HHS Public Access
Author manuscript
Infancy. Author manuscript; available in PMC 2021 September 01.

Published in final edited form as:
Infancy. 2020 September ; 25(5): 640–657. doi:10.1111/infa.12341.

Object Exploration During the Transition to Sitting: A Study of Infants at Heightened Risk for Autism Spectrum Disorder

Erin N. Jarvis, **Kelsey L. West**, **Jana M. Iverson**
University of Pittsburgh

Abstract

Learning to sit promotes infants' object exploration because it offers increased access to objects and an improved position for exploration (e.g., Rochat & Goubet, 1995; Soska & Adolph, 2014). Infants at heightened risk (HR) for autism spectrum disorder (ASD) exhibit delays in sitting and differences in object exploration. However, little is known about the *association* between sitting and object exploration among HR infants. We examined changes in object exploration as HR infants (N = 19) and comparison infants with no family history of ASD (Low Risk; LR; N = 23) gained experience sitting independently. Infants were observed monthly from 2.5 months until one month after the onset of independent sitting. At 12, 18, 24, and 36 months, infants completed standardized developmental assessments, and HR infants were assessed for ASD symtoms at 36 months. Although HR infants began sitting later than LR infants, both groups increased time spent grasping, shaking, banging, and mouthing objects as they gained sitting experience. Groups only differed in time spent actively mouthing objects, with LR infants showing a greater increase in active mouthing than HR infants. Findings suggest that HR infants experience a similar progression of object exploration across sitting development, but on a delayed timescale.

When infants hold objects, they learn about them by visually and manually exploring their properties. Infants turn objects in their hands, feel their texture with their fingers, mouth them, and view them from multiple angles. A rich body of work indicates that in neurotypical development, object exploration is a means by which infants discover the surrounding world and acquire new knowledge (e.g., Berthier & Keen, 2006; Rochat, 1989; Ruff, 1984). Notably, the onset of independent sitting brings new opportunities for infants to explore objects. With their hands and arms free while in a sitting posture, infants are able to deploy and refine new object exploration skills (Marcinowski, Tripathi, Hsu, Westcott McCoy & Dusing, 2019; Rochat & Goubet, 1995; Sacrey et al., 2013; Soska & Adolph, 2014).

Growing evidence indicates that motor development is delayed among infants who are at heightened risk (HR) for developing autism spectrum disorder (ASD) by virtue of having an affected older sibling (e.g., Garrido, Petrova, Watson, Garcia-Retamero & Carballo, 2017; Ozonoff et al., 2011; West, 2018). Indeed, both sitting and object exploration skills may be

Address correspondence to: Jana M. Iverson, Department of Psychology, University of Pittsburgh, 3415 Sennott Square, 210 S. Bouquet St., Pittsburgh, PA 15260, jiverson@pitt.edu, Phone: 412.624.6160.
Kelsey L. West is now at the Department of Psychology, New York University.

The authors report no conflicts of interest with regard to the funding source for this study.

affected. Studies have separately reported differences in object exploration and later attainment of independent sitting among HR infants compared to infants with no family history of ASD (Low Risk; LR; Di Cesare et al., 2017; Kaur, Srinivasan & Bhat, 2015; Libertus & Landa, 2014; Libertus, Sheperd, Ross & Landa, 2014; Landa & Garrett-Mayer, 2006; Leonard, Elsabbagh, Hill & the BASIS team, 2013; Ozonoff et al., 2008; Leezenbaum & Iverson, 2019; Nickel, Thatcher, Keller, Wozniak & Iverson, 2013). In this study, we examined object exploration development during the transition to independent sitting in HR infants and a comparison group of LR infants.

Object Exporation and Sitting in Neurotypical Development

Object exploration encompasses a variety of behaviors, including mouthing, visual inspection, grasping, and finger manipulation. These behaviors appear as early as 2 months and become increasingly complex, coordinated, and multimodal over time (Berthier & Keen, 2006; Rochat, 1989; Ruff, 1984). Mouthing allows infants to explore various textures and tastes. Looking cultivates perceptual abilities through exposure to various patterns, shapes, and colors. Manual manipulation allows infants to explore texture, three-dimensional shape, and weight through actions like grasping, lifting, fingering, and turning. All of these actions provide multiple, dynamic angles from which to view objects and support the initiation of social bids with others (Bornstein, Tamis-Lemonda, Hahn, & Haynes, 2008).

Understanding the developmental progression of object exploration is critical in light of its links to cognitive development. Advances in object exploration are associated with cognitive advances related to attention, understanding object permanence, and language acquisition (e.g., Fenson, Kagan, Kearsley, & Zelazo, 1976; Gottwald, Achermann, Marciszko, Lindskog, & Gredebäck, 2016; Gredebäck & Falck-Ytter, 2015; Sacrey et al., 2013; Sommerville, Woodward & Needham, 2005). For example, multimodal exploration of objects (i.e., simultaneously looking and touching) is related to advances in perceptual development (Soska, Adolph, & Johnson, 2010). Additionally, infants' object exploration influences their social interactions and language input from caregivers. Caregivers are sensitive responders to infant actions, and they tend to talk about objects as infants hold them. Thus, as infants increasingly explore objects and do so in new ways, they also elicit new forms of language inputs from caregivers (West & Iverson, 2017).

Infants' object exploration skills co-develop with independent sitting, which presents new opportunities for infants to explore objects (Rochat & Goubet, 1995). Compared to prone or supine positions, sitting provides an elevated vantage point—a 180-degree panoramic view of the room—enabling visual detection of nearby objects (Rochat, 1989). Additionally, sitting is a more functional posture for reaching and grasping objects. In the prone position, infants must prop themselves up with their elbows or hands, occupying their arms (Soska & Adolph, 2014). In the supine position, infants face the challenge of gravity: they must generate sufficient torque to lift their arms and hold objects in place in their hands (Carvalho, Tudella, & Savelsbergh, 2007). In contrast, sitting upright frees the arms for object exploration.

Indeed, infants display more mature object exploration in sitting compared to other earlier established postures (Carvalho et al., 2007; Out, Van Soest, Savelsbergh, & Hopkins, 1998; Rochat, 1992; Soska & Adolph, 2014; Woods & Wilcox, 2013). For instance, Soska and Adolph (2014) found that while sitting, 5- to 7- month-old infants rotated objects more frequently and performed more coordinated exploratory behaviors (e.g., alternated between mouthing and looking at objects) compared to supine or prone positions.

Object Exploration and Sitting in Infants with Heightened Risk for ASD

The recurrence rate for ASD among HR infants is approximately 18.7% (e.g., Ozonoff et al., 2011), putting them at increased risk of receiving an ASD diagnosis compared to infants with no family history of ASD (Low Risk; LR). Notably, HR infants as a group—even those who do *not* receive an ASD diagnosis—display differences in fine motor skill and object exploration (e.g., Di Cesare et al., 2017; Iverson et al., 2019; Kaur et al., 2015; Libertus & Landa, 2014; Libertus et al., 2014). As early as 6 months, HR infants display reduced bimanual control, grasping, and mouthing relative to LR infants (Bhat, Downing, Galloway, & Landa, 2009; Kaur et al., 2015; Koterba, Leezenbaum, & Iverson, 2014; Libertus & Landa, 2014; Ozonoff et al., 2008). In addition, HR infants show *increased* visual attention to objects (Bhat, Galloway, & Landa, 2010). However, little is known about the development of these differences in object exploration among HR infants.

