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The onset of reaching significantly impacts how infants explore both objects and their bodies

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ABSTRACT

The purpose of this study was to describe how reaching onset affects the way infants explore objects and their own bodies. We followed typically developing infants longitudinally from 2 through 5 months of age. At each visit we coded the behaviors infants performed with their hand when an object was attached to it versus when the hand was bare. We found increases in the performance of most exploratory behaviors after the emergence of reaching. These increases occurred both with objects and with bare hands. However, when interacting with objects, infants performed the same behaviors they performed on their bare hands but they performed them more often and in unique combinations. The results support the tenets that: (1) the development of object exploration begins in the first months of life as infants learn to selectively perform exploratory behaviors on their bodies and objects, (2) the onset of reaching is accompanied by significant increases in exploration of both objects and one's own body, (3) infants adapt their self-exploratory behaviors by amplifying their performance and combining them in unique ways to interact with objects.

1. Introduction

Humans spend much of their early years actively exploring objects. Object exploration is a highly engaging behavior that allows immediate learning and impacts future cognitive, language and social development. For instance, object exploration advances infants' understanding of object properties and ability to remember objects (Lederman and Klatzky, 1987, 1993). It also facilitates object segregation, completion of partially viewed objects, and familiar object recognition (Needham, 2001; Needham et al., 2002). As infants gain more knowledge about objects, they build a foundation for language development as they learn to categorize, discriminate, relate, and infer meaning about objects (Iverson, 2010; Klatzky and Lederman, 1992). Oral exploration of objects allows infants to perform novel types of vocalizations (Fagan and Iverson, 2007). Increased knowledge of object properties and the ability to relate objects for construction during play is strongly associated with the emergence of words and increase in vocabulary size (Lifter and Bloom, 1989). Object exploration abilities in the first year of life have been associated with attention measures at 3.5 years of age (Ruff, 1986). Socially, objects become increasingly embedded in caregiver and peer interactions in the first years of life (Bakeman and Adamson, 1984; Bakeman et al., 1990). For example, within the first year of life, infants transition from focusing primarily on people, to focusing primarily on objects, to learning to use objects as tools to initiate and sustain social interactions with others. Because of their foundational role in early, grounded development, object exploration behaviors have been extensively studied and their ontogeny after 6 months of age has been well documented. Interestingly, fewer studies have focused on the ontogeny of object exploration behaviors in the first six months of life.

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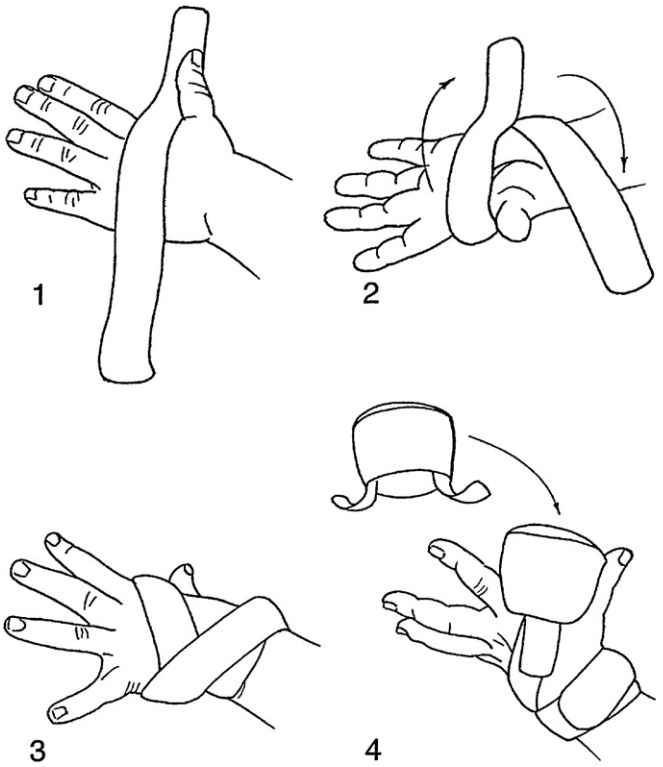

Fig. 1. Attachment system for the objects. Illustration of the steps involved to don the hook and loop band to an infant's hand and then to attach one of the objects. Note that the bands do not restrict movement or tactile potential of the fingers.

Although older infants seem to demonstrate a greater variety of object exploration behaviors, object exploration originates much earlier in development as infants utilize their available abilities to gain information about their world. The lack of early object exploration studies is understandable given that young infants do not begin to consistently reach for and contact objects with their hands until 4–5 months of age (Thelen et al., 1993; von Hofsten, 1991) and do not reliably grasp objects until 7–9 months of age (Konczak and Dichgans, 1997). Therefore, many might perceive the study of object exploration behaviors prior to 6 months of age to be constrained by infants' object interest and/or their motor abilities. Nonetheless, there have been a few studies aimed at describing the ontogeny of object exploration behaviors before 6 months. Case-Smith et al. (1998) presented 2- and 6-month-old infants with objects of varying properties and observed their grasping patterns as they explored. They found that the grasping patterns infants used to handle objects varied in relation to age but that infants in both groups varied their grasping patterns based on the properties of the objects presented. Rochat (1989) studied 2- to 5-month old infants and found that older infants showed increased multimodal exploration of objects and that bimanual exploration was first linked to mouthing and later to looking. Even younger, at just 3 days old, neonates demonstrated exploratory behaviors and the ability to learn about object properties via loosening and tightening of their grasp on objects (Jouen and Molina, 2005; Molina and Jouen, 2004). Further study of the origins of object exploration are necessary so we can understand how this critical tool for learning emerges and so we can design interventions to advance this behavior in infants with delays.

