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Dynamics of the dyad: How mothers and infants co-construct interaction spaces during object play

Joshua L. Schneider[1], **Emily J. Roemer**[1], **Jessie B. Northrup**[2], **Jana M. Iverson**[1]

[1]Department of Psychology, University of Pittsburgh, USA

[2]Department of Psychiatry, University of Pittsburgh, USA

Abstract

Studies of dyadic interaction often examine infants' social exchanges with their caregivers in settings that constrain their physical properties (e.g., infant posture, fixed seating location for infants and adults). Methodological decisions about the physical arrangements of interaction, however, may limit our ability to understand how posture and position shape them. Here we focused on these embodied properties of dyadic interaction in the context of object play. We followed 30 mother-infant dyads across the first year of life (at 3, 6, 9, and 12 months) and observed them during five minutes of play with a standard set of toys. Using an interval-based coding system, we measured developmental change in infant posture, how mothers and infants positioned themselves relative to one another, and how they populated interaction spaces with objects. Results showed that mother-infant dyads co-constructed interaction spaces and that the contributions of each partner changed across development. Dyads progressively adopted a broader spatial co-orientation during play (e.g., positioned at right angles) across the first year. Moreover, advances in infants' postural skills, particularly increases in the use of independent sitting in real time, uniquely predicted change in dyadic co-orientation and infants' actions with objects, independent of age. Taken together, we show that the embodied properties of dyadic object play help determine how interactions are physically organized and unfold, both in real time and across the first year of life.

Keywords

dyadic interactions; mother-infant dyads; infant posture; body positioning; object play; interval coding

Dyadic interactions between infants and caregivers are dynamic. They occur in moment-to-moment exchanges and evolve in form and complexity across development. Interactions are also embodied, contextually bound to bodies that perform actions while adopting particular postures and positions in space. Most studies of dyadic interaction place an emphasis

Corresponding author: joshua.schneider@pitt.edu.

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on infants' communicative exchanges with their caregivers (e.g., gaze, vocalization, joint attention) in settings that constrain the physical characteristics of interaction (e.g., posture, movement, relative positioning of the dyad). Indeed, the literature is replete with illustrations of how infants and caregivers engage in reciprocal interactions during face-to-face play in predetermined arrangements (e.g., Beebe et al., 2016; Cohn & Tronick, 1987; de Barbaro et al., 2016; Deák et al., 2014; Jaffe et al., 2001; Yale et al., 2003). Dyads are often asked to sit across from one another at a table or on the floor, with caregivers in chairs and infants in highchairs or seats that provide postural stability and prevent them from leaving the interaction space. While this work has provided a wealth of information about the dynamics of early infant-caregiver interactions, researchers have rarely measured the physical properties of interaction that may play a role in advances in social communication (see Adolph & Hoch, 2019; Iverson, 2021). Procedural decisions about the physical arrangements of interaction, however, may inadvertently limit our ability to understand how posture and position shape them.

For infants, dyadic interactions often take place in the context of everyday play with objects (e.g., Bakeman & Adamson, 1984). Infants and caregivers engage with objects and create moments of shared attention (e.g., an infant and caregiver fit shapes into a shape sorter while seated together on the floor). These moments are particularly important opportunities for infant learning and development as they provide openings for caregivers to share information about objects and the environment with their infants (e.g., object labels, object functions; Pereira et al., 2014; Tomasello & Farrar, 1986; Yu & Smith, 2012). Learning opportunities such as these, however, are likely the result of a number of underlying physical components. For example, before an infant can push a shape into its designated slot in a shape sorter and a caregiver can follow-in with a label, dyads must select the objects they will engage with, position their bodies in particular ways, and continuously update these parameters as interactions unfold.

How do infants and caregivers organize the physical spaces in which they interact? Caregivers may position themselves in ways that facilitate interaction based on their infants' developing postural skills. And reciprocally, infants' propensity to shape dyadic interactions may also increase as their own abilities advance over time. Thus, the overall goal of this study was to characterize the dynamics of dyadic co-construction of interaction spaces during object play and to chart its developmental progression across the first year of life.

Infant posture creates opportunities for dyadic interaction

Infants acquire and refine a host of new motor skills across the first year of life, expanding the repertoire of postures that can be used during play (Adolph & Berger, 2015; Leezenbaum & Iverson, 2019). Infant posture is particularly important as it alters how infants organize their bodies in space, and by extension, constrains and creates opportunities for dyadic interaction.

For example, at 3 months, infants spend much of their time lying supine on their backs or held in their caregivers' arms (Franchak, 2019), lacking sufficient strength to fight gravity and switch between postures easily. For very young infants, caregivers often determine their positions in space, placing them as they choose and effectively curating the physical interaction space. By 6 months, as independent sitting emerges, infants begin to play a more active role in object interactions. Sitting reorganizes infants' body positions, resulting in an upright torso and free hands that can be used to grasp and manipulate objects more easily (Marcinowski et al., 2019; Rochat & Goubet, 1995; Soska et al., 2010, 2014).

Around 9 months, most infants are able to crawl, thereby expanding opportunities for interaction. Compared to pre-locomotor infants, crawlers pay more attention to distal objects and people and show increased engagement during play with their caregivers (Campos et al., 1992, 2000). An additional and perhaps unintentional consequence of crawling is that infants must transition into the crawling posture from other stationary postures, most often from sitting. Interestingly, the real-time transitions from sitting to crawling (and vice versa) are accompanied by an average 90-degree reorientation in infants' bodies (i.e., a right angle; Soska et al., 2015). This change in position may result in new opportunities for interaction with objects and caregivers. A recent longitudinal investigation of postural development and mother-infant interaction supports this possibility. Not only do infants generate more posture transitions across locomotor development (Thurman & Corbetta, 2017), but they also use their advancing postural repertoires to engage in increasingly complex interactions with objects and their mothers (e.g., from passive holding to tailored actions like pushing buttons and throwing balls; Thurman & Corbetta, 2019).

Finally, by 12 months, most infants (raised in Western cultures) acquire independent upright locomotor skills like walking (Adolph et al., 2010). Walking allows infants to move with increased efficiency: infants are faster, travel greater distances, and take advantage of a new visual perspective while moving (Adolph et al., 2012; Kretch et al., 2014). Walking effectively "opens" interaction spaces even further by providing infants with new access to distal objects and supporting object retrieval, carrying, and subsequent sharing with caregivers (Heiman et al., 2019; Karasik et al., 2011; West & Iverson, 2021). Taken together, the advances in postural and locomotor skills observed across the first year of life and real-time transitions between them expand the possible network of interaction spaces for infants and increase their ability to initiate dyadic play.

Dyadic positioning and co-orientation during interaction

Little is known about how infant-caregiver dyads position themselves during object play. Some preliminary evidence comes from a series of studies in which Fogel and colleagues (1992, 1993, 1999) examined infant posture and the relative positioning of mother-infant dyads during face-to-face interactions. Using an experimental design (Fogel et al., 1992), researchers placed 3- to 6-month-old infants in a seating device that could alter infants' postures from supine to reclined or sitting in real time. There was an effect of posture on patterns of infant gaze: infants looked the most at their mothers while supine and the least while sitting. This suggests that infants' in-the-moment postures (and consequently, their position relative to their mothers) impacted opportunities for social interaction.

In a subsequent study, Fogel et al. (1993) followed a group of mother-infant dyads longitudinally across the first six months of life to measure change in how mothers spontaneously positioned their infants during interactions. Mothers were free to position infants in any way they chose, but position categories were grouped to represent time spent supine, sitting, and upright (facing either toward or away from the mother). Mothers optimized their infants' relative positions to engage infants and gain their attention (i.e., mothers were more likely to orient their infants to a sitting or upright facing position when infants looked away). Moreover, another study using the same sample (Fogel et al., 1999) showed that changes in infant posture (more time spent sitting and upright) uniquely shaped longitudinal patterns of gaze, underscoring the importance of posture for developmental change in dyads' communicative exchanges.

Though little work has directly examined dyadic co-orientation during everyday object play in the home, several recent studies provide compelling evidence for the potential impact of posture and position on infant-caregiver interactions. For example, a longitudinal study of object play in the laboratory revealed an effect of infant age on dyadic positioning: caregivers spent more time positioned behind their infants at younger ages in order to support them in a sitting posture (Frank et al., 2013). And an increase in time spent sitting at older ages corresponded to an increase in infants' visual access to caregivers' faces and hands (Long et al., 2022). Other work has demonstrated that infants and caregivers often coordinate their postures. Specifically, the time caregivers spent upright vs. down on the floor was explained not only by infants' locomotor status (i.e., whether an infant was a crawler or walker), but also by the amount of time infants themselves spent in each posture. In turn, dyads' postural co-orientations shaped patterns of interaction—moments of shared attention to objects occurred more frequently when infants and caregivers were sitting on the floor (Franchak et al., 2018).