Differences in object exploration may be influenced at least in part by delays in the development of sitting. On average, HR infants begin sitting later than do LR infants (e.g., Bhat, Galloway, & Landa, 2012; Landa & Garrett-Mayer, 2006; Leonard et al., 2013; Nickel et al., 2013). Further, even after HR infants being sitting, they spend less time in this posture than their LR peers. Nickel et al. (2013) found that total time spent sitting for 6 month-old HR infants was one-third of that for LR infants. In light of the known links between sitting and object exploration in neurotypical development, differences in sitting onset and experience may impact the development of object exploration skills.

The Present Study

While object exploration has been studied in HR infants, it has not yet been investigated in the context of sitting development. In this study, we examined object exploration longitudinally in HR and LR infants at two timeponts: the onset of independent sitting and one month later. Using an object exploration task adapted from previous research (Ruff, 1984), infants were observed interacting with a standard set of toy blocks, and we examined their manual, oral, and visual exploratory actions. In particular, we evaluated changes in: (1) the duration of object exploration; (2) the specific exploratory behaviors utilized by infants when exploring objects; (3) visual attention to objects; and (4) the coordination of object exploration and visual attention. We also analyzed whether these behaviors differed for LR vs. HR infants.

Methods

Participants

Participants included 42 infants who had at least one older sibling. Nineteen infants (11 male) had an older full biological sibling with a diagnosis of ASD and were classified as being at heightened risk (HR) for ASD. Twenty-three infants (16 male) had a neurotypically developing older sibling and no family history of ASD, and were classified as low risk (LR). The ASD diagnosis of the older sibling of each HR infant was verified prior to enrollment by a trained clinician at a university autism center using the Autism Diagnostic Observation Schedule (ADOS; Lord et al., 2000). If the sibling's score met the threshold for ASD on the ADOS, the infant was enrolled in the study. Participants in both groups were born from full-term, uncomplicated pregnancies and were from monolingual, English-speaking households. Thirty-four infants were Caucasian, three were Hispanic, two were African American, and three were multiracial. Parental educational level was comparable between groups. Among parents of HR infants, 73.7% completed a degree at a four-year college or beyond; 7.9% completed an associates degree or some college; and 13.2% completed high school. Among parents of LR infants, 78.3% completed a degree at a four-year college or beyond, and 15.2% completed an associates degree or some college. The present study was conducted according to the guidelines of the Declaration of Helsinki, with written informed consent obtained from a parent for each infant before any assessment or data collection. All procedures involving human subjects in this study were approved by the Institutional Review Board at the University of Pittsburgh. Additionally, the study was conducted in accordance with the ethical standards of the American Psychological Association.

Procedure

Data were collected as part of a larger longitudinal study focused on motor and communicative development in HR and LR infants.

HR and LR infants were visited in their homes every two weeks beginning at 2.5 months of age. At the start of each visit, an experimenter assessed the infants' ability to sit independently. This was done by placing the infant in an upright sitting position and measuring the duration of sitting without support and with hands free to move. If the infant sat for 30 seconds without support, the visit was designated as the "sit onset" visit. Each sitting assessment was terminated when 2 minutes had elapsed and the infant had not met the 30 second criterion. Biweekly visits continued until one month after the sit onset visit. Here we focus on data from the sit onset visit and the visit one month later (post-sit visit).

Follow-up visits were conducted in the home at 12, 18, 24, and 36 months of age. At each follow-up visit, an experimenter administered the Mullen Scales of Early Learning (MSEL; Mullen, 1995) and a parent completed the MacArthur-Bates Communicative Development Inventory (CDI; Fenson et al., 1994). Additionally, at 36 months all HR infants visited the university autism center for outcome assessments conducted by a clinician naive to all previous study data using the ADOS and DSM-IV-TR criteria (American Psychiatric Association, 2000). None of the HR infants in this study received an ASD diagnosis.

Object exploration task—Once infants met criteria for independent sitting (sit onset session), they completed an object exploration task adapted from a previous study of neurotypically developing infants (Ruff, 1984) at each visit. Twelve wooden objects of similar size, all weighing precisely 0.4 oz., were organized into three sets varying in texture, shape, and pattern. Color was randomized throughout these sets (i.e., every set was multi-colored; see Figure 1). Infants sat on a caregiver's lap at a table and were presented with one object at a time for 30 seconds each. Caregivers were directed to allow their infant to explore with the objects without prompting, but they could bring the object within reach if necessary. Because we wished to obtain a complete picture of infants' object exploration skills, and because sitting ability varied across sessions, the task was always presented with infants seated on the caregiver's lap. Infants were videorecorded from the front to ensure visibility of visual, oral, and manual object interaction.

Coding and Data Reduction

Coding was conducted using StopFrameCoding, a software developed to code multiple behaviors organized within specified categories (Libertus, 2013). Behavioral coding procedures were adapted from those previously used by Ruff et al., (1984, 1992) and Libertus, Joh, & Needham (2016). Coders were initially trained to a minimum of 80% agreement on all coding categories for three consecutive videos and were naïve to infants' group membership. After completing training, coders continued to double code 20% of the videos to assess inter-rater reliability and prevent coder drift. Disagreements were resolved through discussion.

Manual object engagement—Coders identified all moments when the infants' hands (one or both) were in contact with the object. Any contact of infants' hand/s with the object, regardless of the action with the object, was classified as *object engagement*. Within these moments, coders further identified moments when the infant was *grasping* the object. Grasping was only coded if the infant held the object with either a whole-hand palmar grasp or a pincer grasp with the thumb and finger. The total durations (in seconds) of overall object engagement and grasping were calculated for each trial.

Coders next viewed moments of object engagement and identified three specific actions: (1) *Inspective actions*, which included fingering and turning the object in hand; (2) *Rhythmic actions*, which included shaking the object in the air repeatedly, or banging the object on the table top repeatedly; and (3) *Mouthing*, which included *active mouthing* (the object touched the lips and tongue and was either moved around with the hands or held in place while the lips or tongue moved around the object) and *passive mouthing* (the object was held stationary on the lips or tongue). From this coding, we calculated the total durations in seconds for each of these behaviors.

Visual attention to objects—In a separate pass through the videos, coders focused on infants' eye gaze and identified moments when their gaze was directed toward the object. We calculated the total duration in seconds of infants' looking at the object.

Coordination of hands and gaze on objects—Finally, we examined the temporal overlap of infants' manual contact and gaze. Using the previous coding, we calculated the duration in seconds of simultaneous looking at the object with manual object engagement (i.e., any time a hand was in contact with the object).