The first goal of this study was to test how the emergence of reaching affects infants' exploratory behaviors. Unlike previous object exploration studies which have looked at changes in exploratory behaviors based on age alone, this study aimed to look at the ontogeny of these behaviors in relation to developmental ability. The emergence of reaching is important for the development of object exploration behaviors because infants use reaching to transition from relatively passive observers to more active explorers of objects in the world (Lobo and Galloway, 2008). Early reaching likely cues caregivers to present infants with greater opportunities to explore objects (Fogel, 1997).

Infants in this study were presented equal and extended time periods to explore objects at each visit both when they were not able to reach and after reaching emerged. This was achieved utilizing a paradigm where objects were attached to infants' hands using hook and loop bands (see Fig. 1). The bands wrapped around infants' palms and wrists so objects remained on the hand and all of the fingers were exposed and free to move for potential exploration. In effect, this paradigm allowed us to assess longitudinal changes in object exploration behaviors irrespective of reaching and grasping ability. Based on the theory that infants learn about the affordances of objects and how to interact with them via their daily experiences exploring objects, we hypothesized that the ways they interact with objects, even those not requiring reaching and grasping ability to hold, should be different after they learn to reach (Gibson and Pick, 2000). We were able to assess for object exploration

changes in relation to reach onset while minimizing the effects of age alone by providing some infants in the study with enhanced experiences known to advance the onset of reaching (Lobo and Galloway, 2008).

The second goal of this study was to test how the behaviors infants perform with objects relate to the behaviors they perform with their bare hands. This comparison demonstrates whether infants' behaviors are specific to objects and helps determine whether object-oriented behaviors and behaviors performed without objects are related. Based on the theory that novel abilities emerge from prior experiences and the literature suggesting that reaching, a foundational skill for object exploration, emerges from infants' spontaneous arm flapping (Bhat et al., 2005), we hypothesized that: (1) before infants had extensive experience exploring objects in their daily lives, they would behave more similarly with their hands whether or not they had an object attached, and (2) the behaviors infants would use to explore objects would build upon the behaviors they used to explore their bare hands (Lobo et al., 2004; Thelen et al., 1993; van der Meer et al., 1995; von Hofsten, 1997).

2. Materials and methods

2.1. Participants

The data reported are a novel subset of data from infants reported on in a previous study whose aim was to test the ability of different experiences to advance reaching ability, thereby advancing future object exploration and means-end ability (Lobo and Galloway, 2008). Forty-two healthy infants born full-term were recruited from the local area. Infants entered the study when they were 2 months of age and not yet reaching. Forty of the babies were Caucasian and two were African-American. Caregivers provided informed consent. Fourteen additional infants were excluded from the study. Nine were excluded at the first visit because of advanced reaching evidenced by more than ten object contacts during the reaching task. Excluding these infants was important because one goal of this study was to assess changes in exploratory behavior both before and after the onset of reaching. The remaining five infants were excluded because caregivers did not meet the minimum inclusion criterion for provision of the experiences (see details below).

2.2. Experience groups

Before the first visit, infants were randomly assigned to one of three groups matching for gender so each group had 14 infants, half of those being male. Their caregivers were asked to provide them 3 weeks of prescribed experiences 15 min daily. Caregivers were trained to perform the experiences via an illustrated instruction manual and hands on instruction from a trained experimenter at the first visit. They were asked to perform the experiences when their infants were awake and alert. They could divide the experience into shorter periods if necessary to maximize infant participation. They were provided with a diary to record daily the frequency and duration of experience performance. At the second visit in the middle of the 3-week experience period, the experimenter requested the caregiver provide an independent demonstration of the experiences with his/her infant and any suggestions or modifications were made. At the end of the 3-week experience period, the experimenter reviewed the diary for each infant and any family who did not perform the experiences greater than 60% of the days was excluded from the study at that time.

The experiences infants received were either control experiences, enhanced handling and positioning experiences, or enhanced object-related experiences. Infants in the control group (age at Visit 1: $M = 2.02$ months, SD = .17 months, range = 1.79–2.56 months) received 15 min daily of social and movement experiences typical for 2–3 month olds. Their caregivers placed them in supine and engaged them in face-to-face interactions. The purpose of these experiences was to control for the social experiences occurring in the other two groups.