Another study that tracked mother-infant locomotor activity also revealed dyadic coordination in patterns of movement (Hoch et al., 2021). Mothers and infants spontaneously synchronized their locomotor actions while moving through a laboratory playroom (i.e., their paths mimicked one another in space and time). Interestingly, infants were more likely than mothers to initiate locomotion and thereby potential opportunities for social interaction. Mothers, in turn, followed their infants' lead.

Finally, in another set of studies, researchers examined relations between interpersonal distance and initiations of social interaction (via eye contact) in the context of infants' developing locomotor skills. This work showed that while the general distance between dyads did not substantially change across the transition from crawling to walking, infants were more likely than mothers to initiate social interactions from greater distances (Yamamoto et al., 2019). Moreover, the number of objects available for play increased substantially as the distance between dyads (i.e., the interaction space) increased (Yamamoto et al., 2020).

Current study: How do mother-infant dyads co-construct interaction spaces?

Taken together, the existing literature suggests that infant posture and mother-infant positioning are important features of dyadic interaction. In this study, we directly measured these embodied properties longitudinally in the context of everyday object play in the home.

The study had two goals. The first was to describe longitudinal change in three properties of dyadic interaction: (1) infant posture; (2) how mother-infant dyads spontaneously positioned their bodies relative to one another (i.e., dyadic co-orientation); and (3) how dyads populated their interaction spaces with objects (i.e., object density and object placement). We expected that infants' postural repertoires would advance over time given the abundance of previous literature on the developmental progression of infants' motor skills across the first year (e.g., Leezenbaum & Iverson, 2019). Existing work suggests that dyads spend a majority of their time facing one another during everyday play at younger ages (e.g., Fogel et al., 1993) and that an increasing postural repertoire may lead to progressively "larger" interaction spaces (e.g., play at right angles; Soska et al., 2015). Thus, we hypothesized that dyadic positioning would change across the first year of life, and that mothers and infants would increasingly position themselves to adopt a broader spatial co-orientation. Finally, we expected dyads' interaction spaces to become more densely populated with objects as infants got older.

Our second goal was to examine developmental change in the propensity for infants (vs. mothers) to initiate changes to the dyadic interaction space (e.g., by initiating orientation transitions or moving objects in and out of the space). Moreover, we assessed whether advances in postural development—specifically the amount of time infants spent in independent sitting—uniquely predicted change in measures of dyadic interaction above and beyond the effects of infant age. We expected that infants would increasingly take an active role in dyadic interactions as they got older. But we also hypothesized that developmental change in dyadic interactions, and particularly in infants' initiations, would be predicted by infants' use of more advanced postural skills (e.g., independent sitting; Marcinowski et al., 2019; Soska et al., 2010, 2014).

Method

Participants

Video data for the current report were drawn from 30 mother-infant dyads who participated in a study examining dyadic coordination during infant-caregiver interactions (first reported in Northrup & Iverson, 2019, 2020). The original study recruited participants from a larger sample followed longitudinally across the first three years of life to investigate the relations between the development of infant posture, object exploration, and language (e.g., Jarvis et al., 2020; Roemer et al., 2021). All infants were born at term and from uncomplicated pregnancies. Data were collected between 2013 and 2017 in one Midwestern city. All participants provided written informed consent as approved by the Institutional Review Board at the University of Pittsburgh (PRO13090529; "Parent-Infant interactions and the development of infants at risk for ASD").

The sample included 13 infants (9 boys, 4 girls) at elevated likelihood for developing Autism Spectrum Disorder (ASD), defined by the presence of an older sibling already diagnosed with ASD. Seventeen infants (12 boys, 5 girls) had no first- or second-degree relatives with ASD and at least one neurotypically developing older sibling. A preliminary goal of this project was to examine whether measures of dyadic interaction varied among infants with vs. without an older sibling with ASD. However, there were no significant differences between groups on any measure. Moreover, none of these infants received an ASD diagnosis at the conclusion of the study. Thus, data from all mother-infant dyads were collapsed into a single group.

Caregivers reported their infant's race and ethnicity: 26 infants were White (1 was Hispanic or Latino), 1 was Black, and 3 were Multiracial. Mothers and fathers were similar in age (*M* mothers = 33.37, *SD* = 3.89; *M* fathers = 34.63, *SD* = 6.07) and education (90% of mothers and 93.3% of fathers held a college degree or higher).

Procedure

Researchers visited each mother-infant dyad in the home when infants were approximately 3 (*M* = 3.27, *SD* = 0.33), 6 (*M* = 6.39, *SD* = 0.30), 9 (*M* = 9.19, *SD* = 0.16), and 12 months of age (*M* = 12.25, *SD* = 0.22). Most visits occurred on weekdays during times when infants were awake, alert, and ready to play. At each visit, dyads were observed during play with a standard set of toys for 10 minutes. The toy set (see Figure 1) contained a total of 24 individually manipulable objects (a book, a rattle, a set of stacking rings, and a spherical puzzle ball). We asked mothers to play with their infants as they typically would and did not constrain their interactions in any way.

A Boppy pillow was available in the event that mothers chose to provide their infants with additional postural support during play. Sixty percent of mothers at 3 months (12/20) and 35% at 6 months (9/26) used the pillow to lay their infants supine or support them in a sitting posture for the majority of the play interaction (*M* number of 5-second intervals = 56.92, *SD* = 9.44); none used the pillow at 9 or 12 months. Dyads played in one main room (typically the living room) and were videorecorded with two handheld cameras to fully capture interactions. One camera focused on the infant and the other focused on the mother, ensuring the entire body of each participant was in view at all times. Prior to filming, mothers were asked to put away all other toys and clear a space for play, but no other instructions were given. Researchers remained at a distance during filming and did not interact with dyads.

Video data were available for different numbers of mother-infant dyads at each time point. Of the 30 dyads who participated in the study, 20 dyads provided video data at 3 months, 26 dyads at 6 months, 28 dyads at 9 months, and 24 dyads at 12 months. Thus, 98/120 sessions were available in the dataset. Missing data were due to missed visits (n = 17), late study enrollment (n = 4), and infant fussiness (n = 1).

Data coding

Dyadic interactions were coded using Datavyu (datavyu.org), a computerized coding tool that allows for scoring of simultaneous behaviors from multiple videos. Coders were trained until overall percent agreement reached ≥ 90% on all coding categories for three consecutive videos. After establishing reliability, a primary coder scored 100% of each dyad's video data, and a reliability coder independently scored a randomly selected 25% of each video to verify inter-observer reliability. Two coders (an undergraduate researcher and the first author) coded the 98 available sessions in the dataset. Each coder scored half the sample (balanced for sessions within each age point) as the primary coder and the other half as the reliability coder. All disagreements were resolved through discussion. Reliability statistics were calculated based on original codes and are reported as mean percent agreement and mean kappa across participants. Our coding materials are shared on Databrary.org (databrary.org/volume/1361; Schneider & Iverson, 2021).

We selected the middle five minutes of each 10-minute observation for coding, as it allowed for a short warm-up period for each dyad but also minimized infant fatigue. Each 5-minute observation was divided into sixty, 5-second intervals. We established interval length using an iterative pilot coding process in which codes were tested using a variety of interval durations. Our goal was to select an interval that was long enough to provide an appropriate level of detail for capturing change in dyadic behavior over time while also maintaining coder efficiency (see Bakeman & Gottman, 1997). Based on these initial observations, a 5-second interval was chosen as the best solution for balancing these parameters. Rather than coding behavior at a single moment of video anchored to each interval (i.e., coding at the onset of each interval), we scored behavior based on what occurred *across* the entire five seconds, allowing us to gather information about approximate durations. To facilitate coding, we synchronized the two camera views from each session so that coders were able to watch the videos of mothers and infants simultaneously.

Infant posture.—Coders first identified infant posture throughout each interval. Posture was categorized using six mutually exclusive categories adapted from previous work (e.g., Leezenbaum & Iverson, 2019). We scored whether infants were: (1) *prone* (lying on their bellies, on all fours, or crawling), (2) *supine* (lying on their backs), (3) *supported sitting* (with help from their mothers, the pillow we provided, or supported by their own hands), (4) *independent sitting* (with hands off the ground), (5) *upright* (standing with support from furniture or the mother, standing independently, cruising, or walking), or (6) *held* (in mother's arms or fully supported in her lap).

We only coded one of the six posture categories if the infant remained in the same posture across the entire 5-second interval. If there was a transition between postures during an interval (e.g., the infant switched from prone to sitting), coders scored this in a separate *posture transitions* category. Coders agreed on 96.3% of intervals when determining infant posture (κ = 0.94).

Dyadic positioning.—We next scored each dyad's physical co-orientation during each interval; that is, how mothers' and infants' bodies were positioned relative to one another in space. As shown by the line drawings in Figure 2, we coded whether dyads adopted one of four mutually exclusive orientation types throughout the entire interval or if the interval represented a transition between orientations.

