suggest that healthy babies in the

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US may still not experience the recommended levels of daily prone play (Davis et al., 1998). This is despite attempts of the Prone to Play campaign to educate caregivers on the importance of play time on the stomach (Dudek-Shriber & Zelazn, 2007). This may not have serious consequences for typically developing children but may have longer-term impact for children at risk for movement impairments and learning disabilities (Fetters & Huang, 2007).

Behaviors with Objects in Relation to Object Properties: Infants Learn to Match Their Abilities to the Properties of Objects Early in Life

Infants were able to match the performance of many behaviors with the affordances of objects within the first month of life (Bourgeois et al., 2005; Molina & Jouen, 2004; Palmer, 1989; P. Rochat, 1987; Ruff, 1984). This was true for holding, overall behavioral performance, cyclical movement, and picking. This suggests that very young infants are already active explorers, learning to selectively use their existing abilities to interact with objects to gather information about their world (Jouen & Molina, 2005; P. Rochat, 1987). This confirms findings from a handful of studies on selectivity of behaviors on objects and surfaces in early infancy. For instance, 3 day olds tailored their holding and grip force to changes in object texture and 4 month olds adapted mouthing behavior and grip configuration based on object size (Molina & Jouen, 2004; Whyte, Mc Donald, Baillargeon, & Newell, 1994). For some behaviors, body scaling likely accounts for early selectivity of performance. For instance, it is easier to hold and therefore explore smaller objects as a newborn with small hands. For other behaviors, infants' increasing knowledge of the interaction between object properties and his/her own behaviors likely accounts for the selectivity of performance. For instance, very young infants can learn to change their sucking or kicking patterns to generate auditory and visual reinforcement so infants in this study likely learned to associate certain behaviors and outcomes, such as associating cyclical movement of certain objects with sound production (Hayne, Greco, Earley, Griesler, & Roveecollier, 1986; Mehler, Bertoncini, Barriere, & Jassikgerschenfeld, 1978).

As infants develop better postural control, manual control, and increased object knowledge, they increase the repertoire of exploratory behaviors they can perform with objects and their ability to match these behaviors to the affordances of objects (E. J. Gibson, 1988; Thelen & Spencer, 1998). This was reflected in our findings that other behaviors, such as bilateral holding, looking, and fingering were selectively performed on objects in relation to their affordances later in the first year of life (between 9 and 12 months). Looking requires coordinated postural and manual control to maintain an object within view (Bertenthal & Von Hofsten, 1998). Bilateral holding and fingering by our definitions required the coordinated use of both upper extremities and this is a challenging task for young infants (Chen, Lo, & Heathcock, 2013).

The findings highlight that the ability to match one's behaviors with the affordances of objects depends not on ability or knowledge of objects alone, but on the interplay of the two (E.J. Gibson & Pick, 2000). Recent literature suggests that infants born at risk for future delays have delayed or absent abilities to adapt their exploratory behaviors to the properties of objects relative to infants without risk (M. A. Lobo, Kokkoni, E., Cunha, A.B., &

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Galloway, J.C., in review). Therefore, future research should focus on important questions about the type of information gathered via different modes of exploration, if and when some modes of exploration are more effective than others for knowledge acquisition, and how to design effective early interventions to facilitate object exploration.

Implications of the Findings

This study serves as an example of the dynamic nature of the emergence of early perceptual-motor behaviors and how infants learn to match these evolving behaviors to constraints and object properties. The findings reveal several important aspects of typical development that require more investigation. First, the ability and drive to explore objects is present in the first weeks of life and does not wane throughout the first two years (holding and overall behavioral performance were high throughout). Second, most of the behaviors infants performed on the objects used in this study underwent their greatest rate of change in the first 6 months of life. By 6 months, infants had already become intense and sophisticated explorers of objects, dynamically and rapidly shifting among a variety of behavioral combinations to gather information (bouts and variability of behavior were high). Third, the behaviors we observe infants performing on objects reflect infants' abilities, constraints, and knowledge of the affordances of objects so that behaviors on objects develop along different trajectories and cross-sectional behavioral profiles vary with age (Thelen, 2000, 2005). Fourth, the sitting and supine positions similarly facilitate object exploration, while the prone position remains overly challenging for object play, suggesting object exploration in supine is a relevant topic for future research and that the need remains for educating parents about the importance of providing regular play experiences in prone. Fifth, infants can learn to match some of their behaviors to the properties of objects as neonates whereas they must gain perceptual-motor ability and object experience and knowledge before they learn to match their performance of other behaviors to the properties of objects.

A strength and limitation of this study was that the task and objects did not change across time. This strengthened our internal validity but did not allow us to capture the behaviors that older infants perform when provided with more complex objects, more than one object, or objects in relation to a surfaces (Bourgeois et al., 2005; Cox & Smitsman, 2006).

This study has implications for infants at risk for motor and cognitive delays. First, exploratory play with objects should be encouraged from birth to facilitate early learning and skill development rather than waiting 3-5 months until reaching emerges. Second, interventionists should provide infants with ongoing opportunities to perform a wide range of complex behaviors on objects. Our data reveal that typically developing infants engage with objects the majority of time they are holding them using many combinations of behaviors along with frequent and rapid changes in behaviors. We should aim for this same level of exploration for infants at risk for delays to maximize their early learning abilities. Third, interventionists should provide infants opportunities to interact with objects across multiple contexts, across postures, with objects of varying properties, and across social situations (M. A. Lobo & Galloway, 2013b). It is not enough just that infants can perform a behavior. It is also important they learn to match that behavior to task and environmental constraints and to object properties in order to effectively gather information, to learn, and to

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interact with objects and people (E. J. Gibson, 1988; Ruff, McCarton, Kurtzberg, & Vaughan, 1984).