Reliability

Twenty percent of the video clips were independently coded by two trained coders to assess interrater reliability. Video clips were selected to include infants from both groups at both observations. Cohen's kappa was calculated for six different coding categories: object exploration (object engagement and grasping) for the right hand ($\kappa = 0.79$; range = 0.72–0.91) and left hand ($\kappa = 0.85$; range = 0.75–1.00); type of action (inspective and rhythmic actions) for the right hand ($\kappa = 0.88$; range = 0.75–1.00) and left hand ($\kappa = 0.88$; range = 0.75–1.00); mouthing (active and passive; $\kappa = 0.88$; range = 0.76–0.98); and visual attention ($\kappa = 0.79$; range = 0.72–0.90).

Results

This study was designed to assess whether and how object exploration changed with sitting experience in HR and LR infants. Specifically, we examined: (1) duration of overall object engagement; (2) the specific action types infants employed to explore objects; (3) visual attention to objects; and (4) coordination of object engagement and visual attention. All statistical analyses were performed with SPSS software (version 25.0). Descriptive statistics and significant effects for all dependent variables are presented in Table 1.

Preliminary Analyses

Before conducting our primary analyses, we examined whether LR and HR infants differed in the age at which they achieved the independent sitting milestone (sit onset). A one-way ANOVA revealed that HR infants tended to sit about a half month later than LR infants ($M_{\mathrm{HR}} = 6.95$ months, $SD_{HR} = 0.62$; $M_{\mathrm{LR}} = 6.30$ months, $SD_{LR} = 0.81$), $F(1,41) = 8.073$, $p = 0.007$. In light of this difference, age at sit onset was included as a covariate in all subsequent analyses. Additionally, because HR and LR groups differed in their sex composition (the LR group was 69.6% male, and the HR group was 57.9% male), we also included sex as a covariate.

Does the duration of object engagement change with sitting experience?

We first asked whether the duration of object engagement (i.e., any manual contact with objects) changed from the sit onset to post-sit session. These data are displayed for LR and HR groups in Figure 2A, with both groups showing an increase across sessions. At sit onset, infants spent an average of 21 seconds within each of the 30-second trials engaging with objects (i.e., infants touched the objects for around two-thirds of each trial). This increased to 24.5 seconds at the post-sit session. A 2 (Session) × 2 (Risk Group) repeated measures ANOVA revealed a main effect of Session, $F(1,38) = 4.803$, $p = 0.035$, $\eta_p^2 = 0.112$. Neither the main effect of Risk Group nor the interaction term were significant.

Next, we examined whether the duration of grasping changed across sessions. As can be seen in Figure 2B, both groups increased the time they spent grasping objects. At the sit onset session, on average infants grasped the object for 15 seconds in the 30-second trials. At the post-sit session, they increased to 20.5 seconds. A 2 (Session) × 2 (Risk Group) repeated measures ANOVA confirmed a main effect of Session on grasping duration, $F(1,38) = 10.824$, $p = 0.002$ $f^2 = .534$, $\eta_p^2 = 0.222$. Neither the main effect of Risk nor the interaction were significant. Thus, all infants—regardless of risk group—spent progressively more time engaging with and grasping objects with increased sitting experience.

Do the types of object exploration behaviors change with sitting experience?

The next set of analyses focused on types of exploratory behaviors that infants used: inspective actions (fingering, turning objects), rhythmic actions (shaking, banging), and mouthing (actively chewing/moving object in the mouth, passively mouthing).

Inspective actions—Figure 3A shows data on inspective actions for both groups. As can be seen, HR and LR infants spent similar amounts of time engaged in inspective actions. Both groups spent very little time fingering objects—on average, only 0.51 seconds at sit onset and 0.55 seconds at the post-sit session. Infants spent much more time turning the object in hand, with no change apparent across sessions. Infants turned objects for an average of 5.77 seconds at sit onset and 5.57 seconds at the post-sit session. This pattern was confirmed by a 2 (Action Type; finger, turn) × 2 (Session) × 2 (Risk Group) repeated measures ANOVA. There was a main effect of Action Type, revealing that the duration of turning was greater than that for fingering, $F(1, 40) = 78.98$, $p < 0.001$, $\eta_p^2 = 0.705$. There were no other significant effects.

Rhythmic actions—Next, we examined two types of rhythmic actions: shaking objects in the air, and banging them on the tabletop. These data are depicted in Figure 3B, showing that overall, infants increased the durations of rhythmic shaking and banging from sit onset to post-sit. This pattern was supported by a 2 (Action Type: shake, bang) × 2 (Session) × 2 (Risk Group) repeated measures ANOVA, which revealed a main effect of Session, $F(1,38) = 4.45$, $p = 0.042$, $\eta_p^2 = 0.105$. There were no other significant main effects or interaction terms.

Mouthing—Finally, we examined changes in the durations of active and passive mouthing across sessions. These data are presented in Figure 3C. Both groups spent very little time engaged in passive mouthing, and it remained stable across sessions. Active mouthing occurred for much longer durations. Notably, LR and HR infants demonstrated slightly different patterns of active mouthing over time. While both groups increased active mouthing from the sit onset to post-sit session, the increase was amplified for LR infants, who doubled their time spent in active mouthing from 3.4 to 7.2 seconds. In contrast, HR infants spent more time actively mouthing initially (5.2 seconds on average) and increased more modestly to 6.4 seconds. A 2 (Mouthing Type: active, passive) × 2 (Session) × 2 (Risk Group) repeated measures ANOVA revealed a significant three-way interaction between Mouthing Type, Session, and Risk, $F(1,38) = 4.672$, $p = 0.0037$, $\eta_p^2 = 0.090$. There were no other significant effects or interaction terms.

To identify the source of this interaction, we conducted separate ANOVAs for each risk group. For LR infants, the 2 (Action Type: active, passive) × 2 (Session) repeated measures ANOVA revealed main effects of Session, $F(1,22) = 8.679$, $p = 0.007$, $\eta_p^2 = 0.283$, and Mouthing Type, $F(1,22) = 35.019$, $p < 0.001$, $\eta_p^2 = 0.614$. These were qualified by a significant interaction between Session and Mouthing Type, $F(1,22) = 14.423$, $p = 0.001$, $\eta_p^2 = 0.396$. Follow-up pairwise comparisons indicated that for LR infants, active mouthing increased significantly between sessions, $p = 0.002$, but passive mouthing did not, $p = 0.202$.

For HR infants, the 2 (Action Type: active, passive) × 2 (Session) repeated measures ANOVA revealed only a main effect of Action Type, $F(1,18) = 24.124$, $p < 0.001$, $\eta_p^2 = 0.573$., with HR infants engaging in more active than passive mouthing. There was no effect of Session, and no significant interaction between Session and Action Type.

Does visual attention to objects change with sitting experience?

Next, we examined whether HR and LR infants' visual attention to objects changed across sessions. Descriptive statistics are presented in Table 1. Overall, both groups spent a substantial amount of time looking at the objects, with a slight decrease over time. At sit onset, infants spent 13.3 seconds on average looking at objects, and this fell to 10.8 seconds at the post-sit session. A 2 (Session) × 2 (Risk Group) repeated measures ANOVA revealed no significant main effects or interaction terms.

How are visual and manual object engagement coordinated during the transition to sitting?