We coded whether dyads were *facing* each another (the blue drawing; Figure 2a) and thus sharing the space between them. Coders also identified when infants and mothers were positioned at *right angles* to one another, creating an angular configuration of approximately 90 degrees (the orange drawing; Figure 2b). Dyads could also be *back-to-front* (the purple drawing; Figure 2c), in which infants were positioned in front of their mothers and shared the space directly in front of them. And finally, infants and mothers could be oriented in *different directions* (the green drawing; Figure 2d), positioned back-to-back or facing separate areas of the room.

As with infant posture, we only coded one of the four orientation types if the dyad remained in the same orientation for the entirety of the 5-second interval. If the dyad changed orientations during the interval, we assigned it to a separate *orientation transitions* category (the grey drawing; Figure 2e) and noted which partner (mother or infant) initiated the transition. Mothers could initiate transitions either by repositioning themselves or moving their infants; infants could initiate transitions by repositioning their own bodies. Inter-observer reliability was high for categorizing dyadic positioning (coders agreed on 95.1% of intervals, $\kappa = 0.92$) and identifying the initiator of transitions (agreement on 97.2% of intervals, $\kappa = 0.77$).

Object density.—We coded how densely populated dyads' interaction spaces were with objects. To do this, coders counted the total number of objects that were within infants' presumed wingspans and thus accessible for potential manipulation and interaction. The shaded regions of each line drawing in Figure 2 illustrate the conceptual criteria used to determine infants' potential reach radius (i.e., an open fan radiating from the infant as its midpoint). Thus, coders included objects in the density count if infants could presumably reach the toy from their current position, without requiring a change in posture.

Figure 1 shows our standard set of toys with a total of 24 individual objects. The book and rattle (Figures 1a-b) were not transformable and remained as single objects regardless of how they were played with. The stacking rings and spherical puzzle ball (Figures 1c-d), however, were transformable and allowed for increases in object density based on their affordances for play. The stacking rings and ball were always presented as single objects (i.e., all rings and duck head placed on the stacker base; both halves of the ball tightly shut and enclosing the small shapes inside) at the start of each play session. However, the individual components of each object (up to eight for the stacking rings and up to 14 for the ball) were removeable and could become independent objects (e.g., a ring from the stacker became available for density coding when it was removed from the base and within infants' reach). Thus, object density reflected the cumulative number of independent objects from the toy set available in the interaction space at any point across each 5-second interval. An intraclass correlation coefficient showed a high level of agreement between coders on object density counts ($ICC = .99$, $p < .001$).

Object placement.—Finally, coders noted if infants or mothers changed object density counts by adding or removing toys from the interaction space with a manual action. For example, infants could remove objects from the space by pushing shapes back inside the puzzle ball or flinging toys to the other side of the room. Similarly, mothers could add

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objects by taking rings off the stacker base and handing them to their infant or by retrieving objects that fell outside their infant's reach during a previous interval. Thus, this measure reflected initiations on the part of infants and mothers in changing the number of objects available for play and credited each partner if this behavior occurred during each 5-second interval.

We scored whether each interval contained an object placement and when it did, identified which partner (mother or infant) was responsible for it. In the event that both mothers and infants produced a placement, we credited the partner who first initiated the behavior. However, these cases were rare and summed to a total of 14 instances across the entire dataset (i.e., 1.4% of all intervals containing an object placement). Inter-observer agreement was similarly high for determining if an object placement occurred (coders agreed on 95.1% of intervals, $\kappa = 0.84$) and for identifying the initiator of the placement (agreement on 94.5% of intervals, $\kappa = 0.83$).

Analytic approach

We used hierarchical linear modeling (HLM; Raudenbush & Bryk, 2002) to examine growth trajectories for each measure of interest. We chose HLM as it is particularly well-suited for partitioning the variance of nested data into within-cluster and between-cluster effects. In our case, sessions (i.e., 3, 6, 9, and 12 months) were nested within individual dyads. An additional advantage of HLM is that it accommodates missing data (Huttenlocher et al., 1991; Willett et al., 1998). For the present study, 98 of 120 (81.7%) possible observations were complete. Missing data were considered to be missing completely at random (MCAR) as the reasons for missingness (e.g., missed study visits, timing of study enrollment) were unrelated to the variables of interest in this study (Curran et al., 1998). Moreover, preliminary analyses revealed no significant differences in patterns of dyadic interaction between dyads with complete vs. incomplete sets of longitudinal observations (all *p*s > .05). HLM analyses were run using the lme4 and lmerTest packages in R (Bates et al., 2015; Kuznetsova et al., 2017).

A multi-step process was conducted to determine the best and most parsimonious model for the data for each of our measures. This process began by fitting a fully unconditional random intercept model (with no within- or between-subjects predictors), also known as a means-only model. To determine the most appropriate model of change across the four sessions, we examined change in model fit from the means-only model to a linear model, and subsequently to a quadratic model. Chi-square tests of deviance were calculated to determine whether the linear or quadratic models lead to a significant reduction in deviance compared to the previous model (i.e., was a better fit for the data). Higher order growth models were retained only if they significantly reduced the deviance (i.e., improved the fit) of the model and the growth term was significantly greater than zero. A random effect was included on the growth term if the variance was significantly greater than zero.

Results

The overarching goal of this study was to characterize the embodied properties of dyadic interactions during object play and describe change in these features across the first year of life. We first examine change over time in infant posture across the four sessions. Next, we describe developmental change in dyadic positioning—how mothers and infants organized their bodies during object play—and which partner initiated the transitions between orientation types. We then present data on change in the number of objects available for play across the first year and on infants' and mothers' object placement behaviors. Finally, we analyze how advances in infants' postural skills, particularly time spent in independent sitting, predict change in measures of dyadic interaction above and beyond infant age. Descriptive statistics are presented in Table 1. Results of HLM analyses are provided in Tables 2 and 3.

Infant posture.

We first examined the proportions of intervals infants spent in each posture during play. Because a single posture category (or orientation type) was only coded if it spanned the entire 5-second interval (see Method), we also present the data as approximate durations by scaling the number of intervals of each behavior by a factor of five (i.e., the duration of the interval) to derive an estimate of time spent in each posture (or orientation type). The data on infant posture are displayed in Figure 3.

In general, infants were rarely prone, upright, or held, regardless of age (see Table 1). Given the infrequency of these postures (occurring less than 5% of the time at 3 or more ages), we did not include them in longitudinal analyses. Thus, we only present growth models for supine, supported sitting, independent sitting, and posture transitions below.

At 3 months, infants were most likely to play while lying supine on their backs, followed by supported sitting and being held by their mothers. A larger repertoire of postures emerged at 6 months, including time spent supine and in supported sitting, as well as time in independent sitting for those infants who acquired the skill (12/30 infants spent approximately half of their play time in independent sitting at 6 months). By 9 and 12 months, however, independent sitting became the prevailing posture used by all infants during play (Table 1).

We observed unique patterns of change for each posture (see the trajectories in Figure 3). A quadratic model best fit the rate of change in the proportion of intervals infants spent supine. As can be seen in Figure 3a, time spent supine decreased drastically between 3 and 6 months, with a flattening in change between 6 and 12 months. There was a significant linear decrease at the 3-month time point ($\beta_{10} = -0.19$, $SE = 0.02$, $p < .001$), with a subsequent deceleration in change over time ($\beta_{20} = 0.01$, $SE = 0.002$, $p < .001$). Thus, while infants spent an average of 61% of their play time supine at 3 months (equivalent to 3.05 minutes), they were spending <1% of time in this posture by 12 months (or 2.07 seconds). Time spent in supported sitting also decreased, with a linear model representing the best fit for the data (Figure 3b). HLM analyses confirmed a significant linear decrease across the four sessions, such that infants spent approximately 4% fewer intervals in supported sitting (equivalent to a monthly decrease of 20 seconds spent in the posture) each month ($\beta_{10} = -0.04$, $SE = 0.01$, $p < .01$).

Instead, infants were increasingly likely to engage in independent sitting during object play with their mothers across the first year (Figure 3c). Specifically, infants quickly increased the amount of time spent sitting independently between 3 and 9 months, followed by a flattening in change between 9 and 12 months. By 9 months, infants were spending approximately 83% of their play time sitting independently (equivalent to 4.15 minutes). The rate of change in independent sitting was best fit by a quadratic model, such that infants showed rapid linear growth early in the first year (β_{10} = 0.21, SE = 0.03, $p < .001$) followed by deceleration (β_{20} = −0.01, SE = 0.003, $p < .001$).

Finally, we also examined developmental change in how likely intervals were to contain a posture transition. Infants steadily increased in how likely they were to transition between postures during play, resulting in approximately 13% of intervals spent in posture transitions by 12 months (see Table 1; Figure 3d). There was a significant linear increase in the proportion of intervals with posture transitions across the four sessions, indicating a 1% increase in posture transition intervals each month (β_{10} = 0.01, SE = 0.003, $p < .001$).

Dyadic positioning.