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Research Highlights

- We studied infants' object behaviors across time, position, and object properties
- By 6 months, infants were dynamic, variable, sophisticated explorers
- Less object interaction happened in prone than in sitting and supine
- Behavioral performance in supine and sitting were similar
- Infants matched many behaviors to objects' properties in their first months

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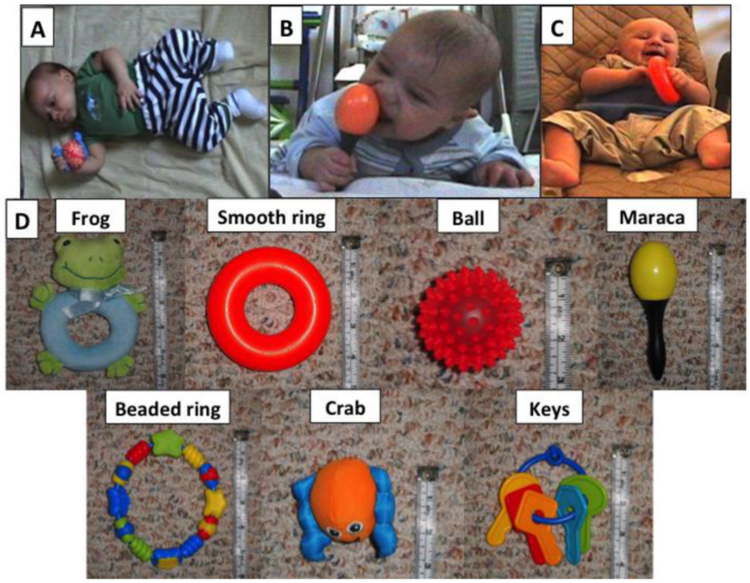

Figure 1.
Infants were provided 30-second opportunities to interact with seven objects (D) in supine (A), prone (B), and sitting (C).

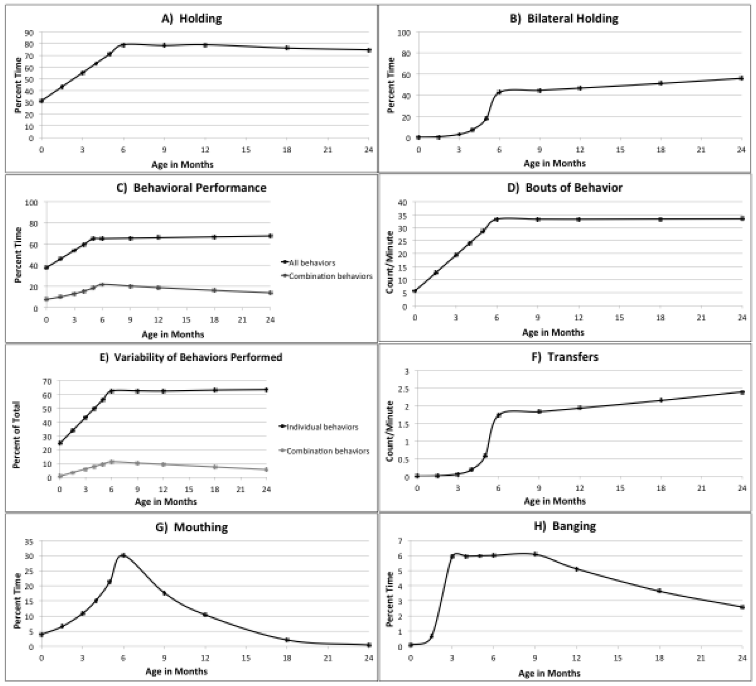

Figure 2.

Growth models for developmental trajectories across time for behaviors with the greatest rate of change between birth and six months.

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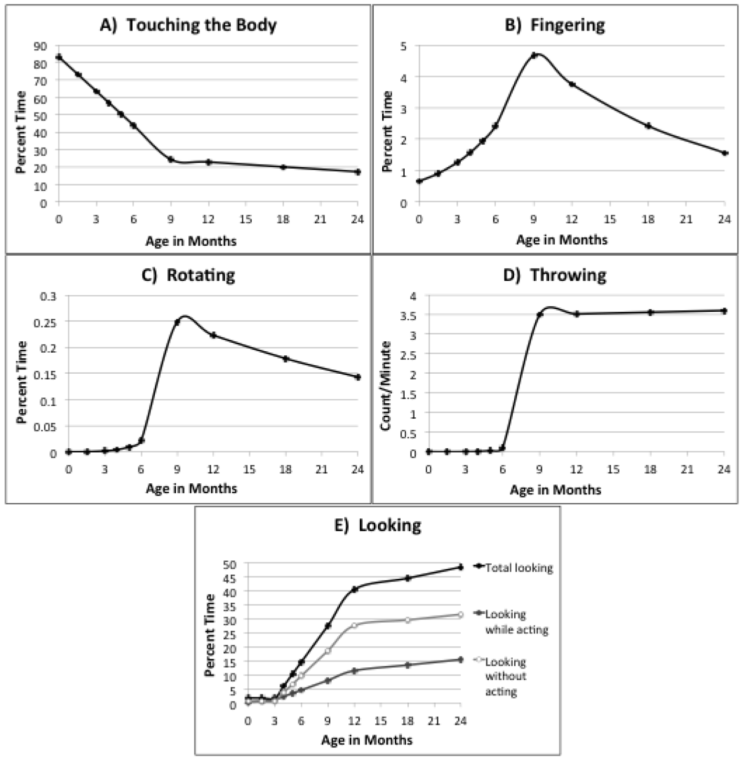

Figure 3.

Growth models for developmental trajectories across time for behaviors with the greatest rate of change between birth and twelve months. Behaviors in 3A through 3D showed the greatest change through nine months. Looking (3E) showed the greatest change between three and twelve months.