The other infants were assigned to one of two groups whose experiences were aimed at advancing the emergence of reaching. Inclusion of these infants allowed us to minimize the natural confound of age in the analyses of exploration in relation to reach onset because these infants were expected to reach weeks to months earlier than infants in the control group. Infants in the enhanced handling and positioning experience group (age at Visit 1: $M = 2.06$ months, SD = .17 months, range = 1.89–2.62 months) received activities 15 minutes daily aimed at advancing their early experiences and abilities associated with play in prone, sitting, and standing. Infants in the enhanced object-oriented experience group (age at Visit 1: $M = 2.03$ months, SD = .17 months, range = 1.83–2.46 months) received activities 15 min daily aimed at providing them scaffolded opportunities in supine to reach for and interact with objects. Both types of experiences were 'enhanced' because 2 month olds in Western cultures typically spend most of their day in supine engaging in non-object-oriented face-to-face play with their caregivers (Fogel et al., 1999).

2.3. Procedure

The same experimenter visited families in their homes for six visits over a period of 12 weeks. Visits 1, 3, 4, 5, and 6 were separated by 3-weeks. Visits 1, 2, and 3 were separated by 1.5-weeks, and spanned the 3 weeks of prescribed experiences. The ages of infants among groups were not different at any visit. We documented each session using two synchronized video recordings to provide right and left frontal views of infants for coding by experimenters blind to group assignment. A splitter was used to place both views on one screen and a vertical interval time code generator was used to superimpose

Fig. 2. Participant in the exploration paradigm. Infants were seated in the custom chair during the exploration and reaching paradigms. Note that infants were supported at their trunks but had unrestricted mobility of their arms.

the hour, minute, second, and frame on the image. Assessments were conducted when infants were in a positive or neutral behavioral state.

Parents provided enhanced experiences daily *only between Visits 1 and 3*. Thus, parents were asked to provide the experiences for a total of 3 weeks when infants were between 2- and 3-months old. At each visit we coded the behaviors of infants' hands during an exploration paradigm and during a reaching paradigm.

2.3.1. Exploration paradigm

At each visit, infants were provided opportunities to explore objects or their bare hand while sitting upright in a special infant seat (Fig. 2). Infants had their trunks secured but had freedom of movement of their arms. Infants could not reliably grasp objects for prolonged periods at the start of the study and we did not want this to limit the time for potential exploration. Thus, objects were attached to infants' wrists using hook and loop bands (Fig. 1). The experimental design for this task was based on Ruff (1984) in that three pairs of objects varying in weight, texture, or sound-making ability were presented to infants for exploration. One object in each pair served as the familiarization object and the other object served as the novel object. Infants had 60 s to explore each familiarization object and 45 s to explore each novel object. Because we did not observe consistent differences in the ways infants explored the individual objects, for the purposes of this article we test our hypotheses on global exploration of the objects by grouping the data for all object sets.

Each trial was immediately preceded by the experimenter attaching the object to the band, raising the infant's hand with the object into the infant's view, and then releasing the infant's hand. There was no physical contact between the experimenter and infant during trials. Successive objects were attached to alternating hands. The initial hand of attachment was the right for half of the infants in each group and left for the others. Within infants, the initial hand of attachment was altered at each visit.

2.3.2. Reaching paradigm

At each visit, infants were provided separate opportunities to reach for an object while lying supine and sitting in the custom seat. In each of the two positions, infants were provided one 3-min opportunity to reach for and interact with a stationary, midline object held an arm's length away at chest level. The object distance was determined at the beginning of each trial by extending the infant's arm into midline, noting the location of the infant's wrist, and presenting the object in this location. Trials began when infants were in a positive behavioral state and visually attending to the object (Prechtl, 1974).

2.4. Data analysis

All coders were blind to group assignment and did not attend data collections. For each variable, reliability across 20% of the data was calculated using the equation: [Agreed/(Agreed + Disagreed)] $\times$ 100. Individuals were qualified for coding once they achieved and maintained inter- and intra-rater reliabilities greater than 85% for all object exploration variables and greater than 90% for all reaching variables (see Table 1).

Table 1
Percent agreement between the two coders for the object exploration and reaching behaviors. The inter-rater reliability reports the agreement between Coder 1 and Coder 2. The intra-rater reliability reports the agreement between Coder 1 and herself and Coder 2 and himself, respectively.

Behavior	Inter-rater reliability (%)	Intra-rater reliability (%)
Mouthing	91.1	92.4, 93.3
Looking	94.2	94.0, 96.5
Touching the body	93.0	95.1, 94.6
Fingering	91.4	92.9, 92.8
Cyclical movement	87.3	91.3, 90.0
Resting	86.3	92.2, 93.7
Positive vocalizations	95.2	97.6, 96.1
Positive vocalizations object in mouth	94.6	96.8, 95.5
Number of object contacts	92.1	95.3, 96.0

2.4.1. Exploration paradigm variables

Two trained experimenters reviewed the exploration videos to code continually within each visit the behaviors infants were performing with: (A) the hand with the object attached, and (B) the hand without the object attached. The coding protocol was created by first reviewing the literature and our videos to create a list of the behaviors infants performed with their hands (Palmer, 1989; Ruff, 1984). The following list accounted for these behaviors: (1) *Mouthing* occurred when the object (or hand without the object) was in contact with the inside of the mouth or on the lips; (2) *Looking* occurred when the infant's eyes were directed at the object (or at the hand without the object); (3) *Touching the body* occurred when the object (or the hand without the object) was in contact with the head, face, shoulders, or neck but not the mouth; (4) *Fingering* occurred when the opposite hand was in contact with and feeling the object (or the hand without the object); (5) *Cyclical movement* occurred when the arm with the object (or without the object) moved cyclically so that: (a) the distance travelled by the hand was greater than two times the length of the baby's fisted hand from the wrist to the knuckles, (b) it involved more than two movements with a change in direction between them, and (c) it did not involve a resting period of greater than 3 s between movements. 6) *Resting* occurred when the hand with (or without) the object was still and the infant was not performing other behaviors on it.