We next examined change in the proportion of intervals mother-infant dyads spent in each of the four possible orientations and the proportion of intervals they spent transitioning between orientations. Figure 4 presents the data on dyadic positioning. The raster plot in Figure 4a shows individual timelines for each dyad—color-coded by orientation type (see the line drawings in Figure 4b for a legend)—and represents both the real-time fluctuations of orientations between each 5-second interval within a session and change in patterns of orientations across sessions. Figure 4c highlights longitudinal change with proportional data for each orientation type.

As shown in the figure, dyads spent progressively less time facing one another during play (see the decrease in blue bars across Figure 4a and the decreasing slope in Figure 4c; Table 1). HLM analyses confirmed a linear decrease over time in the proportion of intervals spent in the facing orientation, such that dyads spent approximately 6% fewer intervals (equivalent to a decrease of 18.45 seconds) facing one another during play each month (β_{10} = −0.06, SE = 0.01, $p < .001$). Instead, dyads increasingly positioned themselves at right angles (see the increase in orange bars across Figure 4a and corresponding increase in slope in Figure 4c; Table 1). This growth was also best represented by a linear model, with a significant increase in the proportion of intervals spent at right angles per month (β_{10} = 0.04, SE = 0.01, $p < .01$). Specifically, mother-infant dyads showed a 4% increase in right angle intervals (accumulating an additional 11.40 seconds of play in this angular configuration) each month.

In contrast, we saw general stability in how likely mothers and infants were to position themselves back-to-front or in different directions across the four sessions. In fact, they rarely adopted these configurations (see the smattering of purple and green bars across Figure 4a and relatively flat growth over time in Figure 4c; Table 1). HLM analyses did not show linear or quadratic growth in either behavior (see Table 2).

Next, we analyzed developmental change in how likely intervals were to contain transitions between the four orientations. As shown in Figure 4, dyads transitioned between orientation types more often as infants got older (see the increasing number of grey bars across Figure 4a and corresponding increase in slope in Figure 4c; Table 1). A linear rate of change best characterized growth in orientation transitions over time and indicated a 1% increase in transition intervals each month (β_{10} = 0.01, *SE* = 0.002, $p < .001$). Thus, while mother-infant dyads rarely transitioned between orientation types at 3 months (*M* number of intervals = 0.35, *SD* = 1.09), they did so much more frequently by 12 months, with an average of 6.00 transition intervals (*SD* = 5.06) per five minutes.

Was the increasing number of orientation transitions due to changes in infants' or mothers' behaviors? To address this question, we calculated the proportion of transitions initiated by infants vs. mothers to control for each dyad's base rate of transition intervals and to determine which partner set the stage for play at each age. However, due to the low and unequal number of dyads contributing data on transition intervals at each age (N 3 months = 2; N 6 months = 10; N 9 months = 13; N 12 months = 19; see also Figure 4a), we present the data on longitudinal change descriptively. Figure 5 shows the proportional data on orientation transitions.

Dyads generated a total of 304 orientation transitions across the dataset (i.e., the sum of grey bars in Figure 4a); mothers initiated 113 transitions and infants initiated 191. We saw developmental change in the proportion of transitions that were initiated by infants vs. mothers. At 3 months, mothers initiated all of the transitions that occurred (seven in total across all dyads) and exclusively shaped the configuration of dyad's interaction spaces. However, this changed across the first year, such that mothers became less and less likely and infants became increasingly likely to initiate transitions between orientations (see Figure 5, Table 1). Specifically, by 12 months, infants were responsible for nearly 72% of dyad's transition intervals.

Object density.

The third feature of dyadic interaction we measured was how densely populated interaction spaces were with objects. Recall that the total number of objects possible for play in our standard toy set was 24 (see Method, Figure 1). All dyads had access to at least one object during each interval and some had all 24 available for play. We averaged density counts across the 60 intervals to derive a mean object density score for each dyad at each session. Figure 6 presents these data.

In general, dyads played with an average of 1-2 objects per interval at 3 months, often engaging with the same toy for the entirety of the play session. However, the average number of objects available in the interaction space increased substantially across the four sessions (see Figure 6, Table 1). HLM analyses revealed significant linear growth in the mean number of objects available per interval across the first year, such that dyads accumulated an average of 1.81 additional objects for play each month (β_{10} = 1.81, *SE* = 0.40, $p < .001$).

Object placement.

We also examined object placement behaviors to determine how likely mothers and infants were to add or remove toys from the interaction space. Figure 7 presents the data on object placement. Object placements were generally stable over time and occurred during approximately 16.9% of intervals (*SD* = 7.5%) at each time point (see Figure 7a, Table 1). There was no significant linear or quadratic growth in this behavior across the first year (Table 2).

Mothers were more likely than infants to perform object placements at all ages. However, the proportion of placements made by mothers decreased over time as infants became increasingly likely to move objects in and out of the interaction space as they got older (see Figure 7b, Table 1). Given that these proportional values were reciprocals of one another, we included only infants' rate of initiations for analysis. Results indicated that infants were significantly more likely to perform object placements across the four sessions, with a 3% increase in the proportion of object placement intervals each month ($\beta_{10} = 0.03$, $SE = 0.01$, $p < .001$).

Infant posture and dyadic interaction.

Our final set of analyses examined whether advances in infants' postural repertoires were related to patterns of dyadic interaction. Specifically, we assessed whether time spent in independent sitting (the predominant posture used by infants during play) predicted the change we observed in our other measures of interaction above and beyond the effects of age. To do this, we added the proportion of intervals infants spent in independent sitting as a time-varying predictor to the HLM models.

First, we asked whether time spent in independent sitting predicted time spent in the different orientation types. We only included orientations that showed significant longitudinal change (i.e., facing and right angles). HLM analyses revealed that the proportion of intervals in independent sitting significantly predicted the proportion of intervals spent at right angles, above and beyond infant age ($\beta_{11} = 0.27$, $SE = 0.12$, $p < .05$). In fact, age was no longer a significant predictor of time spent at right angles once independent sitting was added to the model, suggesting that change in this orientation type was better predicted by postural development rather than infant age (see Table 3). In contrast, this relation did not hold for the proportion of intervals spent facing, and age remained the best predictor of time spent in this orientation (Table 3).

We next added the proportion of intervals infants spent in independent sitting as a predictor of dyads' average object densities but there were no significant relations between the two measures ($p > .05$). In other words, changes in independent sitting did not predict the observed increase in object density counts above and beyond the effect of age (Table 3). Finally, we assessed whether time spent sitting independently predicted the proportion of infant-initiated object placements. HLM analyses confirmed a significant effect, such that the proportion of intervals in independent sitting predicted the proportion of infant-initiated object placements, controlling for age ($\beta_{11} = 0.11$, $SE = 0.05$, $p < .05$).

Discussion

This study focused on the embodied properties of dyadic interaction during unconstrained object play in the home. We measured longitudinal change in the postures infants used, how mothers and infants positioned their bodies relative to one another, and how dyads populated their interactions spaces with objects. Moreover, we quantified change in these behaviors as they unfolded in relation to one another across developmental time and examined the effects of infants' in-the-moment postures on patterns of dyadic action.

Mother-infant dyads co-constructed interaction spaces, and the contributions of each partner changed across development. Across the first year of life, dyads continuously reorganized the physical arrangements of their bodies during play, but progressively adopted a broader spatial co-orientation (i.e., right angles) as opposed to facing one another. At younger ages, mothers exclusively shaped the physical context of dyadic interactions: they determined their infants' posture and position in space and selected the objects for play. However, at older ages and as infants' postural skills advanced (particularly after the acquisition of independent sitting), so did their agency for action. Specifically, infants were more likely than their mothers to initiate orientation transitions and increasingly engaged in object placement behaviors. Moreover, the time that infants spent in independent sitting uniquely predicted the observed changes in dyadic positioning and infants' actions with objects, independent of age.

The current study also provides the literature with new methodological avenues for the measurement and quantification of how infants and caregivers organize the physical spaces in which they interact. Our application of an interval-based coding system (which quantified behavior *across* the duration of each interval) allowed for efficient coding of complex behaviors from video. Moreover, our approach captured several interconnected behaviors (from infants and mothers) at multiple levels simultaneously (e.g., dyadic co-orientation, density counts).

Infants increasingly shape the co-construction of interaction spaces

To illustrate the increasing complexity of dyadic interactions across the first year of life and highlight each of our key findings, we provide a detailed account of one dyad's (#10 in Figure 4a) interactions across the four sessions. Play at 3 months was heavily structured by the mother. She placed the infant supine and faced her infant from above, dangling a single ring from the stacker. The mother continued this pattern of play for long stretches of intervals, occasionally swapping out one ring for another, but never changing her relative position. At 6 months, the infant was not yet able to sit independently and so the mother used the pillow we provided to support a sitting posture and orient the infant to be facing. Two transitions occurred (both initiated by the mother) that resulted in a brief switch to right angles and then back to facing. The transition resulted in an increased number of objects as the mother moved her infant after opening the puzzle ball and tumbling out the shapes inside.