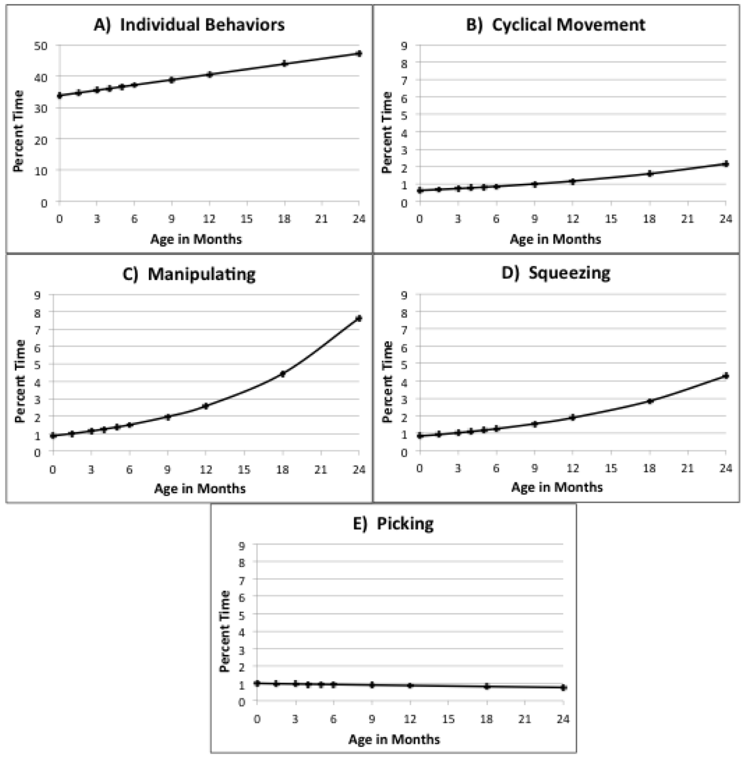

Figure 4.

Growth models for developmental trajectories across time for behaviors with more consistent rates of change throughout the first two years.

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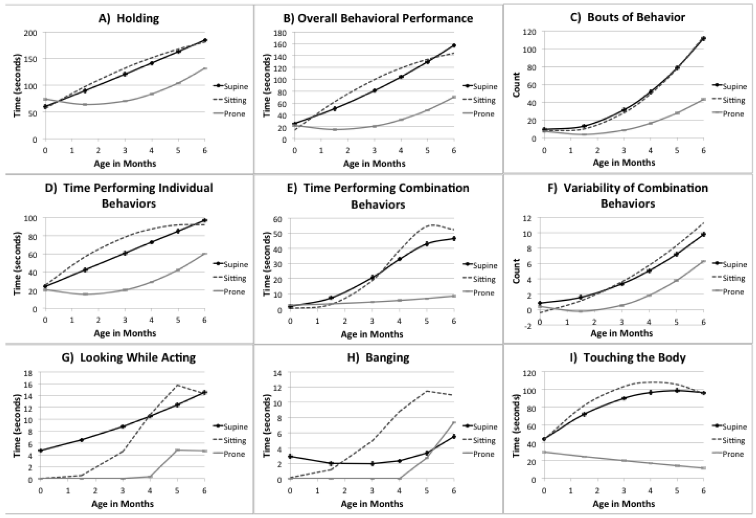

Figure 5.

Estimated growth curves for behaviors that were performed similarly in supine and sitting but greater than in prone based on t-tests comparing intercepts and slopes (see Results, Behaviors with Objects in Relation to Body Position for specific t and p values).

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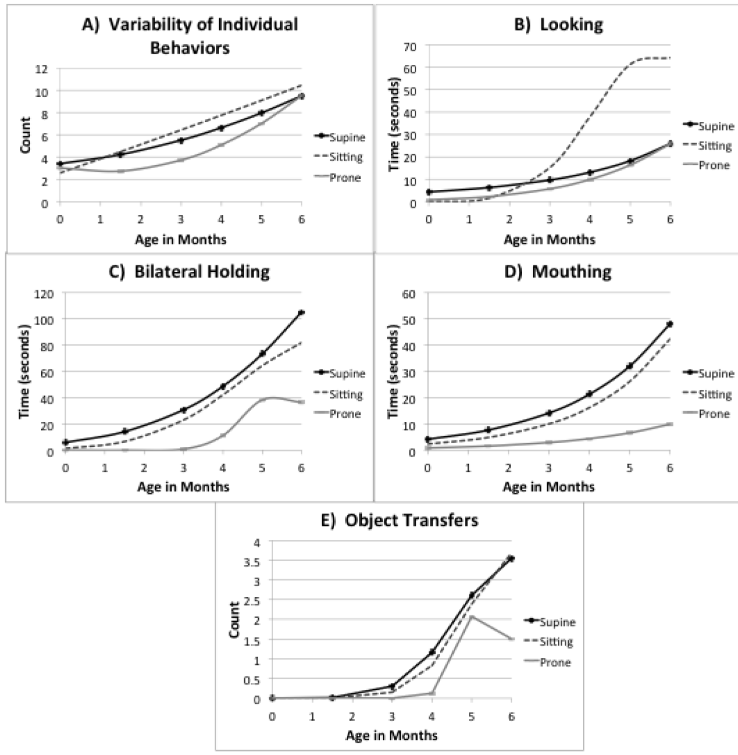

Figure 6.

Growth models for behaviors that were performed differentially across body positions (6A-D) or for which no difference was found (6E) based on t-tests comparing intercepts and slopes (see Results, Behaviors with Objects in Relation to Body Position for specific t and p values). There was higher variability of individual behaviors (6A) and more looking (6B) in sitting. There was more bilateral holding (6C) and mouthing (6D) in supine.