Coders reviewed the videos to record the behavior(s) infants were performing at each visit. We determined the percentage of the assessment time infants performed each individual behavior across visits from these data. Coders then reviewed the data to determine when performance of the behaviors overlapped. All of the instances when two or more behaviors were performed in combination were defined as *combination behaviors*. We determined the percentage of the assessment time infants performed combinations of the behaviors across visits from these data. Most combination behaviors occurred for brief periods except for mouthing while fingering and cyclical movement while looking, so we analyzed these two behavioral categories individually in addition to analyzing the sum of all combination behaviors.

The comparison of information across modalities and behaviors is important as it allows infants to more effectively examine objects and process and compare information about them (Rochat, 1989). Thus, we also reviewed the data to count the *number of mouthing bouts immediately followed by fingering or by looking* at each visit (Ruff, 1984).

Coders also reviewed the videos to code for vocalizations infants produced. The placement of objects in the mouth has been reported to allow infants to explore novel forms of sound production (Fagan and Iverson, 2007). Thus, we quantified how infants' vocalizations evolved as infants changed their object exploration behaviors. Coders first reviewed the videos to listen for vocalizations. A vocalization occurred when infants emitted any sound from their mouths excluding coughs, sneezes, or loud breaths or sighs. A vocalization began when the sound began and ended when the sound ended. Coders next qualified each vocalization as either a positive/neutral vocalization representing an interested, happy, or neutral state or as a negative vocalization representing a sad, angry, or complaining state (Izard et al., 1989). Finally, coders recorded for each vocalization whether the object was in the infant's mouth. This allowed us to report the *number of positive vocalizations infants performed in total and with objects in the mouth*.

2.4.2. Reaching paradigm variables

Two trained experimenters coded the number of object contacts, or the number of times when any surface of either of the infant's hands contacted the object. The coders then used these data to classify each infant as a reacher or non-reacher at each visit. The *visit of reach onset* was then determined by identifying the first visit where an infant contacted the object >10 times during the reaching assessment and continued to do so at all future visits. These criteria are based on our past reaching studies with infants demonstrating that infants who have learned to reach perform this action repeatedly and reliably across sessions after the onset of reaching with large numbers of object contacts (Lobo et al., 2004; Lobo and Galloway, 2008; Heathcock et al., 2008).

2.5. Statistical analyses

2.5.1. Changes in exploratory behaviors in relation to the emergence of reaching

We compared behaviors performed on the object and on the bare hand in relation to reach onset. Once we determined the visit of reach onset for an infant, we averaged the percent time the infant performed each exploratory behavior for all

prior visits to represent exploration before reach onset. We averaged the percent time the infant performed each behavior from the visit of reach onset and after to represent exploration after reach onset. We used 2-tailed paired samples *t*-tests with $\alpha \leq .05$ to compare these pre- and post-reaching behaviors within infants. We corrected the alpha level to account for the 26 *t*-tests performed so test results were considered significant if they were $\leq$.002. The 13 variables tested for in the object and bare hand conditions were: resting, combination behaviors, cyclical movement, touching the body, looking, mouthing, fingering, cyclical arm movement while looking, mouthing while fingering, fingering after mouthing, looking after mouthing, positive vocalizations, and positive vocalizations with object in mouth.

To demonstrate that reaching onset was different between control infants and those in the two enhanced experience groups, we compared the number of reachers at each visit using repeated measures ANOVA with Mauchly's W with significance level of .05 to test for violation of the assumption of sphericity and the Greenhouse–Geisser correction when this assumption was violated. Significance was set at $\leq$.05 and Dunnett post hoc tests were used to compare reaching to the control group.

2.5.2. Object exploration versus self-exploration behaviors

We compared how infants behaved with objects versus with their bare hand at each visit and in relation to the emergence of reaching. Recall that for each trial the object was switched between hands so this measure quantifies how an infant shifts attention to behave differently when an object is attached to his/her hand. We used 2-tailed paired samples *t*-tests with $\alpha \leq .05$ to compare the behaviors on the hand with the attached object versus the hand without an attached object. We corrected the alpha level to account for the 66 tests with age ($\alpha \leq .001$) and the 22 tests in relation to reach onset ($\alpha \leq .002$). The 11 variables tested were: resting, combination behaviors, cyclical movement, touching the body, looking, mouthing, fingering, cyclical arm movement while looking, mouthing while fingering, fingering after mouthing, looking after mouthing. Vocalization variables were not compared because object and bare hand data arose from the same samples of time so there were not two sets of data for these variables.