By 9 months, the infant could sit independently and often transitioned to all fours and subsequently back to sitting. Fourteen orientation transitions occurred (most often to or from right angles), eight of which (57%) were initiated by the infant as a result of a transition in posture. Finally, at 12 months, the content of dyadic interaction was most complex. The infant switched postures, moved objects, and initiated nearly all of the orientation transitions. The dyad accumulated 13 transitions but never faced one another. Instead, they spent most of their time at right angles and occasionally switched to be back-to-front or facing different directions.

It is clear from the example above that the physical context of dyadic interaction was scaffolded to meet infants' developmental level, and this is consistent with our findings at the group level. For example, at 3 months, while infants were predominantly supine (see Figure 3), mothers' behaviors allowed the dyad to achieve shared attention to objects and each other's faces despite the infant not yet having the capacity to initiate these moments (e.g., Fogel et al., 1993; de Barbaro et al., 2006). Instead, as infants got older and acquired more advanced postural skills, they were able to contribute to and shape the context of dyadic interactions more readily. Infants initiated more transitions between orientations and increasingly brought objects into and out of the interaction space. Finally, the striking increase in the average number of objects available for play underscores the increasing complexity of dyadic interaction across the first year.

Posture is a time-varying predictor of dyadic positioning and object actions

Our longitudinal results on infant posture replicated existing findings in the literature (Franchak, 2019; Leezenbaum & Iverson, 2019; Thurman & Corbetta, 2017). In general, we found a shift from time spent mostly supine and supported sitting to a majority of time in independent sitting during play (see Figure 3). We did not observe much time in prone or upright postures, but this is likely due to our context for interaction. Infants were always free to move and adopt whichever posture they chose as we did not constrain their actions in any way. However, it is likely that the objects in our toy set did not entice locomotion as other objects might (e.g., strollers, poppers; Hoch et al., 2019).

The real-time repercussions of postural advances may serve as a developmental conduit for learning across domains. Indeed, infants' evolving repertoires for action appear to spill over into their interactions with caregivers which in turn, result in new opportunities for development (see Iverson, 2021). When infants sit independently, for example, they are able to explore objects in more sophisticated ways (Soska et al., 2014), are more likely to receive opportunities for cognitive stimulation from their caregivers (Kretch et al., 2022), and more frequently engage in joint attention (Franchak et al., 2018). Thus, it is not surprising that research has uncovered longitudinal relations between sitting, spatial memory, and language (spatial and receptive; Libertus & Violi, 2016; Oudgenoeg-Paz et al., 2015).

In our case, sitting modulated the physical properties of dyadic interaction: infants' use of independent sitting in real time uniquely predicted the proportion of intervals that dyads spent at right angles and infants' propensity to initiate object placements, above and beyond the effects of age. Research has previously documented associations between sitting and 90-degree body reorientations via posture transitions (Soska et al., 2015) and demonstrated that sitting equips infants with increased efficiency for object exploration (Marcinowski et al., 2019; Rochat & Goubet, 1995). We add to this literature by showing direct links between the use of sitting in real time and the physical organization of the dyadic interaction space, perhaps in part due to the corresponding increase in posture transitions (see Figure 3d). Moreover, our findings also demonstrate that sitting supports infants' object actions that introduce or remove objects from the immediate interaction space (e.g., pushing, throwing).

Thus, while mothers were primarily responsible for object placements at younger ages, often bringing the same single object in and out of the space; infants became active partners in retrieving and removing objects and determined (along with their mothers) the increasing number of objects available for play.

Our results suggest that dyads spend relatively little time back-to-front or facing different directions during object play, regardless of infant age (see Figure 4). This differs from previous work which documented an abundance of time spent in the back-to-front position in very young infants during a laboratory task in which dyads were asked to explore pairs of objects (e.g., Frank et al., 2013). This is likely due to differences in the interactive context. Our observations occurred in the home, where mothers had access to familiar surfaces to place their infants (e.g., on blankets, soft rugs, or even the couch) and a large set of interactive toys. Moreover, at younger ages, roughly half of the mothers in our sample elected to use the Boppy pillow we provided to support their infants in a lying or sitting posture, and as a result, spent more time in the facing position. It may be that the use of such infant-support structures—presumably common pieces of furniture found in the home—serve as a way for caregivers to support face-to-face interactions before infants are able to sit on their own, thereby enriching the dyadic environment during play. This seemingly everyday practice may indicate an important access point when creating parent-led interventions for infants with motor delays and physical impairments (see Lobo et al., 2013 for a relevant review).

Limitations and future directions

Several limitations warrant mention when interpreting the results of this study. First, our findings were drawn from videos of 5 minutes of dyadic play with objects. And while comparable with existing studies in the literature (Fogel et al., 1993, 1999, 5 minutes; Deák et al., 2014, 7-10 minutes; de Barbaro et al., 2016, 3 minutes), this short duration does not equate to the daylong repertoires of action and interaction between infants and their mothers. Second, although a strength of this study was its use of a standard toy set to allow for precise measurement of how dyads populated interaction spaces with objects, curated toy sets do not represent the breadth of everyday object play. Objects are plentiful and often strewn about floors or tucked away in containers (Herzberg et al., 2022); as such, the embodied properties measured in this study may only generalize to predominantly stationary (and seated) object play. Future studies should examine dyadic positioning in other contexts (e.g., while infants engage in locomotion during everyday activities at home) to further assess how dyads spontaneously position themselves and how this shapes social interaction. Third, our sample exclusively consisted of mother-infant dyads from predominantly White and highly educated sociocultural backgrounds. Future work should extend these measures to samples of fathers and other primary caregivers with more representative demographic composition.

Despite these limitations, a major strength of this study was its use of densely sampled, longitudinal video observations of dyadic interactions during free-flowing object play in the home. While many studies of dyadic interaction have relied on structured contexts with posture and position constrained (e.g., Beebe et al., 2016; Cohn & Tronick, 1987; Jaffe et al., 2001; etc.), the current findings represent a first step in systematically quantifying the physical properties of unconstrained interactions between infants and their mothers. We demonstrated the feasibility of overlaying such a coding system on existing studies of dyadic interaction that have typically focused on infants' and mothers' social behaviors in the absence of concurrent information on physical context. Additional research is needed to bridge the gap between these developing domains and integrate these measures with commonly assessed aspects of communication (e.g., gaze, vocalization, and their coordination; see Northrup & Iverson, 2019, 2020) to examine whether and how the behaviors measured here shape dyads' social interactions.

Conclusions

Dyadic interactions are complex, occur on multiple timescales, and are shaped by behavior across multiple domains. In this study, we showed that the embodied properties of object play help determine how interactions are physically organized and unfold over time. Dyads progressively occupied broader interaction spaces that contained larger numbers of possible objects for play. And infants' postural development, particularly the use of independent sitting in real time, predicted change in dyadic co-orientation and infants' actions with objects. Taken together, our findings highlight the role of these understudied features in the development of dyadic interaction and the need for additional research elucidating their contributions to social and communicative behaviors during dyadic exchanges.

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References

Adolph KE, & Berger SE (2015). Physical and motor development. In Bornstein MH & Lamb ME (Eds.), Development science: An advanced textbook (7ed., pp. 261–333). New York: Psychology Press/Taylor & Francis.

Adolph KE, Cole WG, Komati M, Garciaguirre JS, Badaly D, Lingeman JM, Chan GLY, & Sotsky RB (2012). How do you learn to walk? Thousands of steps and dozens of falls per day. Psychological Science, 23(11), 1387–1394. 10.1177/0956797612446346 [PubMed: 23085640]

Adolph KE, & Hoch JE (2019). Motor development: Embodied, embedded, enculturated, and enabling. Annual Review of Psychology, 70(1), 141–164. doi:10.1146/annurev-psych-010418-102836

Adolph KE, Karasik LB, & Tamis-LeMonda CS (2010). Motor Skill. In Bornstein MH (Ed.), Handbook of cultural developmental science (pp. 61–88). Psychology Press.