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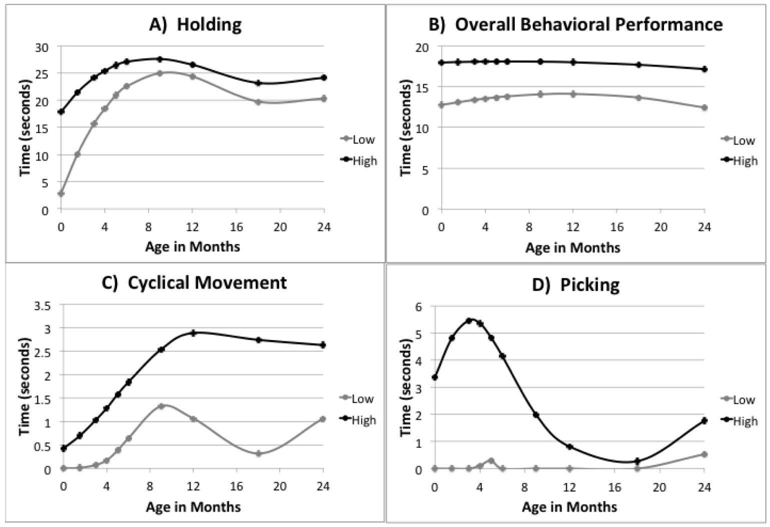

Figure 7.

Growth models for behaviors infants performed selectively with objects relative to their properties from the first weeks of life based on t-tests comparing the means (see Results, Behaviors with Objects in Relation to Object Properties for specific t and p values). Objects were grouped based on their properties into categories expected to elicit high levels or low levels of each behavior.

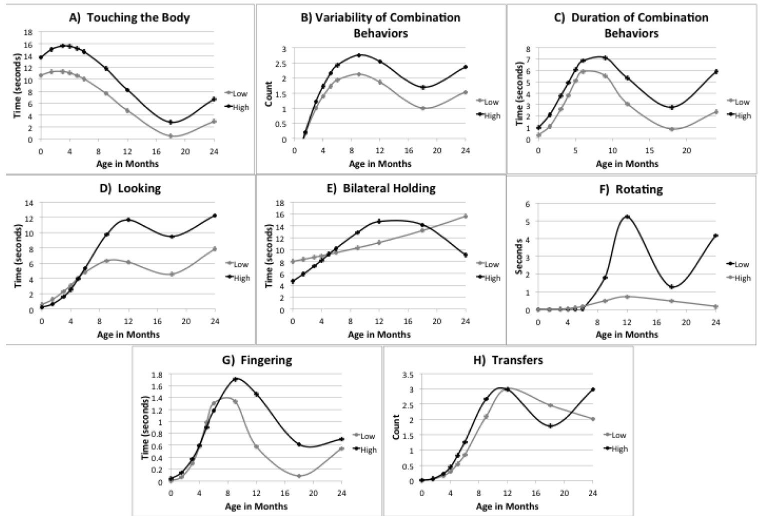

Figure 8.
Growth models for behaviors infants learned to perform selectively with objects relative to their properties throughout the first year based on t-tests comparing the means (see Results, Behaviors with Objects in Relation to Object Properties for specific t and p values). Objects were grouped based on their properties into categories expected to elicit high levels or low levels of each behavior. Touching the body matched object properties by 1.5 months (8A). Variability (8B) and duration (8C) of combination behaviors matched object properties by four months. Looking behaviors matched object properties by nine months (8D). Bilateral holding (8E), rotating (8F), and fingering behaviors (8G) matched object properties by twelve months. Transfers (8H) did not match object properties.

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Table 1

Variables analyzed

Variable	Definition
Holding	When object was held in contact with the right, left, or both hands
Bilateral	holding When object was held in contact with both hands
Overall behavioral performance	When participant was holding the object and performed any behavior or combination of behaviors on it
Bouts of behavior	Number of times switched from performing one behavior to another on an object. A measure of behavioral change rather than variability because it requires only that two consecutive behaviors be distinct to be counted as bouts.
Individual behaviors	When only one behavior was performed in isolation, such as mouthing or looking alone.
Combination behaviors	When two or more behaviors were performed simultaneously for any duration of time, such as looking while fingering or mouthing while picking.
Variability of individual behaviors	Number of different individual behaviors performed by a participant (total of 14 possible behaviors).
Variability of combination behaviors	Number of different combination behaviors performed by a participant (total of 155 observed combination behaviors).
Banging	When the hand or toy contacted a surface or part of the participant’s body at the end of a movement excursion during cyclical movement.
Cyclical movement	When moving the object continuously in a cyclical path with reversals of direction (waving or flapping) for more than 2 sec. This measure was exclusive of instances of banging.
Fingering	When the participant moved one or more fingers of one or both hands over the surface of the object to feel it for 2 sec or more.
Looking	All instances when the eyes were directed at the object.
Looking without acting	When the eyes were directed at the object but the participant was not performing other behaviors on the object.
Looking while acting	When the eyes were directed at the object and the participant was performing another behavior on the object (multimodal behaviors).
Manipulating	When the participant held the object with both hands and used at least one hand to move parts of the object for 2 sec or more.
Mouthing	When the object was in contact with the mouth, tongue, or lips.
Picking	When the participant used his/her fingertips to make an upward and downward motion to dig in and out of the object surface.
Rotation	When the participant moved the object in a manner rotating it through at least 45 degrees.
Squeezing	When the participant applied pressure to the object with his/her fingers.
Touching the body	When the participant brought the object in contact with any part of his/her body excluding the mouth and other hand.

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Variable	**Definition**
Transferring	When the participant moved the object from one hand to the other.