3. Results

3.1. The onset of reaching significantly impacts how infants explore objects and their bodies

3.1.1. Infants with enhanced experiences had earlier reach onsets

We experimentally advanced the emergence of reaching for infants in the enhanced experience groups. As a result of the experiences provided, infants in both enhanced experience groups displayed advanced reaching (main effect: $F(4, 156) = 41.39$, $p = .000$; effect among groups: $F(2, 39) = 285.80$, $p = .000$; handling and positioning experience versus control: $p = .02$; object-related experience versus control: $p = .001$). Infants all began the study at 2 months of age unable to reach and ended the study at 5 months of age able to reach. The number of new reachers at each age was well distributed with 10 new reachers at 2.5 months (0 control, 4 handling, 6 object group), 10 at 2.7 months (2 control, 4 handling, 4 object group), 9 at 3.5 months (4 control, 2 handling, 3 object group), 7 at 4.2 months (4 control, 2 handling, 1 object group), and 6 at 5 months (4 control, 2 handling, 0 object group).

3.1.2. Object exploration behavior changed significantly after reach onset

Performance of almost every behavior measured changed significantly after the onset of reaching (Fig. 3). After reach onset, infants spent more time mouthing, fingering, and performing combination behaviors on objects and had more bouts of fingering or looking at objects after mouthing. In addition, they spent less time resting and more time exploring, more time looking alone and looking in combination with cyclical movement, and more time simultaneously mouthing and fingering objects. Furthermore, although their number of positive vocalizations during the assessment did not change after reach onset they did increase the number of these vocalizations that occurred with objects in their mouths.

3.1.3. Self-exploratory behavior also changed significantly after reach onset

Interestingly, infants also significantly changed the way they explored their bare hands after reach onset. The behaviors they performed on their bare hands changed in a pattern that reflected the changes in their behaviors on objects after reach onset. Specifically, they demonstrated all of the same behavioral changes observed with objects, except that they did not have a greater number of instances of looking at their bare hands after mouthing them (see Fig. 3).

3.2. With age and reaching experience, infants learned to amplify and combine their behaviors in unique ways to explore objects

Although the onset of reaching was associated with similar patterns of change in exploratory behaviors for objects and bare hands, infants adapted their behaviors to act differently when objects were present both with advancing age and in relation to reach onset (Fig. 4). Infants acted differently on objects than on their bare hands at all ages, but they acted most differently on objects from 3.5 to 5 months of age by amplifying and combining their self-exploration behaviors to explore objects. Across time, at almost every age infants spent less time cyclically moving their hand with an attached object. At 2–3 months old, they spent more time touching their body with the object. At 3–5 months old, they mouthed, simultaneously