Bakeman R, & Adamson LB (1984). Coordinating attention to people and objects in mother-infant and peer-infant interaction. Child Development, 55, 1278–1289. 10.2307/1129997 [PubMed: 6488956]

Bakeman R, & Gottman JM (1997). Observing interaction: An introduction to sequential analysis (2nd ed.). Cambridge University Press. 10.1017/CBO9780511527685

Bates D, Mächler M, Bolker B, & Walker S (2015). Fitting linear mixed-effects models using lme4. Journal of Statistical Software, 67(1), 1–48. doi:10.18637/jss.v067.i01

Beebe B, Messinger DS, Bahrick LE, Margolis A, Buck KA, & Chen H (2016). A systems view of mother-infant face-to-face communication. Developmental Psychology, 52, 556–571. 10.1037/a0040085 [PubMed: 26882118]

Campos JJ, Anderson DI, Barbu-Roth MA, Hubbard EM, Hertenstein MJ, & Witherington D (2000). Travel broadens the mind. Infancy, 1(2), 149–219. 10.1207/S15327078IN0102_1 [PubMed: 32680291]

Campos JJ, Kermoian R, & Zumbahlen MR (1992). Socioemotional transformations in the family system following infant crawling onset. New Directions for Child and Adolescent Development, 1992(55), 25–40. 10.1002/cd.23219925504

Cohn J, & Tronick E (1987). Mother-infant face-to-face interaction: The sequence of dyadic states at 3, 6, and 9 months. Developmental Psychology, 23, 68–77. 10.1037/0012-1649.23.1.68

Curran D, Bacchi M, Schmitz SF, Molenberghs G, & Sylvester RJ (1998). Identifying the types of missingness in quality of life data from clinical trials. Statistics in Medicine, 17(5-7), 739–756. 10.1002/(sici)1097-0258(19980315/15)17:5/7<739::aid-sim818>3.0.co;2-m [PubMed: 9549820]

de Barbaro K, Johnson CM, Forster D, & Deák GO (2016). Sensorimotor decoupling contributes to triadic attention: A longitudinal investigation of mother-infant-object interactions. Child Development, 87, 494–512. 10.1111/cdev.12464 [PubMed: 26613383]

Deák GO, Krasno AM, Triesch J, Lewis J, & Sepeta L (2014). Watch the hands: Infants can learn to follow gaze by seeing adults manipulate objects. Developmental Science, 17, 270–281. 10.1111/desc.12122 [PubMed: 24387193]

Fogel A, Dedo JY, & McEwen I (1992). Effect of postural position and reaching on gaze during mother-infant face-to-face interaction. Infant Behavior and Development, 15, 231–244. 10.1016/0163-6383(92)80025-P

Fogel A, Nwokah E, Hsu H-C, Dedo JY, & Walker H (1993). Posture and communication in mother-infant interaction. In Savelsbergh GJP (Ed.), The development of coordination in infancy (pp. 395–422). North-Holland/Elsevier Science Publishers. 10.1016/S0166-4115(08)60961-9

Fogel A, Messinger DS, Dickson KL, & Hsu HC (1999). Posture and gaze in early mother-infant communication: Synchronization of developmental trajectories. Developmental Science, 2, 325–332. 10.1111/1467-7687.00078

Frank M, Simmons K, Yurovsky D, & Pusiol G (2013). Developmental and postural changes in children’s visual access to faces. In Proceedings of the 35th Annual Meeting of the Cognitive Science Society.

Franchak JM (2019). Changing opportunities for learning in everyday life: Infant body position over the first year. Infancy, 24, 187–209. 10.1111/infa.12272 [PubMed: 32677202]

Franchak JM, Kretch KS, & Adolph KE (2018). See and be seen: Infant-caregiver social looking during locomotor free play. Developmental Science, 21(4), 1–13. 10.1111/desc.12626

Heiman CM, Cole WG, Lee DK, Adolph KE (2019). Object interaction and walking: Integration of old and new skills in infant development. Infancy. 24(4):547–569. doi:10.1111/infa.12289 [PubMed: 31244556]

Herzberg O, Fletcher KK, Schatz JL, Adolph KE, & Tamis-LeMonda CS (2022). Infant exuberant object play at home: Immense amounts of time-distributed, variable practice. Child Development, 93, 150–164. 10.1111/cdev.13669 [PubMed: 34515994]

Hoch JE, O’Grady SM, & Adolph KE (2019). It’s the journey, not the destination: Locomotor exploration in infants. Developmental Science, 22(2), 1–12. 10.1111/desc.12740

Hoch JE, Ossmy O, Cole WG, Hasan S & Adolph KE (2021), “Dancing” Together: Infant–Mother Locomotor Synchrony. Child Development, 92: 1337–1353. 10.1111/cdev.13513 [PubMed: 33475164]

Huttenlocher J, Haight W, Bryk A, Seltzer M, & Lyons T (1991). Early vocabulary growth: Relation to language input and gender. Developmental Psychology, 27, 236 248. 10.1037/0012-1649.27.2.236

Iverson JM (2021). Developmental variability and developmental cascades: Lessons from motor and language development in infancy. Current Directions in Psychological Science, 30(3), 228–235. 10.1177/0963721421993822 [PubMed: 34194130]

Jaffe J, Beebe B, Feldstein S, Crown CL, Jasnow MD, Rochat P, & Stern DN (2001). Rhythms of dialogue in infancy: Coordinated timing in development. Monographs of the Society for Research in Child Development, 66, 1–132.

Jarvis EN, West KL, & Iverson JM (2020). Object exploration during the transition to sitting: A study of infants at heightened risk for autism spectrum disorder. Infancy, 25(5), 640–657. 10.1111/infa.12341 [PubMed: 32857443]

Karasik LB, Tamis-LeMonda CS, & Adolph KE (2011). Transition from crawling to walking and infants' actions with objects and people. Child Development, 82(4), 1199–1209. 10.1111/j.1467-8624.2011.01595 [PubMed: 21545581]

Kretch KS, Franchak JM, & Adolph KE (2014). Crawling and walking infants see the world differently. Child Development, 85(4), 1503–1518. 10.1111/cdev.12206 [PubMed: 24341362]

Kretch KS, Koziol NA, Marcinowski EC, Kane AE, Inamdar K, Brown ED, Bovaird JA, Harbourne RT, Hsu L-Y, Lobo MA, & Dusing SC (2022). Infant posture and caregiver-provided cognitive opportunities in typically developing infants and infants with motor delay. Developmental Psychobiology, 64,e22233. 10.1002/dev.22233 [PubMed: 35050510]

Kuznetsova A, Brockhoff P, & Christensen R (2017). lmerTest Package: Tests in linear mixed effects models. Journal of Statistical Software, 82(13), 1–26. doi:10.18637/jss.v082.i13

Leezenbaum NB, & Iverson JM (2019). Trajectories of posture development in infants with and without familial risk for autism spectrum disorder. Journal of Autism and Developmental Disorders, 49(8), 3257–3277. doi:10.1007/s10803-019-04048-3 [PubMed: 31079276]

Libertus K, & Violi DA (2016). Sit to talk: Relation between motor skills and language development in infancy. Frontiers in Psychology, 7, Article 475. 10.3389/fpsyg.2016.00475 [PubMed: 27065934]

Lobo MA, Harbourne RT, Dusing SC, & McCoy SW (2013). Grounding early intervention: Physical therapy cannot just be about motor skills anymore. Physical Therapy, 93(1), 94–103. 10.2522/ptj.20120158 [PubMed: 23001524]

Long BL, Sanchez A, Kraus AM, Agrawal K, & Frank MC (2022). Automated detections reveal the social information in the changing infant view. Child Development, 93(1), 101–116. 10.1111/cdev.13648 [PubMed: 34787894]

Marcinowski EC, Tripathi T, Hsu LY, Westcott McCoy S, & Dusing SC (2019). Sitting skill and the emergence of arms-free sitting affects the frequency of object looking and exploration. Developmental Psychobiology, 61(7), 1035–1047. [PubMed: 31012090]

Northrup JB, & Iverson JM (2019). The development of mother-infant coordination across the first year of life. Developmental Psychology, 56(2), 221. 10.1037/dev0000867 [PubMed: 31750669]

Northrup JB, & Iverson JM (2020). Multimodal coordination of vocal and gaze behavior in mother-infant dyads across the first year of life. Infancy. 25:952–972. 10.1111/infa.12369 [PubMed: 33063950]

Oudgenoeg-Paz O, Leseman PP, & Volman MC (2015). Exploration as a mediator of the relation between the attainment of motor milestones and the development of spatial cognition and spatial language. Developmental Psychology, 51(9), 1241–1253. 10.1037/a0039572 [PubMed: 26192037]

Pereira AF, Smith LB, & Yu C (2014). A bottom-up view of toddler word learning. Psychonomic Bulletin & Review, 21(1), 178–185. [PubMed: 23813190]

Raudenbush SW, & Bryk AS (2002). Hierarchical linear models: Applications and data analysis methods (Vol. 1). Thousand Oaks, CA:Sage.

Rochat P & Goubet N (1995). Development of sitting and reaching in 5-to-6-month-old infants. Infant Behavior and Development, 18, 53–68.