Finally, we examined the multimodal coordination of visual attention and manual object engagement. That is, how much time did infants spend looking at objects while manually engaging with them? Figure 4 presents the mean durations of object engagement without looking to the object and of object engagement coordinated with looking. Surprisingly, the coordination of object manipulation and gaze decreased slightly over time for both groups. At sit onset, infants spent 9.7 seconds on average coordinating manual action with gaze to the object. At the post-sit session, this decreased slightly to 8.0 seconds. However, manual engagement without gaze to the object increased considerably, from 11.7 to 16.5 seconds across sessions.

This pattern was confirmed by a 2 (Type of Engagement: coordinated manual and visual engagement, manual engagement alone) × 2 (Session) × 2 (Risk Group) repeated measures ANOVA. There were main effects of Type of Engagement, $F(1, 40) = 24.42$, $p < 0.001$, $\eta_p^2 = 0.379$, and Session, $F(1, 40) = 7.23$, $p = 0.01$, $\eta_p^2 = 0.153$, but these were qualified by a significant interaction between Type of Engagement and Session, $F(1, 40) = 18.36$, $p < 0.001$, $\eta_p^2 = 0.315$. Follow-up pairwise comparisons revealed that coordinated looking and manual object engagement decreased across sessions, $p = 0.018$, while manual engagement alone increased, $p < 0.001$. There were no significant effects or interactions related to Risk Group.

Post-hoc power analysis

To assess whether our sample size was sufficient to detect group differences in dependent variables, we conducted a post-hoc power analysis using G*Power 3.1 (Faul, Erdfelder, Buchner & Lang, 2009). The sample size of 42 was used to assess statistical power for a repeated measures ANOVA with two observations (sit onset and post-sit sessions) for two independent samples (HR and LR groups). Using standard criteria, $f^2 = .02$ was considered a small effect size, $f^2 = 0.15$ a medium effect size, and $f^2 = 0.35$ a large effect size (Cohen, 1988). The alpha level for this analysis was $p < 0.05$. Power was 0.99 to detect a large effect, 0.48 for a medium effect, and 0.06 for a small effect. Thus, there was adequate power to detect a moderate to large effect of Risk Group. However, we cannot rule out the possibility that small to medium effects of Risk Group were undetected.

Discussion

Although prior research has described object exploration in HR infants, it has not been studied in the context of sitting development. Doing so is important for two reasons. First, learning to sit supports the development of object exploration (e.g., Marcinowski et al., 2019; Rochat & Goubet, 1995; Soska & Adolph, 2014); Second, HR infants as a group begin to sit later than their LR peers, and this transition may unfold differently for them (e.g., Leezenbaum & Iverson, 2019; Nickel et al., 2013; West, 2018). Our data revealed that all infants—regardless of risk status—demonstrated changes in object exploration behavior as they transitioned from novice to experienced sitting. Notably, HR and LR infants were only differentiated by their mouthing behavior. We discuss these findings in turn.

Object exploration changes with sitting experience

Infants' exploratory actions with objects facilitate learning (e.g., Piaget, 1954; Gibson, 1988). For this reason, researchers have investigated factors that influence object exploration, revealing a developmental link to independent sitting (e.g., Marcinowski et al., 2019; Rochat & Goubet, 1995; Soska & Adolph, 2014). We investigated this link in a sample of infants at heightened risk for ASD who are known to have highly variable profiles of early motor development (e.g., Bhat et al., 2012; Landa & Garrett-Mayer, 2006; Leonard et al., 2013; Leezenbaum & Iverson, 2019). For both groups of infants, the transition from novice to experienced sitting was associated with enhanced object exploration—this was significant above and beyond the effect of chronological age. Infants spent greater amounts of time touching, grasping, shaking, banging, and mouthing objects as they gained sitting experience. Although the scope of these gains was relatively modest (i.e., time spent grasping increased by around 35%, from 15.2 to 20.6 seconds per trial on average), over the course of daily life, an increase of this magnitude is likely to translate into a larger, meaningful difference in time spent exploring toys and other objects.

Contrary to past work, we found no change in the time infants spent exploring objects via coordinated visual and manual actions as they gained sitting experience. In a previous study, Soska and colleagues (2010) reported a significant association between sitting experience and infants' coordination of gaze and manual object exploration. This discrepancy is likely due to differences in sitting ability of the infants in these samples. Infants enrolled in the

Soska et al. study represented a very wide range of sitting skill—including infants with no sitting experience whatsoever, infants who "tripod" sat using their arms for support, and infants who were expert sittters. In the present study, variability in sitting skill was considerably reduced because all infants could sit independently (without arm support) for a full 30 seconds at the first session. Therefore, although our "novice" sitters had newly acquired the skill, they demonstrated comparable base levels of proficiency. It may be that the transition from non-sitting to sitting does indeed correspond to increased visual-manual coordination, but that this increase is attenuated as infants gain additional sitting experience.

Taken together, these findings highlight the role of sitting as a catalyst for a cascade of advances in other behaviors. The emergence of independent sitting creates opportunities for increased object engagement and for the deployment of progressively more sophisticated exploratory actions. Advances in exploratory actions in turn provide infants with greater access to information about objects and their properties. Along these lines, Ruddy & Bornstein (1982) found a strong, positive correlation (.53) between object exploration (e.g., fingering, squeezing, banging) at 4 months and parent-reported vocabulary at 12 months. This finding suggests that infants who more frequently engage in object examination have enhanced opportunity to extract information about object categories that is critical for lexical development (Ruff, 1984).

HR and LR infants demonstrated similar patterns of object exploration

Consistent with past work, HR infants achieved the independent sitting milestone later than LR infants (e.g., Nickel et al., 2013). However, it is important to note the wide variability in onset ages among HR infants: the youngest HR sitter was 5 months old, and oldest was 8.5 months old. Thus, although on average sitting occured later for HR infants, it was well within the typical timeframe for sitting development (e.g., Adolph & Berger, 2006).

Importantly, with one exception, we did not replicate previous findings of differences in object exploration between HR and LR infants (Di Cesare et al., 2017; Koterba et al., 2014; Libertus et al., 2014). The HR infants in this study spent just as much time interacting with objects as their LR peers, and the two groups showed similar patterns of change in exploratory behaviors across sessions. One explanation for this difference in findings may be that whereas prior research has generally compared HR and LR infants at the same chronological ages (e.g., at 6 months; Libertus et al., 2014), our study employed a milestone-based design, with observations anchored by sitting experience. It may be the case that the way in which object exploration changes with the onset of independent sitting in HR infants follows a developmental pattern similar to that observed in LR infants, but it unfolds on a somewhat delayed timescale. Aligning groups on the basis of time relative to sit onset (rather than chronological age) may have eliminated the previously reported group-level differences.

Our data revealed only one difference between groups: LR infants showed a greater increase in active mouthing following sit onset than did HR infants. As noted above, active mouthing involves the mouth moving over the object, or the hands moving the object around the mouth. Prior research has highlighted two important roles served by active mouthing in infant development. One is as an exploratory behavior. Ruff and colleagues (1992) conducted a series of detailed analyses of active vs. other mouthing (akin to our passive mouthing) and reported strong evidence indicating that active mouthing is an exploratory behavior, while passive mouthing is not. Active mouthing declined as a function of familiarization with objects, whereas other mouthing did not. Importantly, active mouthing was immediately followed by looks to the object at rates significantly above chance, and this pattern was not observed for passive mouthing. They interpreted the active mouthing-looking sequence as indicative of infants' focused attention on the object: having detected something interesting about the object during mouthing, attention to the object is sustained via immediate deployment of looking following mouthing.