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Table 2

Groupings for object analyses

Behavior(s)	Hypothesis	Criterion for Inclusion In High Behavior Group	High Behavior Objects	Low Behavior Objects
Holding & Overall behavioral performance	Expect more for objects with smaller areas for grasping	Graspable area < 1 cm	Beaded ring, keys, maraca	Ball, crab, frog, smooth ring
Bilateral holding	Expect more for objects with greater overall size	Overall width > 5 cm	Ball, beaded ring, crab, frog, smooth ring	Keys, maraca
Combination behaviors (duration & variability)	Expect more for objects with a variety of exploratory affordances	Two or more of the following: moving parts, textured surface, sound making ability, patterned surface, squeeze-ability	Ball, beaded ring, crab, frog, keys	Maraca, smooth ring
Cyclical movement	Expect more for objects with sound-making potential	Ability to produce sound when moved	Frog, keys, maraca	Ball, beaded ring, crab, smooth ring
Fingering	Expect more for objects with textured surfaces	Textured surface (i.e. soft cloth, fur, bumps)	Ball, beaded ring,	Keys, maraca, smooth ring
Looking	Expect more for objects with a variety of detail and exploratory affordances	One or more of the following: Surface with more than one color, textured surface, moveable parts	Ball, beaded ring, crab, frog, keys, maraca	Smooth ring
Picking	Expect more for objects with unevenly textured surfaces	Bumpy, unevenly textured surface	Ball, beaded ring	Crab, frog, keys, maraca, smooth ring
Touching the body	Expect more for objects with a larger area affording greater opportunity to contact body surfaces when held	Overall width times length $> 50\ cm^2$	Beaded ring, frog, keys, smooth ring	Ball, crab, maraca
Transferring	Expect more for objects with a large graspable area remaining exposed when held in one hand	Ringed objects with enough easily graspable area for 2 hands	Beaded ring, frog, keys, smooth ring	Ball, crab, maraca

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Table 3

Raw data (observed) means and standard errors of the mean (SEM) for data across time (supine, sitting, and prone collapsed) and within each position.

Behavior	Condition	Value	Age in Months									
			0	1.5	3	4	5	6	9	12	18	24
Holding	Across Time (%)	Mean	32.2	34.6	50.6	62.1	70.7	77.5	81.5	77.2	75.8	71.7
		SEM	(6.5)	(3.0)	(3.1)	(2.6)	(3.5)	(2.9)	(4.5)	(3.6)	(4.9)	(5.5)
	Supine (s)	Mean	65.1	82.1	112.4	151.2	168.9	176.7				
		SEM	(9.1)	(8.2)	(9.4)	(5.9)	(7.8)	(7.2)				
	Sitting (s)	Mean	75.3	86.8	136.3	153.7	171.2	179.9				
		SEM	(20.5)	(8.8)	(6.8)	(6.0)	(5.0)	(6.0)				
	Prone (s)	Mean	73.6	65.9	64.0	85.2	105.1	133.7				
		SEM	(21.9)	(10.5)	(11.2)	(9.7)	(14.8)	(12.4)				
Bilateral holding	Across Time (%)	Mean	3.0	0.6	7.5	25.0	38.5	47.1	43.0	56.6	54.1	56.2
		SEM	(2.2)	(0.4)	(1.8)	(4.3)	(4.7)	(3.2)	(4.2)	(2.9)	(3.1)	(3.7)
	Supine (s)	Mean	3.9	0	7.0	48.0	76.2	104.4				
		SEM	(2.4)	(0)	(2.9)	(9.2)	(12.7)	(8.9)				
	Sitting (s)	Mean	3.8	1.9	13.2	42.6	66.8	82.7				
		SEM	(2.7)	(1.2)	(3.3)	(8.8)	(10.0)	(7.9)				
	Prone (s)	Mean	0	0	0	4.1	30.4	43.2				
		SEM	(0)	(0)	(0)	(2.0)	(9.3)	(7.9)				
Overall behavioral performance	Across Time (%)	Mean	41.1	49.9	64.0	71.0	73.1	74.7	66.1	66.8	57.4	63.9
		SEM	(7.5)	(3.8)	(3.4)	(3.2)	(3.2)	(1.4)	(3.3)	(2.5)	(2.4)	(3.6)
	Supine (s)	Mean	32.2	40.5	66.0	122.4	135.0	148.7				
		SEM	(7.6)	(5.7)	(7.3)	(8.0)	(10.5)	(6.4)				
	Sitting (s)	Mean	24.7	56.0	99.3	121.7	134.2	142.7				
		SEM	(7.8)	(9.1)	(6.0)	(7.1)	(7.5)	(5.8)				
	Prone (s)	Mean	19.0	17.2	17.9	28.2	52.3	68.6				
		SEM	(6.7)	(3.5)	(4.3)	(5.4)	(10.2)	(9.3)				
Bouts of behavior	Across Time (%)	Mean	6.2	7.2	12.2	19.6	21.3	34.7	25.4	30.0	24.3	29.5
		SEM	(2.0)	(0.8)	(1.1)	(2.0)	(1.9)	(1.7)	(2.3)	(1.5)	(1.4)	(2.1)
	Supine (s)	Mean	6.2	9.9	22.4	55.7	66.4	116.0				