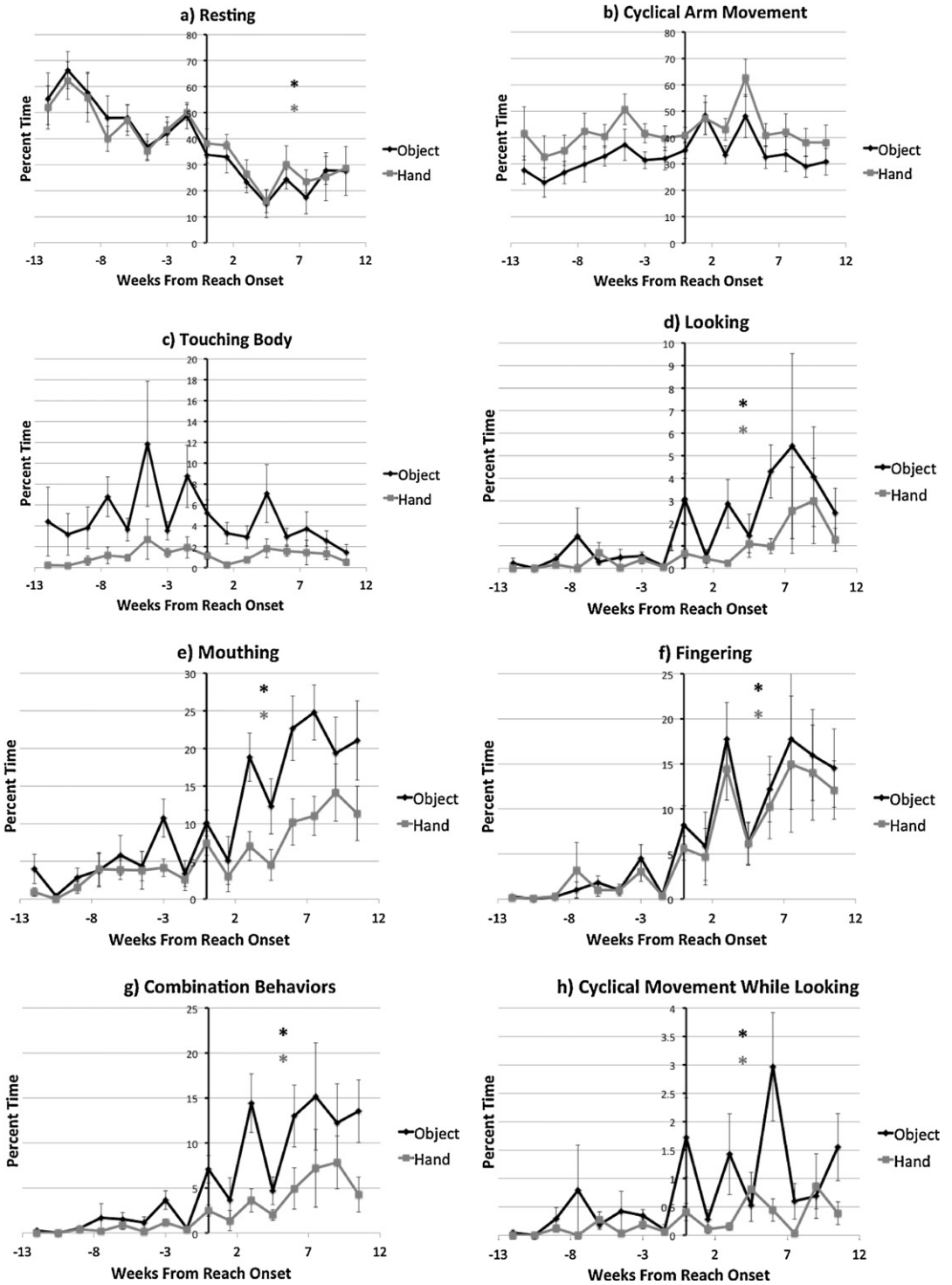

Fig. 3. Changes in behaviors performed on objects and bare hands in relation to the week of reach onset. Changes in the percentage of time infants: (a) did not perform any actions (resting), (b) cyclically moved, (c) touched the body, (d) looked, (e) mouthed, (f) fingered, (g) performed more than one behavior simultaneously (combination behaviors), (h) looked while cyclically moving, and (i) mouthed while fingering; and changes in the frequency of: (j) fingering after mouthing, (k) looking after mouthing, and (l) positive vocalizations (all vocalizations and vocalization with objects in the mouth). Data for subjects are aligned with respect to their week of reach onset (week 0). * Represents a significant change ($p \leq .002$) after reach onset in the way infants behaved on objects or their bare hands (a–k; black represents object, grey represents hands) or in the number of positive vocalizations with objects in the mouth (l). Error bars reflect standard error of the mean. Infants spent less time resting, more time performing most behaviors, and more time performing combinations of behaviors with objects and with their bare hands after reach onset.

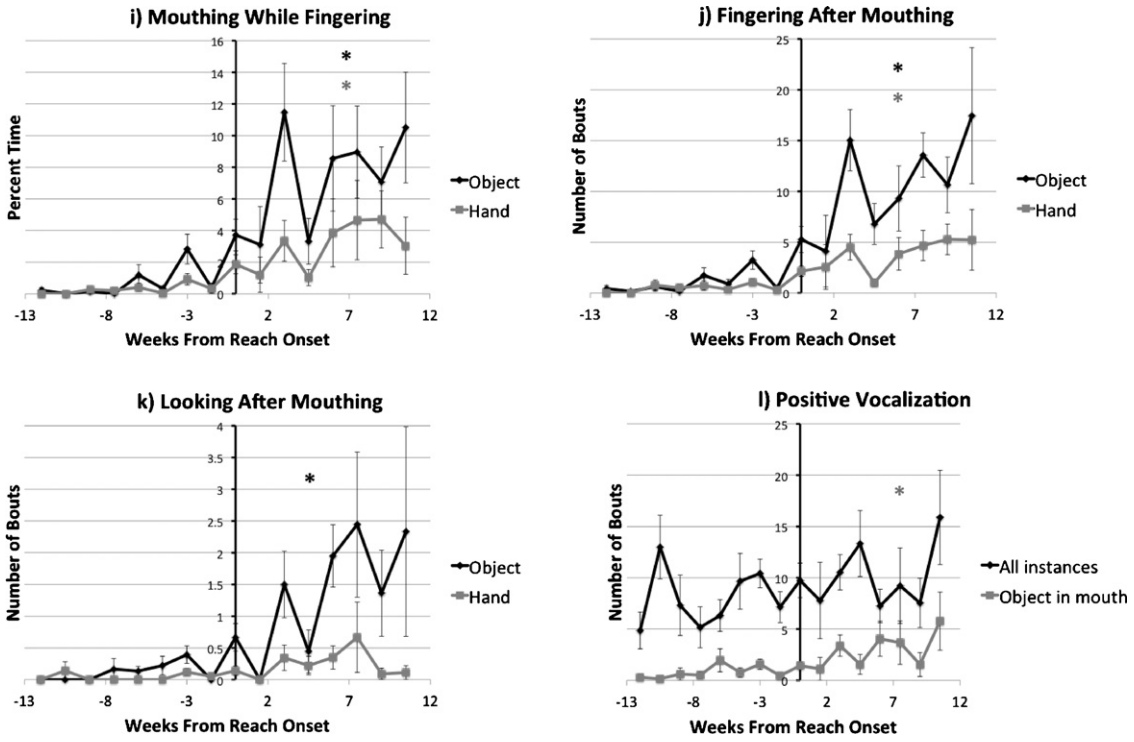

Fig. 3. (*continued*).

mouthed and fingered, looked at, used combination behaviors, and followed mouthing with looking or fingering more with objects than their bare hands.