A second role is in infants' exploration of their own vocal tracts and production of speech sounds. Fagan and Iverson (2007) reported that 6 to 9 month-old infants frequently vocalize while mouthing objects, and that frequent mouthing during vocalization was related to greater variety in consonants, especially supraglottals (e.g., [d]), known to be a reliable predictor of subsequent language growth and delay (e.g., Stoel-Gammon, 1992). When infants mouth an object while vocalizing, they introduce closure into the vocal tract and alter the position of the speech articulators in ways that affect sound production. The multimodal feedback that infants receive as they vocalize while mouthing may encourage further exploration of consonant sounds as they vary the position, size, and shape of the object being mouthed (see Iverson, 2010).

For HR infants, then, the attenuated pattern of change in active mouthing following the onset of sitting may have two developmental implications. First, although we observed no differences in their overall engagement with objects or in the time they spent manually and visually exploring objects, their exploration of objects and extraction of information about them may be less effective than that of LR infants due to reduced time spent in active mouthing. Second, opportunities to vocalize while mouthing objects may be more limited, which may in turn reduce production of consonant-like sounds that are likely to occur during mouthing. This reduction may help explain the well-documented delay in production of syllabic vocalizations (i.e., reduplicated babble) observed among HR infants (e.g., Iverson & Wozniak, 2007; Paul, Fuerst, Ramsay, Chawarska, & Klin, 2011).

Conclusions and Future Directions

These findings raise a series of questions for future studies. First, this study used an established task (Ruff, 1984; Ruff et al., 1992) to examine object exploration. In this task, infants were provided with small, lightweight, perceptually-minimal shapes to explore. However, the objects infants encounter in daily life are vastly more heterogenous—both in their physical properties like size, weight, and texture, and also in their affordances for action (e.g., pacifiers afford mouthing, buttons afford pressing, and balls afford rolling). Future studies should examine how infants' exploratory behaviors vary in relation to a greater diversity of toys and household objects.

Second, during this task, infants were seated on a caregiver's lap, supporting their sitting posture. It is possible that if infants were seated *without* postural support, differences between risk groups may have arisen. Even among infants who are able to sit independently, there are individual differences in postural control (Harbourne, Lobo, Karst, & Galloway, 2013). The task of maintaining a sitting posture while simultaneously interacting with objects may be more difficult, even for experienced sitters. If sitting is more challenging for an infant, more resources may be required to maintain the posture, and consequently behaviors like object exploration may be affected (e.g., Berger, Harbourne, & Guallpa Lliguichuzhca, 2019; Berger, Harbourne, Arman, & Sonsini, 2019; Harbourne, Ryalls, & Stergiou, 2014).

Finally, although the distributions for LR and HR infants on most variables were highly similar, our power analysis does not allow us to rule out the possibility that small to medium effects of Risk Group were undetected. Replication of this research in the future with larger sample sizes is clearly warranted.

In sum, consistent with previous work, we found a relation between object exploration and sitting, underscoring how developing motor skills build on themselves. Newly acquired abilities—such as learning to sit—open up new opportunities for action, and in so doing set the stage for further advances. Notably, we found very few differences between HR and LR infants across this transition, despite the fact that HR infants began sitting later. This suggests that for HR infants, motor development may occur on a delayed time scale, but the progression may follow a typical pattern.

Acknowledgements

This article is based on a thesis submitted in partial fulfillment of the requirements for the degree of Bachelor of Science with Honors in Psychology by the first author. The study was funded by the National Institutes of Health (R01 HD073255) to JMI. Additional support was provided by UL1 RR024153 and UL1 TR000005. During the preparation of this manuscript, KW was supported by an F32 fellowship from the National Institutes of Health (F32 DC017903). We thank members of the Infant Communication Lab at the University of Pittsburgh for help with data collection and coding. Special thanks to the families and infants who participated in the research. It could not have been completed without their enthusiastic and dedicated involvement. Portions of these data were presented at the 2019 Biennial Meetings of the Society for Research in Child Development, Baltimore, MD.

References

Adolph KE, & Berger SE (2006). Motor development. Handbook of Child Psychology.

American Psychiatric Association. (2013). Diagnostic and statistical manual of mental disorders (5th ed.). Arlington, VA: American Psychiatric Publishing.

Berger SE, Harbourne RT, Arman F, & Sonsini J (2019). Balancing act (ion): Attentional and postural control strategies predict extent of infants' perseveration in a sitting and reaching task. Cognitive Development, 50, 13–21.

Berger SE, Harbourne RT, & Guallpa Lliguichuzhca CL (2019). Sit still and pay attention! Trunk movement and attentional resources in infants with typical and delayed development. Physical & Occupational Therapy in Pediatrics, 39(1), 48–59. [PubMed: 29465319]

Berthier NE, & Keen R (2006). Development of reaching in infancy. Experimental Brain Research, 169(4), 507–518. [PubMed: 16341854]

Bhat AN, Downing K, Galloway J, & Landa R (2009). A comparison of object exploration strategies between infant siblings of children with autism and typically developing infants at 6 months of age. Paper presented at the annual international meeting for autism research.

Bhat AN, Galloway JC, & Landa RJ (2010). Social and non-social visual attention patterns and associative learning in infants at risk for autism. Journal of Child Psychology and Psychiatry, 51(9), 989–997. [PubMed: 20456532]

Bhat AN, Galloway JC, & Landa RJ (2012). Relation between early motor delay and later communication delay in infants at risk for autism. Infant Behavior and Development, 35(4), 838–846. [PubMed: 22982285]

Bornstein MH, Tamis-Lemonda CS, Hahn CS, & Haynes OM (2008). Maternal responsiveness to young children at three ages: longitudinal analysis of a multidimensional, modular, and specific parenting construct. Developmental Psychology, 44(3), 867–874. [PubMed: 18473650]

Carvalho R, Tudella E, & Savelsbergh G (2007). Spatio-temporal parameters in infant's reaching movements are influenced by body orientation. Infant Behavior and Development, 30(1), 26–35. [PubMed: 17292777]

Cohen J (1988). Statistical power analyses for the social sciences. Hillsdale, NJ: Lawrence Erlbaum Associates.

Di Cesare G, Sparaci L, Pelosi A, Mazzone L, Giovagnoli G, Menghini D, Vicari S (2017). Differences in action style recognition in children with autism spectrum disorders. Frontiers in Psychology, 8(1456).

Fagan MK, & Iverson JM (2007). The influence of mouthing on infant vocalization. Infancy, 11(2), 191–202. [PubMed: 19081776]

Faul F, Erdfelder E, Buchner A, & Lang AG (2009). Statistical power analyses using G* Power 3.1: Tests for correlation and regression analyses. Behavior research methods, 41(4), 1149–1160. [PubMed: 19897823]

Fenson L, Dale PS, Reznick JS, Bates E, Thal DJ, Pethick SJ, … & Stiles, J. (1994). Variability in early communicative development. Monographs of the society for research in child development, i–185. [PubMed: 8047076]

Fenson L, Kagan J, Kearsley RB, & Zelazo PR (1976). The developmental progression of manipulative play in the first two years. Child Development, 232–236.