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Behavior	Condition	Value	Age in Months									
			0	1.5	3	4	5	6	9	12	18	24
		SEM	(1.1)	(1.9)	(4.1)	(7.8)	(8.7)	(10.7)				
	Sitting (s)	Mean	4.0	10.8	29.1	53.2	62.7	119.6				
		SEM	(1.0)	(1.8)	(2.8)	(5.5)	(6.3)	(10.1)				
	Prone (s)	Mean	4.8	5.7	8.9	12.9	25.6	44.4				
		SEM	(1.8)	(1.1)	(2.4)	(2.6)	(6.3)	(5.9)				
Individual behaviors	Across Time (%)	Mean	34.9	47.3	55.6	49.5	46.8	51.3	50.4	53.4	44.0	46.0
		SEM	(6.1)	(3.3)	(2.9)	(2.7)	(2.1)	(1.2)	(2.4)	(1.9)	(1.3)	(2.9)
	Supine (s)	Mean	29.6	36.4	57.7	81.8	80.7	97.3				
		SEM	(7.4)	(4.7)	(6.2)	(6.2)	(6.4)	(5.4)				
	Sitting (s)	Mean	24.5	53.9	83.4	88.1	81.5	96.4				
		SEM	(7.8)	(8.4)	(4.9)	(6.1)	(4.2)	(4.1)				
	Prone (s)	Mean	16.6	17.1	17.8	26.6	44.9	59.5				
		SEM	(5.1)	(3.5)	(4.3)	(5.1)	(8.9)	(8.6)				
Combination behaviors	Across Time (%)	Mean	6.1	2.6	8.4	21.5	26.3	23.3	15.7	13.3	13.3	17.9
		SEM	(3.9)	(0.8)	(1.4)	(3.1)	(3.2)	(1.9)	(2.2)	(1.7)	(1.9)	(2.1)
	Supine (s)	Mean	2.7	4.0	8.3	40.6	54.3	51.5				
		SEM	(1.3)	(1.6)	(2.5)	(5.2)	(9.2)	(5.0)				
	Sitting (s)	Mean	0.2	2.1	15.9	33.6	52.7	46.3				
		SEM	(0.1)	(1.0)	(2.9)	(5.2)	(7.6)	(4.0)				
	Prone (s)	Mean	2.3	0.1	0	1.7	7.4	9.1				
		SEM	(2.3)	(0.1)	(0)	(0.7)	(1.8)	(1.8)				
Variability of individual behaviors	Across Time (%)	Mean	24.7	25.1	40.5	54.0	61.4	65.4	58.6	63.9	62.6	63.3
		SEM	(1.3)	(1.9)	(2.6)	(1.9)	(1.8)	(1.6)	(2.0)	(2.7)	(2.2)	(1.9)
	Supine (count)	Mean	4.0	3.7	5.1	7.7	7.5	9.5				
		SEM	(0.3)	(0.2)	(0.4)	(0.4)	(0.4)	(0.3)				
	Sitting (count)	Mean	3.7	3.8	6.3	8.2	9.2	10.2				
		SEM	(0.2)	(0.2)	(0.3)	(0.4)	(0.5)	(0.3)				
	Prone (count)	Mean	2.9	3.0	3.5	5.0	7.2	9.4				
		SEM	(0.3)	(0.2)	(0.3)	(0.5)	(0.7)	(0.6)				
Variability of combination behaviors	Across Time (%)	Mean	0.6	0.7	2.5	6.4	8.6	11.2	6.4	5.7	5.0	5.8

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Behavior	Condition	Value	Age in Months									
			0	**1.5**	**3**	**4**	**5**	**6**	**9**	**12**	**18**	**24**
		SEM	(0.2)	(0.2)	(0.4)	(0.8)	(0.9)	(0.6)	(0.6)	(0.6)	(0.6)	(0.6)
	Supine (count)	Mean	0.7	0.7	1.6	6.0	6.1	9.8				
		SEM	(0.3)	(0.2)	(0.4)	(0.9)	(0.9)	(1.3)				
	Sitting (count)	Mean	0.3	0.5	2.9	6.8	7.5	11.1				
		SEM	(0.2)	(0.2)	(0.5)	(0.9)	(1.0)	(0.9)				
	Prone (count)	Mean	0.1	0.1	0.2	1.4	4.2	6.1				
		SEM	(0.1)	(0.1)	(0.1)	(0.4)	(1.1)	(0.7)				
Banging	Across Time (%)	Mean	0	0.2	0.1	1.5	1.6	6.0	2.0	1.6	1.1	0.9
		SEM	(0)	(0.2)	(0.1)	(0.9)	(0.9)	(1.4)	(0.7)	(0.8)	(0.5)	(0.4)
	Supine (s)	Mean	0	0.4	0.4	1.6	3.8	9.5				
		SEM	(0)	(0.4)	(0.2)	(1.0)	(2.9)	(2.9)				
	Sitting (s)	Mean	0	0.3	0	2.6	2.0	14.8				
		SEM	(0)	(0.3)	(0)	(2.0)	(1.0)	(4.1)				
	Prone (s)	Mean	0	0	0	0	1.0	4.4				
		SEM	(0)	(0)	(0)	(0)	(0.7)	(1.8)				
Cyclical movement	Across Time (%)	Mean	0.7	1.2	1.7	1.7	1.9	1.5	3.5	4.2	3.7	2.6
		SEM	(0.7)	(0.6)	(0.5)	(0.9)	(0.7)	(0.5)	(0.9)	(0.9)	(0.9)	(0.9)
	Supine (s)	Mean	0.5	3.0	3.0	4.8	5.7	4.5				
		SEM	(0.5)	(1.6)	(1.4)	(2.7)	(2.1)	(2.3)				
	Sitting (s)	Mean	0	0.2	1.6	2.2	2.1	2.0				
		SEM	(0)	(0.2)	(0.8)	(1.6)	(1.3)	(0.7)				
	Prone (s)	Mean	0	0	0	0	0.1	1.4				
		SEM	(0)	(0)	(0)	(0)	(0.1)	(0.8)				
Fingering	Across Time (%)	Mean	0.1	0.3	0.7	1.7	2.6	2.2	4.1	2.0	1.5	1.4
		SEM	(0.1)	(0.3)	(0.2)	(0.4)	(0.5)	(0.4)	(1.1)	(0.5)	(0.3)	(0.4)
	Supine (s)	Mean	0	0.1	0.2	4.4	3.0	3.6				
		SEM	(0)	(0.1)	(0.1)	(1.4)	(1.1)	(1.0)				
	Sitting (s)	Mean	0	0	1.7	2.4	6.0	4.7				
		SEM	(0)	(0)	(0.6)	(0.7)	(1.9)	(1.0)				
	Prone (s)	Mean	0	0.1	0.1	0.3	2.9	2.4				