Although some behaviors were performed more often with objects than with bare hands before the onset of reaching, all behaviors measured were performed differently on objects after the onset of reaching. This suggests that infants learned how to behave selectively with objects after the onset of reaching. In relation to reach onset, some behaviors were always performed more often on objects than on bare hands. These included touching the body, mouthing, mouthing followed by fingering, and combination behaviors. Infants selectively performed other behaviors on objects more than on their bare hands after the onset of reaching. These included overall exploration (less resting), fingering, mouthing while fingering, looking, looking while cyclically moving, and looking immediately after mouthing.

4. Discussion

The results of this study demonstrate that during the first 6 months of life: (1) the emergence of reaching significantly changes the way infants explore objects; (2) the emergence of reaching also greatly changes the way infants explore their own bodies; and (3) young infants perform the same behaviors on objects as they do on their bare hands but they amplify them and combine them in unique ways when acting on objects. Below we address several basic questions and general conclusions from these findings.

4.1. Why did the onset of reaching impact object exploration so significantly when the assessment paradigm did not require reaching and grasping?

The emergence of reaching was a significant facilitator of change in object exploration behaviors in this study. Reaching is a behavior that allows infants daily opportunities to discover ways they can use their bodies as tools to explore and effect objects (Gibson, 1988; Thelen, 2000). This is in contrast to the months before reach onset, when infants pay less attention to and have fewer physical interactions with objects (Davis et al., 1998; Fogel et al., 1999). Although the object sets presented and the opportunities to explore them were the same at every visit, infants spent less time exploring the objects before reach onset than they did after reach onset. After reach onset, infants began to use their existing behaviors in novel ways to explore objects and themselves. These findings add to the growing body of literature supporting the idea that development is facilitated by one's everyday perception-action experiences rather than by aging or 'maturation' alone (Adolph et al., 1998; Eppler, 1995; Soska et al., 2010).

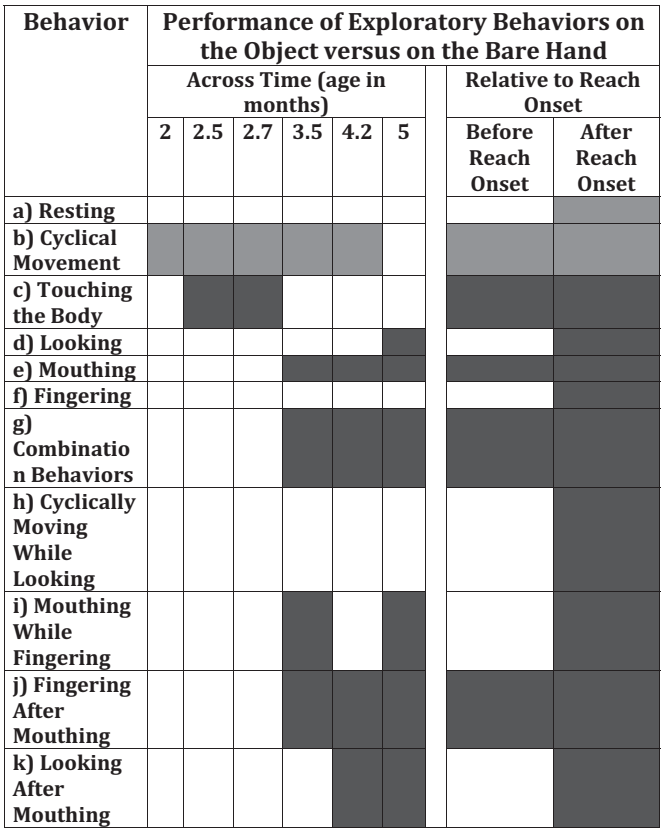

Fig. 4. Comparison of behaviors performed on objects versus on the bare hands. Performance of behaviors on objects compared to the bare hands relative to age and to reach onset for: (a) resting, or times when no behaviors were performed, (b) cyclical arm movement, (c) touching the body, (d) looking, (e) mouthing, (f) fingering, (g) combinations of behaviors, (h) cyclical arm movement while looking, (i) mouthing while fingering, (j) fingering immediately after mouthing, and (k) looking immediately after mouthing. White cells represent behaviors performed a similar amount of time for the object and the bare hand. Grey cells represent behaviors performed less with the object than with the bare hand. Black cells represent behaviors performed more with the object than with the bare hand. Significance was $\leq$.001 with age and $\leq$.002 relative to reach onset after Bonferonni correction for multiple tests. As infants aged and after reach onset, they became more discriminate in their interactions with objects and their bare hands. Although they continued to explore both, they spent more time performing most behaviors and combinations of behaviors with objects than with their bare hands.