Garrido D, Petrova D, Watson LR, Garcia-Retamero R, & Carballo G (2017). Language and motor skills in siblings of children with autism spectrum disorder: A meta-analytic review. Autism Research, 10(11), 1737–1750. [PubMed: 28685955]

Gibson EJ (1988). Exploratory behavior in the development of perceiving, acting, and the acquiring of knowledge. Annual Review of Psychology, 39, 1–41.

Gottwald JM, Achermann S, Marciszko C, Lindskog M, & Gredebäck G (2016). An embodied account of early executive-function development: Prospective motor control in infancy is related to inhibition and working memory. Psychological Science, 27, 1600–1610 [PubMed: 27765900]

Gredebäck G, & Falck-Ytter T (2015). Eye movements during action observation. Perspectives on Psychological Science, 10, 591–598. [PubMed: 26385998]

Harbourne RT, Lobo MA, Karst GM, & Galloway JC (2013). Sit happens: Does sitting development perturb reaching development, or vice versa? Infant Behavior and Development, 36(3), 438–450. [PubMed: 23644424]

Harbourne RT, Ryalls B, & Stergiou N (2014). Sitting and looking: A comparison of stability and visual exploration in infants with typical development and infants with motor delay. Physical & Occupational Therapy in Pediatrics, 34(2), 197–212. [PubMed: 23901882]

Iverson JM (2010). Developing language in a developing body: The relationship between motor development and language development. Journal of Child Language, 37(2), 229–261. [PubMed: 20096145]

Iverson JM, Shic F, Wall CA, Chawarska K, Curtin S, Estes A, … & Libertus K (2019). Early motor abilities in infants at heightened versus low risk for ASD: A Baby Siblings Research Consortium (BSRC) study. Journal of Abnormal Psychology, 128(1), 69. [PubMed: 30628809]

Iverson JM, & Wozniak RH (2007). Variation in vocal-motor development in infant siblings of children with autism. Journal of Autism and Developmental Disorders, 37(1), 158–170. [PubMed: 17191097]

Kaur M, Srinivasan SM, & Bhat AN (2015). Atypical object exploration in infants at-risk for autism during the first year of life. Frontiers in Psychology, 6, 798. [PubMed: 26136702]

Koterba EA, Leezenbaum N, & Iverson JM (2014). Object exploration at 6 and 9 months in infants with and without risk for autism. Autism, 18(2), 97–105. [PubMed: 23175749]

Landa R & Garrett-Mayer E (2006). Development in infants with autism spectrum disorders: A prospective study. Journal of Child Psychology and Psychiatry, 47(6), 629–638. [PubMed: 16712640]

Leonard HC, Elsabbagh M, Hill EL, & the BASIS team. (2013). Early and persistent motor difficulties in infants at-risk of developing autism spectrum disorder: A prospective study. European Journal of Developmental Psychology, 1–18. [PubMed: 25076976]

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, 3257–3277. [PubMed: 31079276]

Libertus K (2013). StopFrameCoding (Version 2.8). Pittsburgh, PA: University of Pittsburgh.

Libertus K, Joh AS, & Needham AW (2016). Motor training at 3 months affects object exploration 12 months later. Developmental Science, 19(6).

Libertus K, & Landa RJ (2014). Scaffolded reaching experiences encourage grasping activity in infants at high risk for autism. Frontiers in Psychology, 5, 1071. [PubMed: 25295021]

Libertus K, Sheperd KA, Ross SW, & Landa RJ (2014). Limited fine motor and grasping skills in 6-month-old infants at high risk for autism. Child Development, 85(6), 2218–2231. [PubMed: 24978128]

Lord C, Risi S, Lambrecht L, Cook EH Jr., Leventhal BL, DiLavore PC, … Rutter M (2000). The autism diagnostic observation schedule-generic: a standard measure of social and communication deficits associated with the spectrum of autism. Journal of Autism and Developmental Disorders, 30(3), 205–223. [PubMed: 11055457]

Marcinowski EC, Tripathi T, Hsu LY, Wescott McCoy S, & Dusing SC (2019). Sitting skill and the emergence of arms-free sitting affects the frequency of object looking and exploration. Developmental Psychobiology.

Mullen EM (1995). Mullen: Scales of early learning. Circle Pines, MN: American Guideline Service.

Nickel LR, Thatcher AR, Keller F, Wozniak RH, & Iverson JM (2013). Posture development in infants at heightened versus low risk for autism spectrum disorders. Infancy, 18(5), 639–661. [PubMed: 24027437]

Out L, Van Soest A, Savelsbergh G, & Hopkins B (1998). The effect of posture on early reaching movements. Journal of Motor Behavior, 30(3), 260–272. [PubMed: 20037083]

Ozonoff S, Macari S, Young G, Goldring S, Thompson M, & Rogers S (2008). Atypical object exploration at 12 months of age is associated with autism in a prospective sample. Autism, 12(5), 457–472. [PubMed: 18805942]

Ozonoff S, Young GS, Carter A, Messinger D, Yirmiya N, Zwaigenbaum L, … Stone, W. L. (2011). Recurrence risk for autism spectrum disorders: A baby siblings research consortium study. Pediatrics, 128(3), e488–e495. [PubMed: 21844053]

Paul R, Fuerst Y, Ramsay G, Chawarska K, & Klin A (2011). Out of the mouths of babes: Vocal production in infant siblings of children with ASD. Journal of Child Psychology and Psychiatry, 52 (5).

Piaget J (1954). The construction of reality in the child (M. Crook, Trans.). New York, NY, US: Basic Books.

Rochat P (1989). Object manipulation and exploration in 2- to 5-month-old infants. Developmental Psychology, 25(6), 871–884.

Rochat P (1992). Self-sitting and reaching in 5-to 8-month-old infants: The impact of posture and its development on early eye-hand coordination. Journal of Motor Behavior, 24(2), 210–220. [PubMed: 14977620]

Rochat P, & Goubet N (1995). Development of sitting and reaching in 5- to 6-month-old infants. Infant Behavior and Development, 18(1), 53–68.

Ruddy MG, & Bornstein MH (1982). Cognitive correlates of infant attention and maternal stimulation over the first year of life. Child Development, 53(1), 183–188. [PubMed: 7060421]

Ruff HA (1984). Infants' manipulative exploration of objects: Effects of age and object characteristics. Developmental Psychology, 20(1), 9–20.

Ruff HA, Saltarelli LM, Capozzoli M, & Dubiner K (1992). The differentiation of activity in infants' exploration of objects. Developmental Psychology, 28(5), 851–861.