Roemer EJ, Kushner EH, & Iverson JM (2021). Joint engagement, parent labels, and language development: Examining everyday interactions in infant siblings of children with autism. Journal of Autism and Developmental Disorders. doi: 10.1007/s10803-021-05099-1

Soska KC, & Adolph KE (2014). Postural position constrains multimodal object exploration in infants. Infancy, 19(2), 138–161. 10.1111/infa.12039 [PubMed: 24639621]

Soska KC, Adolph KE, & Johnson SP (2010). Systems in development: Motor skill acquisition facilitates three-dimensional object completion. Developmental Psychology, 46, 129–138. [PubMed: 20053012]

Soska KC, Robinson SR, & Adolph KE (2014). A new twist on old ideas: How sitting reorients crawlers. Developmental Science, 18(2), 206–218. doi:10.1111/desc.12205 [PubMed: 25041056]

Thurman SL, & Corbetta D (2017). Spatial exploration and changes in infant-mother dyads around transitions in infant locomotion. Developmental Psychology, 53(7), 1207–1221. [PubMed: 28459258]

Thurman SL, & Corbetta D (2019). Changes in posture and interactive behaviors as infants progress from sitting to walking: A longitudinal study. Frontiers in Psychology, 10. doi:10.3389/fpsyg.2019.00822

Tomasello M, & Farrar MJ (1986). Joint attention and early language. Child Development, 57(6), 1454–1463. 10.2307/1130423 [PubMed: 3802971]

West KL, & Iverson JM (2021). Communication changes when infants begin to walk. Developmental Science, 24(5). doi:10.1111/desc.13102

Willett JB, Singer JD, & Martin NC (1998). The design and analysis of longitudinal studies of development and psychopathology in context: Statistical models and methodological recommendations. Development and Psychopathology, 10(2), 395–426. [PubMed: 9635230]

Yale ME, Messinger DS, Cobo-Lewis AB, & Delgado CF (2003). The temporal coordination of early infant communication. Developmental Psychology, 39(5), 815–824. 10.1037/0012-1649.39.5.815 [PubMed: 12952396]

Yamamoto H, Sato A, & Itakura S (2019). Eye tracking in an everyday environment reveals the interpersonal distance that affords infant-parent gaze communication. Scientific Reports, 9(1). doi:10.1038/s41598-019-46650-6

Yamamoto H, Sato A, & Itakura S (2020). Transition from crawling to walking changes gaze communication space in everyday infant-parent interaction. Frontiers in psychology, 10, 2987. 10.3389/fpsyg.2019.02987 [PubMed: 32116864]

Yu C, & Smith LB (2012). Embodied attention and word learning by toddlers. Cognition, 125(2), 244–262. [PubMed: 22878116]

Research Highlights

- Mother-infant dyads reorganized the physical arrangement of their bodies during object play, progressively adopting a broader spatial co-orientation across the first year of life.
- Mothers initially shaped the organization of interaction, but across their first year, infants increasingly altered positioning and placed objects in and out of the space.
- Advances in infants' postural skills, specifically time spent in independent sitting, uniquely predicted developmental change in dyadic positioning and infants' object actions, independent of age.

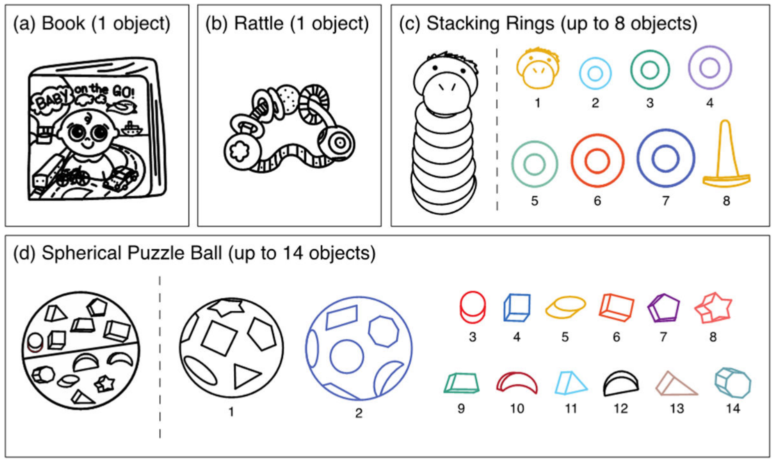

Figure 1.
Line drawings of the standard toy set provided to mother-infant dyads at each home observation. A total of 24 individual objects were possible for play: (a) a book, (b) a rattle, (c) a set of stacking rings with eight unique components, and (d) a spherical puzzle ball with 14 unique components.

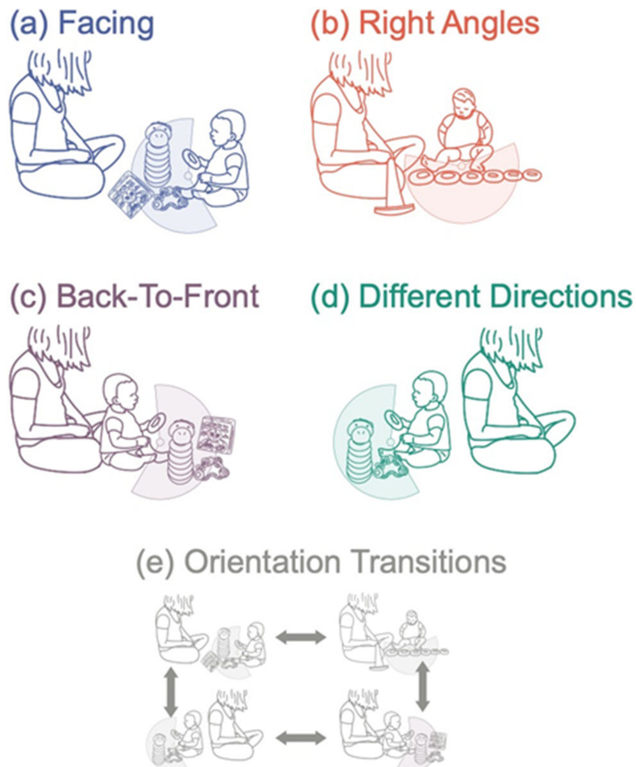

Figure 2.

Line drawings depicting the five possible orientation types identified for coding of dyadic positioning. Orientations are color-coded: blue = facing; orange = right angles; purple = back-to-front; green = different directions; and grey = transitions between orientations. The shaded regions denote the conceptual criteria used to determine infants' presumed wingspans (i.e., a reach radius depicted as an open fan radiating from the infant as its midpoint).

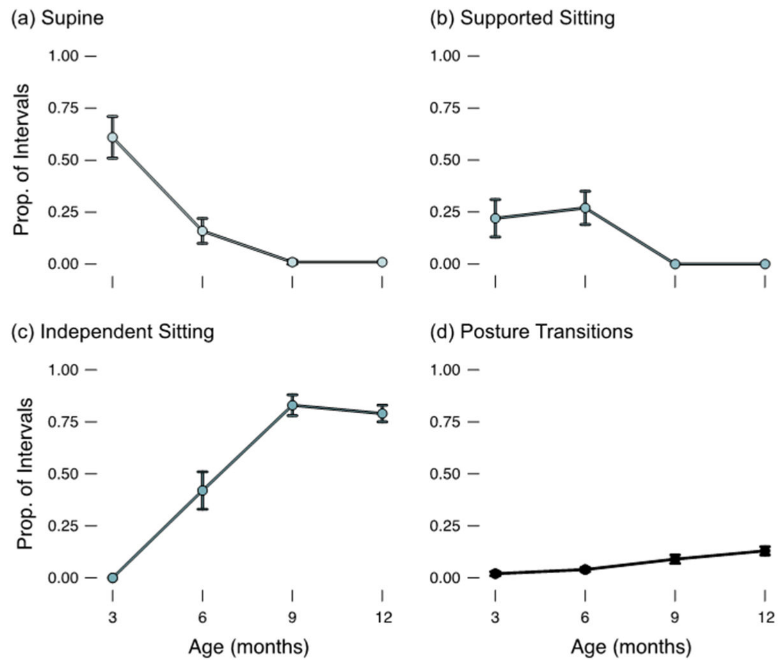

Figure 3.

Longitudinal trajectories of infant posture. Each growth model displays developmental change in the proportion of intervals infants spent: (a) supine (lying on their backs); (b) supported sitting (with help from mothers, the Boppy pillow, or with their own hands); (c) independent sitting (with hands off the ground); or (d) transitioning between postures (e.g., from prone to sitting). Error bars show standard errors.

Figure 4.

Data on dyadic positioning across the first year of life. The raster plot in panel (a) presents individual timelines for each mother-infant dyad's co-orientations across sixty, 5-second intervals spanning a total of five minutes of play. The data represent both the real-time fluctuations of dyadic co-orientation between each 5-second interval within a session and change in patterns of orientations across sessions. Each row displays data from a single dyad's sessions, and the white bars represent missing sessions. Orientations for each interval are color-coded, and the line drawings in panel (b) serve as a legend. Each color represents an orientation: blue = facing; orange = right angles; purple = back-to-front; green = different directions; and grey = transitions between orientations. Panel (c) highlights patterns of longitudinal change with proportional data for each orientation type. Error bars show standard errors.