Behavior	Condition	Value	Age in Months									
			0	1.5	3	4	5	6	9	12	18	24
		SEM	(0)	(0.1)	(0.1)	(0.1)	(0.9)	(0.4)				
Looking	Across Time (%)	Mean	0.7	0.8	2.4	14.8	14.5	23.6	33.7	41.6	40.9	48.0
		SEM	(0.6)	(0.5)	(0.8)	(2.6)	(2.1)	(2.5)	(3.8)	(3.3)	(2.3)	(3.1)
	Supine (s)	Mean	0.1	0.9	1.8	21.8	15.4	39.2				
		SEM	(0.1)	(0.9)	(1.1)	(5.2)	(3.7)	(6.7)				
	Sitting (s)	Mean	0	0.4	3.3	24.4	21.0	38.2				
		SEM	(0)	(0.3)	(1.2)	(5.4)	(4.4)	(5.8)				
	Prone (s)	Mean	0.9	0.9	1.3	7.1	30.0	33.6				
		SEM	(0.9)	(0.9)	(0.9)	(2.6)	(8.8)	(6.0)				
Looking without acting	Across Time (%)	Mean	0.6	0.2	0.8	6.5	7.4	13.8	22.8	30.7	28.6	31.1
		SEM	(0.6)	(0.1)	(0.3)	(1.2)	(1.7)	(1.6)	(2.6)	(2.7)	(1.8)	(2.8)
	Supine (s)	Mean	0	0	0.7	8.9	5.2	21.1				
		SEM	(0)	(0)	(0.3)	(2.1)	(2.2)	(4.1)				
	Sitting (s)	Mean	0	0.1	0.8	10.0	5.9	19.2				
		SEM	(0)	(0.1)	(0.4)	(2.9)	(1.7)	(3.4)				
	Prone (s)	Mean	0.9	0.7	1.1	6.6	24.8	27.7				
		SEM	(0.9)	(0.7)	(1.1)	(6.6)	(24.8)	(27.7)				
Looking while acting	Across Time (%)	Mean	0.1	0.6	1.6	8.1	6.9	9.7	10.7	10.9	12.1	16.5
		SEM	(0.1)	(0.5)	(0.6)	(1.8)	(1.0)	(1.2)	(1.8)	(1.6)	(1.8)	(1.9)
	Supine (s)	Mean	0.1	0.9	1.2	12.8	10.2	18.1				
		SEM	(0.1)	(0.9)	(1.0)	(3.4)	(2.4)	(3.3)				
	Sitting (s)	Mean	0	0.3	2.5	13.9	15.2	19.0				
		SEM	(0)	(0.3)	(0.8)	(3.1)	(3.6)	(3.0)				
	Prone (s)	Mean	0	0	0	0.4	4.3	5.3				
		SEM	(0)	(0)	(0)	(0.3)	(1.2)	(1.2)				
Manipulating	Across Time (%)	Mean	0	0	0.1	0.2	0.6	1.3	1.2	2.6	3.9	6.2
		SEM	(0)	(0)	(0.1)	(0.1)	(0.2)	(0.3)	(0.4)	(0.5)	(0.7)	(1.1)
	Supine (s)	Mean	0	0	0	0.6	0.7	2.7				
		SEM	(0)	(0)	(0)	(0.4)	(0.7)	(1.4)				
	Sitting (s)	Mean	0	0	0.3	0.6	0.6	2.0				

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Behavior	Condition	Value	Age in Months 0	1.5	3	4	5	6	9	12	18	24
		SEM	(0)	(0)	(0.2)	(0.4)	(0.4)	(0.9)				
	Prone (s)	Mean	0	0	0	0.1	1.6	1.6				
		SEM	(0)	(0)	(0)	(0.1)	(0.7)	(0.6)				
Mouthing	Across Time (%)	Mean	5.3	1.3	5.3	15.4	25.5	25.8	13.2	6.3	1.2	0.3
		SEM	(3.8)	(0.5)	(1.3)	(3.0)	(4.1)	(3.3)	(3.8)	(1.9)	(0.5)	(0.2)
	Supine (s)	Mean	2.1	0.8	6.6	32.9	52.9	60.6				
		SEM	(1.1)	(0.4)	(2.5)	(5.6)	(10.6)	(7.5)				
	Sitting (s)	Mean	0.2	1.7	9.2	21.7	44.4	42.1				
		SEM	(0.1)	(0.8)	(2.7)	(5.5)	(8.1)	(7.1)				
	Prone (s)	Mean	2.3	0	0.9	3.5	13.7	25.8				
		SEM	(2.3)	(0)	(0.8)	(1.4)	(3.8)	(6.1)				
Picking	Across Time (%)	Mean	0	0	0.8	0.8	0.7	0.7	0.9	0.3	0.3	1.0
		SEM	(0)	(0)	(0.4)	(0.3)	(0.4)	(0.2)	(0.4)	(0.1)	(0.1)	(0.4)
	Supine (s)	Mean	0	0	0	0.2	0.1	1.0				
		SEM	(0)	(0)	(0)	(0.1)	(0.1)	(0.6)				
	Sitting (s)	Mean	0	0	2.4	2.5	2.7	1.5				
		SEM	(0)	(0)	(1.2)	(1.1)	(1.5)	(0.7)				
	Prone (s)	Mean	0	0	0.1	0.1	0.3	0.5				
		SEM	(0)	(0)	(0.1)	(0)	(0.2)	(0.2)				
Rotation	Across Time (%)	Mean	0	0	0	0.1	0	0.2	1	1.2	0.7	0.9
		SEM	(0)	(0)	(0)	(0.1)	(0)	(0.1)	(0.5)	(0.6)	(0.3)	(0.4)
	Supine (s)	Mean	0	0	0	0.1	0	0.1				
		SEM	(0)	(0)	(0)	(0.1)	(0)	(0.1)				
	Sitting (s)	Mean	0	0	0	0.2	0	0.3				
		SEM	(0)	(0)	(0)	(0.2)	(0)	(0.3)				
	Prone (s)	Mean	0	0	0	0	0.1	0.4				
		SEM	(0)	(0)	(0)	(0)	(0.1)	(0.2)				
Squeezing	Across Time (%)	Mean	0	0.1	0.7	0.5	0.6	0.3	0.6	1.4	0.9	3.6
		SEM	(0)	(0.1)	(0.4)	(0.2)	(0.2)	(0.1)	(0.2)	(0.6)	(0.4)	(0.7)
	Supine (s)	Mean	0	0.3	0	0.1	0.9	0.5				