Sacrey LA, Bryson SE, & Zwaigenbaum L (2013). Prospective examination of visual attention during play in infants at high-risk for autism spectrum disorder: a longitudinal study from 6 to 36 months of age. Behavioural Brain Research, 256, 441–450. [PubMed: 24004846]

Sommerville JA, Woodward AL, & Needham A (2005). Action experience alters 3-month-old infants' perception of others' actions. Cognition, 96(1), B1–B11. [PubMed: 15833301]

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

Soska KC, Adolph KE, & Johnson SP (2010). Systems in development: motor skill acquisition facilitates three-dimensional object completion. Developmental Psychology, 46(1), 129–138. [PubMed: 20053012]

Stoel-Gammon C (1992). Prelinguistic vocal development: Measurement and predictions. Phonological Development: Models, Research, Implications, 439–456.

West KL (2018). Infant motor development in autism spectrum disorder: A synthesis and meta-analysis. Child Development.

West KL, & Iverson JM (2017). Language learning is hands-on: Exploring links between infants' object manipulation and verbal input. Cognitive Development, 43, 190–200.

Woods RJ, & Wilcox T (2013). Posture support improves object individuation in infants. Develeopmental Psychology, 49(8), 1413–1424.

Figure 1.
Objects presented to infants in the object exploration task. Pictured in rows from top to bottom, sets include varied patterns, shapes, and textures. Color is randomized throughout sets.

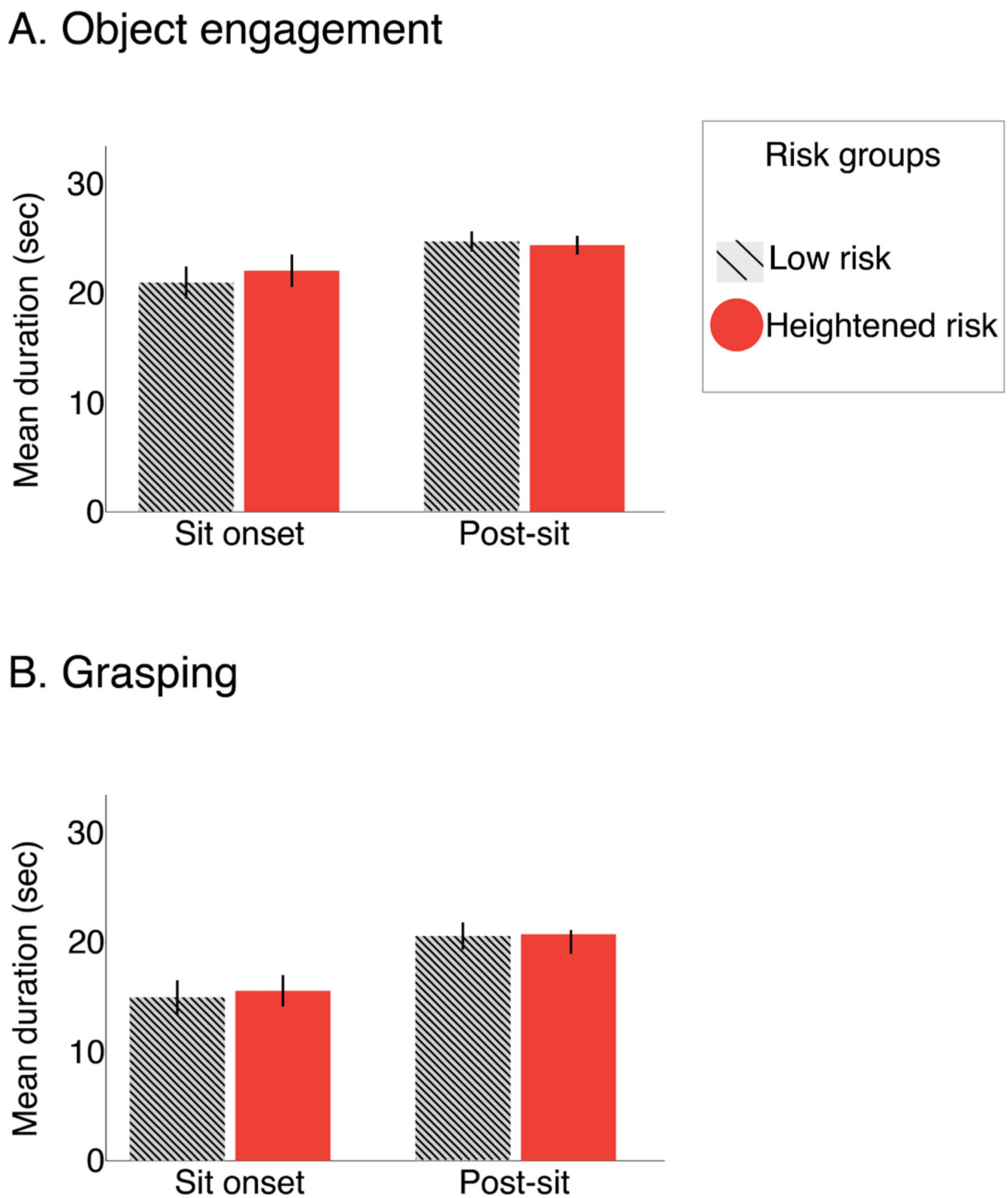

Figure 2.
Mean durations and standard errors of object engagement and grasping in the LR and HR infants.