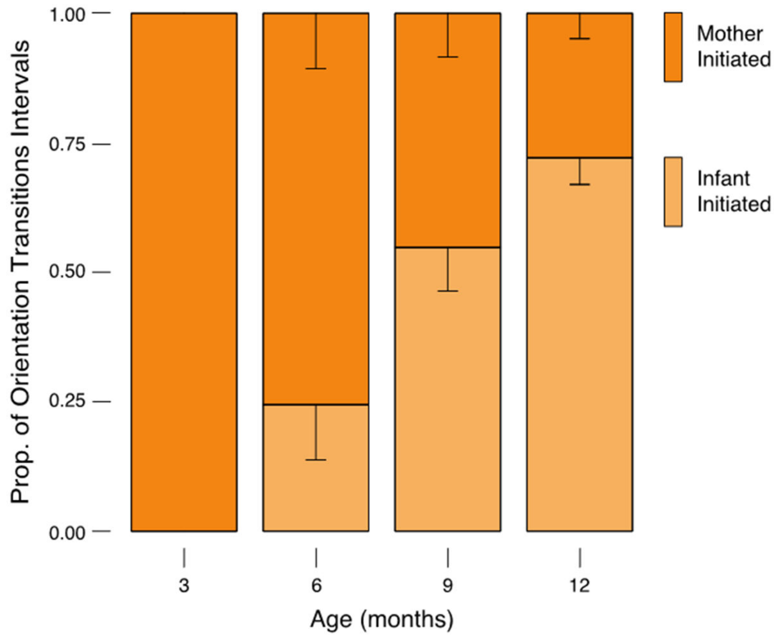

Figure 5.

Proportional data depicting which partner initiated the transitions between orientation types. Mothers (dark orange bars) decreased in their initiations over time, whereas infants (light orange bars) increased. Error bars show standard errors.

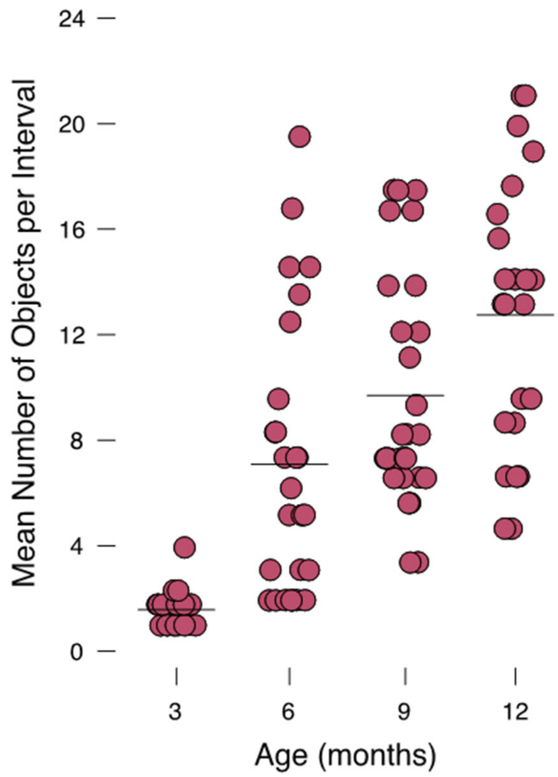

Figure 6.

Mean number of objects per interval available for play in dyads' interaction spaces. Symbols represent individual data for each dyad and horizontal lines describe group means.

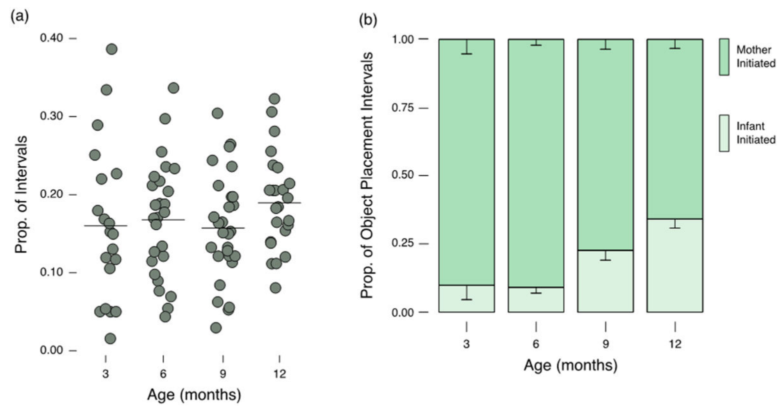

Figure 7.

Data on object placement behaviors. Panel (a) shows the proportion of intervals containing a placement (regardless of initiator). Symbols represent individual data for each dyad and horizontal lines describe group means. Panel (b) presents proportional data on whether mothers (dark green bars) or infants (light green bars) initiated object placements. Error bars show standard errors.

Table 1

Descriptive statistics for all measures of dyadic interaction.

	Age			
	3 (n = 20)	**6 (n = 26)**	**9 (n = 28)**	**12 (n = 24)**
Measure (*M*, *SD*)				
Prop. of intervals in each posture				
Supine	0.61 (0.45)	0.16 (0.29)	0.01 (0.04)	0.01 (0.02)
Prone	0.00 (0.00)	0.04 (0.15)	0.05 (0.13)	0.02 (0.02)
Supported sitting	0.22 (0.38)	0.27 (0.41)	0.00 (0.00)	0.00 (0.00)
Independent sitting	0.00 (0.00)	0.42 (0.47)	0.83 (0.25)	0.79 (0.20)
Upright	0.02 (0.04)	0.01 (0.06)	0.01 (0.03)	0.04 (0.08)
Held	0.13 (0.32)	0.05 (0.17)	0.02 (0.09)	0.02 (0.06)
Posture transitions	0.02 (0.04)	0.04 (0.06)	0.09 (0.11)	0.13 (0.12)
Prop. of intervals in each orientation type				
Facing	0.73 (0.44)	0.64 (0.43)	0.39 (0.44)	0.22 (0.30)
Right angles	0.24 (0.41)	0.27 (0.39)	0.46 (0.42)	0.55 (0.34)
Back-to-front	0.03 (0.13)	0.06 (0.23)	0.06 (0.16)	0.07 (0.12)
Different directions	0.00 (0.00)	0.00 (0.00)	0.02 (0.05)	0.06 (0.11)
Orientation transitions				
Prop. of intervals	0.01 (0.02)	0.02 (0.04)	0.07 (0.10)	0.10 (0.08)
Prop. infant-initiated	0.00 (0.00)	0.24 (0.34)	0.55 (0.31)	0.72 (0.21)
Object density				
Mean number of objects	1.57 (1.44)	7.09 (5.94)	9.69 (5.71)	12.75 (7.34)
Object placement				
Prop. of intervals	0.16 (0.10)	0.17 (0.07)	0.16 (0.07)	0.19 (0.06)
Prop. infant-initiated	0.10 (0.24)	0.09 (0.11)	0.23 (0.19)	0.34 (0.16)

Table 2

HLM models of change: Longitudinal growth for all measures of dyadic interaction.

Measure	Parameter	Coeff.	SE
Prop. of intervals in each posture			
Supine	Intercept, β_{00}	0.65 ***	0.10
	Linear Growth, β_{10}	−0.19 ***	0.03
	Quadratic Growth, β_{20}	0.01 ***	0.002
Supported sitting	Intercept, β_{00}	0.30 ***	0.07
	Linear Growth, β_{10}	−0.04 **	0.01
Independent sitting	Intercept, β_{00}	−0.03	0.05
	Linear Growth, β_{10}	0.21 ***	0.03
	Quadratic Growth, β_{20}	−0.01 ***	0.004
Posture transitions	Intercept, β_{00}	0.02	0.01
	Linear Growth, β_{10}	0.01 ***	0.003
Prop. of intervals in each orientation type			
Facing	Intercept, β_{00}	0.78 ***	0.08
	Linear Growth, β_{10}	−0.06 ***	0.01
Right angles	Intercept, β_{00}	0.21 **	0.07
	Linear Growth, β_{10}	0.04 **	0.01
Back-to-front	Intercept, β_{00}	0.06 **	0.02
Different directions	Intercept, β_{00}	0.02 **	0.01
Orientation transitions			
Prop. of intervals	Intercept, β_{00}	0.001	0.01
	Linear Growth, β_{10}	0.01 ***	0.002
Object density			
Mean number of objects	Intercept, β_{00}	1.85 **	0.58
	Linear Growth, β_{10}	1.81 ***	0.40
Object placement			
Prop. of intervals	Intercept, β_{00}	0.17 ***	0.01
Prop. infant-initiated	Intercept, β_{00}	0.05	0.03
	Linear Growth, β_{10}	0.03 ***	0.01

* $p < .05$

** $p < .01$

*** $p < .001$

Table 3

HLM models of change: Independent sitting as a time-varying predictor of dyadic interaction.

Measure	Parameter	Coeff.	SE
Independent sitting & orientation type			
Facing	Intercept, β_{00}	0.79***	0.08
	Age, β_{10}	−0.05**	0.02
	Sitting, β_{11}	−0.08	0.13
Right angles	Intercept, β_{00}	0.17*	0.07
	Age, β_{10}	0.01	0.02
	Sitting, β_{11}	0.27*	0.12
Independent sitting & object density			
Mean number of objects	Intercept, β_{00}	2.03***	0.54
	Age, β_{10}	1.06***	0.19
	Sitting, β_{11}	1.79	1.54
Independent sitting & object placement			
Prop. infant-initiated	Intercept, β_{00}	0.06	0.04
	Age, β_{10}	0.04***	0.01
	Sitting, β_{11}	0.11*	0.05

* $p < .05$

** $p < .01$

*** $p < .001$