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Behavior	Condition	Value	Age in Months									
			0	1.5	3	4	5	6	9	12	18	24
		SEM	(0)	(0.3)	(0)	(0.1)	(0.5)	(0.3)				
	Sitting (s)	Mean	0	0.2	1.4	1.6	1.4	1.3				
		SEM	(0)	(0.2)	(0.7)	(0.8)	(0.5)	(0.7)				
	Prone (s)	Mean	0	0.1	0	0.2	0.3	0.1				
		SEM	(0)	(0.1)	(0)	(0.1)	(0.2)	(0.1)				
Touching the body	Across Time (%)	Mean	70.6	67.2	69.7	61.0	58.0	40.1	23.2	20.1	18.3	19.3
		SEM	(5.3)	(3.8)	(2.6)	(3.2)	(4.0)	(2.9)	(3.5)	(3.1)	(2.6)	(2.9)
	Supine (s)	Mean	58.8	60.4	78.4	106.7	120.5	83.3				
		SEM	(8.9)	(7.3)	(6.7)	(6.4)	(10.2)	(7.4)				
	Sitting (s)	Mean	62.2	70.0	110.5	103.2	118.6	90.3				
		SEM	(20.8)	(8.6)	(6.7)	(7.2)	(7.0)	(7.0)				
	Prone (s)	Mean	30.6	21.3	16.0	22.8	12.2	11.5				
		SEM	(11.8)	(4.0)	(3.8)	(4.3)	(4.4)	(2.7)				
Transferring	Across Time	Mean	0	0	0	0.5	0.5	1.1	2.0	2.6	2.1	2.3
	(count/minute)	SEM	(0)	(0)	(0)	(0.1)	(0.1)	(0.2)	(0.3)	(0.4)	(0.3)	(0.4)
	Supine (count)	Mean	0	0	0.2	1.2	0.9	4.0				
		SEM	(0)	(0)	(0.1)	(0.3)	(0.4)	(0.8)				
	Sitting (count)	Mean	0	0	0	1.2	1.6	3.8				
		SEM	(0)	(0)	(0)	(0.4)	(0.3)	(0.5)				
	Prone (count)	Mean	0	0	0	0.1	0.8	2.2				
		SEM	(0)	(0)	(0)	(0.1)	(0.6)	(0.7)				

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Table 4

Model estimated intercepts and standard deviations (in parentheses) for each behavior across time (supine, sitting, and prone collapsed) and within each position. Note that for the analyses across positions, we did not model infrequent behaviors that did not occur often until later visits because they did not generate enough non-zero values for the model's estimates.

Behavior	Across Time	Supine	Sitting	Prone
Holding	31.33% (8.46)	60.39 s (10.56)	56.83 s (8.26)	73.73 s (13.09)
Bilateral holding	0.22% (8.42)	5.86 s (1.35)	1.29 s (1.41)	0.00 s (2.23)
Overall behavioral performance	37.68% (18.14)	25.36 s (7.30)	14.54 s (13.02)	22.05 s (8.81)
Bouts of behavior	5.64/min (2.24)	9.31 (8.03)	8.10 (8.71)	7.28 (6.12)
Individual behaviors	33.79% (8.63)	24.05 s (8.62)	25.63 s (11.42)	20.70 s (8.69)
Combination behaviors	7.76% (1.26)	1.67 s (1.39)	0.21 s (1.43)	14.47 s (1.77)
Variability of individual behaviors	24.43% (2.98)	3.43 (0.48)	2.60 (0.93)	3.05 (0.88)
Variability of combination behaviors	0.77% (1.07)	0.82 (3.16)	−0.39 (2.00)	0.41 (0.63)
Banging	0.06% (1.89)	2.92 s (3.84)	0.13 s (2.85)	0.00 s (1.81)
Cyclical movement	0.64% (4.46)	-	-	-
Fingering	0.66% (1.3)	-	-	-
Looking	1.83% (1.03)	4.45 s (1.62)	0.07 s (1.91)	0.88 s (1.67)
Looking without acting	0.59% (0.58)	-	-	-
Looking while acting	0.20% (2.36)	4.74 s (1.96)	0.02 s (1.55)	0.00 s (2.11)
Manipulating	0.88% (1.32)	-	-	-
Mouthing	3.90% (1.74)	4.19 s (1.53)	2.39 s (1.50)	0.90 s (2.25)
Picking	2.32% (3.22)	-	-	-
Rotation	0.00% (1.12)	-	-	-
Squeezing	0.84% (1.74)	-	-	-
Touching the body	83.03% (8.18)	44.49 s (10.83)	43.92 s (10.23)	29.43 s (5.44)
Transferring	0.00/min (1.34)	-	-	-