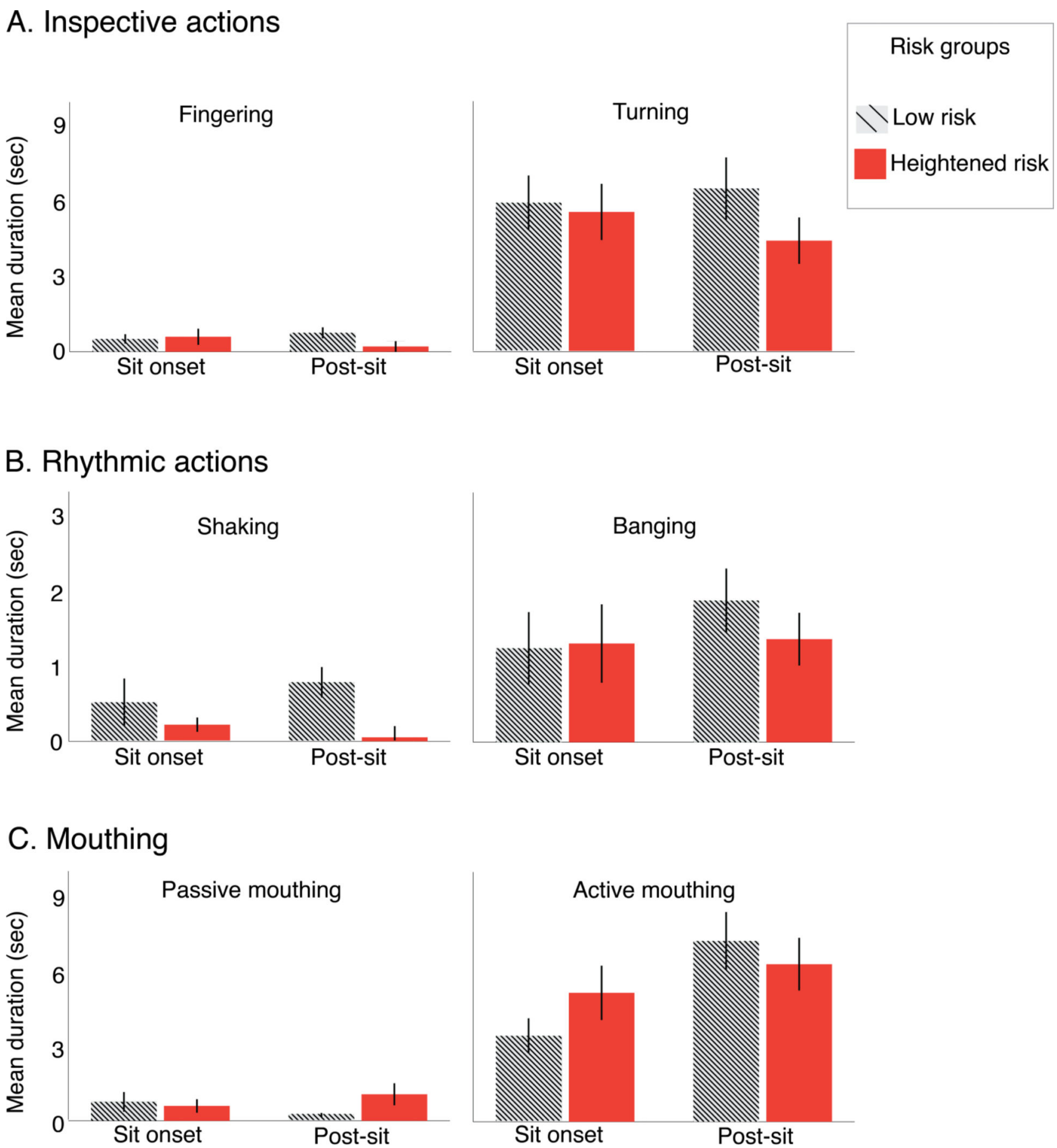

Figure 3.

Mean durations and standard errors of inspective actions, rhythmic actions, and mouthing across sessions in LR and HR infants.

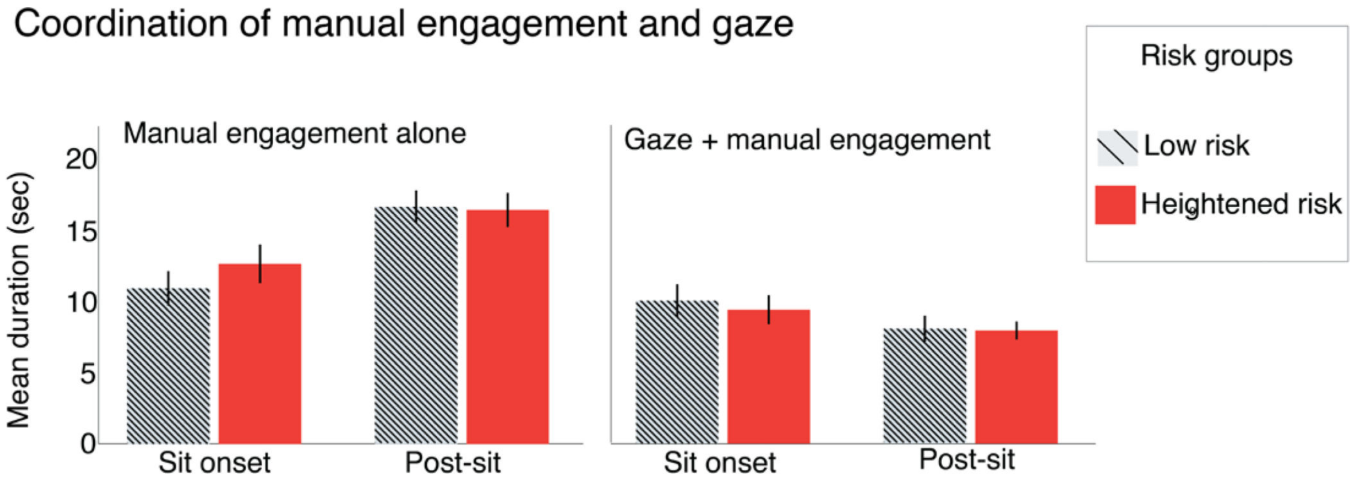

Figure 4.
Mean durations and standard errors of manual object engagement only and manual engagement in coordination with gaze across sessions in LR and HR infants.

Table 1.

Descriptive statistics for object exploration and gaze durations across sessions for LR and HR infants per 30-sec trial.

	LR						HR					
	Sit Onset			Post-Sit			Sit Onset			Post-Sit		
	M	*SD*	*Range*	*M*	*SD*	*Range*	*M*	*SD*	*Range*	*M*	*SD*	*Range*
Object engagement[a]	20.87	7.03	(6.7 – 28.8)	24.63	4.44	(10.4 – 29.4)	21.97	6.41	(1.5 – 28.3)	24.29	3.74	(16.6 – 29.0)
Grasping objects[a]	14.88	7.56	(0 – 28.3)	20.48	5.99	(6.0 – 27.8)	15.49	6.20	(0.3 – 24.9)	20.65	4.71	(10.0 – 27.3)
Inspective actions												
Fingering	0.51	0.91	(0 – 3.9)	0.76	1.04	(0 – 3.6)	0.60	1.41	(0 – 5.6)	0.21	0.93	(0 – 2.6)
Turning	5.94	5.21	(0 – 19.7)	6.50	5.97	(0 – 16.3)	5.57	4.91	(0 – 12.9)	4.41	4.04	(0 – 14.1)
Rhythmic actions[a]												
Shaking	0.51	1.52	(0 – 7.2)	0.78	0.97	(0 – 3.5)	0.21	0.42	(0 – 1.7)	0.05	0.59	(0 – 0.9)
Banging	1.25	2.31	(0 – 7.9)	1.89	2.03	(0 – 6.7)	1.32	2.28	(0 – 7.9)	1.38	1.53	(0 – 5.9)
Mouthing[a,b]												
Active mouthing	3.40	3.37	(0 – 12.9)	7.24	5.56	(0 – 21.7)	5.16	4.75	(0 – 12.7)	6.31	4.59	(0 – 14.1)
Passive mouthing	0.76	1.88	(0 – 8.6)	0.24	0.38	(0 – 1.6)	0.60	1.17	(0 – 4.8)	1.06	1.92	(0 – 6.8)
Gaze to objects	13.82	6.35	(3.5 – 17.4)	10.41	4.86	(3.5 – 17.4)	12.92	5.25	(4.0 – 22.4)	11.24	4.28	(3.4 – 19.4)
Action & gaze[a]												
Manual & gaze	9.98	5.59	(1.1 – 22.8)	8.03	4.33	(1.6 – 16.3)	9.36	4.44	(0.7 – 17.3)	7.91	2.77	(2.5 – 12.9)
Manual alone	10.89	5.79	(0.6 – 22.9)	16.59	5.48	(8.8 – 24.7)	12.60	5.90	(0.8 – 21.8)	16.38	5.21	(7.5 – 24.4)

Note:

[a]There was a significant change from sit onset to the post-sit session

[b]There was a significant difference between risk groups.