4.2. What is the relationship between the behaviors infants perform with their bare hands and the behaviors they perform on objects?

Infants not only increased the amount and variety of exploratory behaviors they performed with objects after the onset of reaching but they also increased the amount and variety of exploratory behaviors they performed on their bare hands after this developmental milestone. Despite similar *patterns* of change for exploring objects and bare hands, infants did behave differently with objects. They amplified their performance of exploratory behaviors and combined these behaviors in novel ways more often with objects than with bare hands. Therefore, object exploration emerged from infants' self-exploration behaviors via amplification and combination.

These findings highlight several important points regarding the relationship between early self-exploration behaviors and developing object exploration behaviors. First, young infants are already actively engaging in exploratory behaviors to inform themselves about the affordances of their own bodies, objects, and the intersect of the two in the first months of life. Second, the emergence of reaching is a significant impetus for advanced object exploration as well as for advanced self-exploration. Third, the behaviors infants use to explore their own bodies and surfaces in the first several months of life may form the pool of behaviors from which they later choose as they begin to interact with objects.

This intimate relationship between self-exploration behaviors and object exploration behaviors may serve as one of the earliest examples of tool use in development. Infants' bodies themselves may serve as the first tool infants can use to act upon objects to gather knowledge, to learn to problem-solve, and to effect change in the environment. In order to explore objects, infants must learn to control their bodies, to understand that objects afford exploration, and to problem-solve ways they can use their bodies to act upon objects to effect their world (Gibson and Pick, 2000). The self-exploratory behaviors infants perform with their bare limbs in the first months of life likely teach them about the physical properties of their limbs and how to move them in coordinated manners through space (von Hofsten, 1997; Lobo et al., 2004). Although these

self-exploratory behaviors exist early in development, it is not until infants begin reaching and interacting regularly with objects that they show widespread adaptations of these self-exploratory behaviors when they are acting on objects. They amplify their performance of these behaviors and combine these behaviors in novel ways when they are acting on objects. This mirrors the process in the development of tool use of transitioning from single behaviors on single objects to multiple behaviors performed in the necessary order on multiple objects as exploratory experience leads to advanced problem-solving ability (Bruner, 1973; Inoue Nakamura and Matsuzawa, 1997; Keen, 2011) Our view aligns with other recent literature on tool use development in that it challenges the traditional view that tool use behavior is a purely cognitive behavior that abruptly emerges in the second year of life when infants develop advanced representational abilities (Lockman, 2000). On the contrary, the development of tool use is an ongoing and continuous process that occurs as infants explore their physical world and learn to use their behaviors to effect change (Gibson and Pick, 2000; Lockman, 2008; Smitsman and Cox, 2008). Our view expands the current thoughts about the development of tool use by suggesting that the body itself is the first tool infants must explore and learn to control in order to explore and effect change in the social and physical environment. Therefore, the transition from self-exploration behaviors to object exploration behaviors may be one of the first instances of tool-use in infancy.

4.3. Significance of the findings

The results of this study support the tenets that: (1) the ontogeny of object exploration begins early in the first half year of life as infants learn to selectively perform exploratory behaviors to learn more about the affordances of their bodies and objects, (2) the onset of reaching changes the way infants perceive their bodies and objects and is accompanied by significant increases in exploration of these both, and (3) early object exploration behaviors emerge from the adaptation of existing self-exploration behaviors.

These results have important implications for both basic and applied sciences. First, there is much to be learned about the ontogeny of cognition by studying the development of very early exploratory behaviors. Researchers interested in the origins of abilities such as problem-solving, means-end, and tool-use should be looking early in development to understand how these abilities emerge. Second, development is dependent upon ability and is grounded in one's everyday perception-action experiences within socio-cultural contexts (Thelen, 2000). This emphasizes the need for more studies using longitudinal designs with comprehensive, repeated assessments to better inform us about development processes in relation to ability and experience. Third, the results provide a foundation for early intervention researchers to design very early assessments and interventions aimed at minimizing future perceptual-motor, language, social, and cognitive impairments for infants born at risk. For example, by enhancing our understanding of how typical infants use their hands for exploration, we can design more sensitive and specific assessments to identify behavioral delays early in life. Furthermore, by enhancing our understanding of the developmental processes underlying exploration, we can design interventions to advance early exploratory abilities, for instance by advancing reach onset.

Although this study provides insight into the ontogeny of early exploratory behaviors, it leaves some important questions unanswered. For instance, the paradigm used in this study does not reflect the everyday exploratory experiences young infants have in natural settings. The infants were seated in special seats and the objects were attached to their hands with hook and loop bands. We need to understand how infants explore their bodies, surfaces, and objects through their typical daily experiences. Furthermore, we need to better understand how object exploration behaviors relate to the self-exploration behaviors infants perform when objects are not within reach. The behaviors described in the present study for the bare hand occurred at the same time an object was attached to the opposite hand. This informed us how infants shifted their focus to behave differently on the hand with an attached object. We do not know if infants would have behaved differently with their bare hands without an object present or how these behaviors would relate to reach onset and to infants' object exploration behaviors. These are important areas of focus for future research.

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