Paper

Human Development 2013;56:223–248
DOI: 10.1159/000351313

Human Development

Twelve-Month "Social Revolution" Emerges from Mother-Infant Sensorimotor Coordination: A Longitudinal Investigation

Kaya de Barbaro Christine M. Johnson Gedeon O. Deák

University of California, San Diego, La Jolla, Calif., USA

Key Words
Attention development · Distributed cognition · Infant development · Joint attention · Longitudinal design · Parent-child interaction · Perception-action · Social interaction

Abstract
Previous accounts of the development of triadic attention identify a "curious" shift around nine to twelve months. We introduce a novel approach inspired by distributed and embodied cognition frameworks. In a longitudinal study of five mother-infant dyads, videos of home play interactions were recorded over the infants' first year. We scrutinized the real-time organization of mother-infant sensorimotor activity, including the targets of hands, gaze, and mouth, as the dyad members attended to one another and to toys. We identified a pervasive developmental pattern: At four months, infants converged all sensory modalities on objects introduced by the mother. From six to twelve months, infants showed increasing decoupling of hands and eyes and increasingly elaborate sequences in *multi*-object play. Concurrently, dyads engaged in increasingly elaborate social exchanges (e.g., turn-taking) as mothers adapted to infants' sensorimotor skills. We therefore theorize that triadic attention emerges not as a novel form of social cognition but as a continuous product of sensorimotor development, scaffolded by parents' expanding social actions.

The period around an infant's first birthday marks a qualitative change in how the infant responds to and participates in the activity of adults. While, from much earlier months, infants will share gaze with a partner or gaze at objects manipulated

This work was part of a doctoral thesis submitted by the first author to the University of California, San Diego, La Jolla, Calif., USA.

KARGER
E-Mail karger@karger.com
www.karger.com/hde

0018–716X/13/0564–0223$38.00/0

Kaya de Barbaro
Department of Cognitive Science
University of California, San Diego
9500 Gilman Dr. # 0515, La Jolla, CA 92093-0515 (USA)
E-Mail kaya@cogsci.ucsd.edu

by a partner, at around twelve months they begin more actively to engage in shared actions on objects such as imitation and games [Bakeman & Adamson, 1984; Hay, 1979; Piaget, 1962; Ratner & Bruner, 1978; Stern, 1985; Trevarthen & Hubley, 1978]. These activities are "triadic" in the sense that they all involve shared attention and activity between the infant, an adult, and an external locus of attention such as an object or an event.

Previous research has shown that triadic attention is a foundation for later learning, including language development [Bruner, 1983], social skills [Bornstein & Tamis LeMonda, 1989], and cultural learning [Tomasello, Carpenter, Call, Behne, & Moll, 2005]. However, we know less about how triadic attention develops. Specifically, previous methods have puzzled researchers eager for a coherent developmental account of the processes that bridge to the dramatic "triadic shift" at twelve months [Adamson & Bakeman, 1991, p. 34; Fogel & DeKoeyer-Laros, 2007]. We aim, in this longitudinal study of naturalistic mother-infant interaction, to demonstrate how a novel approach to studying interaction can make headway on this putatively intractable developmental question.

Our approach comes out of recent theoretical and empirical work in cognitive science that takes as its premise that cognition is fundamentally embodied and distributed [Hutchins, 1995], and can be observed through the systematic microanalysis of multimodal, multiparty interaction. We will first give an overview of methods traditionally used to study triadic attention and consider how they have shaped researchers' interpretation of its development. Next, we review microstudies of infant attention, followed by an overview and motivation of an embodied and distributed cognition approach. Finally, we will describe the results of our application of a microanalysis of multiple attentional modalities in mother-infant interactions, and detail the implications of this approach for the distributed and embodied cognition that develops.

The Triadic "Shift": Previous Accounts

There is a broad consensus that mother-infant face-to-face interaction follows a three-part trajectory [Adamson & Bakeman, 1991; Tomasello et al., 2005]. First, from about two months, infants begin to be able to engage in dyadic states of "shared attention" with their caregivers. Here, shared attention is construed as jointly attending to one another's faces via gaze. Infants both initiate and respond to various facial expressions their caregivers make with increasing amounts of positive engagement. This has been observed both in observational and experimental studies. For example, when mothers are asked to stop responding to their infants by "freezing" their facial expressions, even very young infants will quickly become less positive and animated [Tronick, Als, Adamson, Wise, & Brazelton, 1978] and will make active bids to reengage the mother [Tronick, Ricks, & Cohn, 1982]. Next, starting at around six months, infants show a marked decrease in gaze and positive affect to their mother's face [Kaye & Fogel, 1980; Trevarthen & Hubley, 1978] and become much more attentive to the objects in front of them [Bakeman & Adamson, 1984; Bruner, 1983]. Thus again, it is a dyadic state which predominates the interaction, this time involving the infant and an object of interest. At this stage, infants will occasionally gaze up to the parent while attending to objects. However, they do not make systematic efforts to

involve their partners in their object exploration until near the end of their first year [Bakeman & Adamson, 1984].

Summing over years of research, Adamson and Bakeman [1991] describe a "curious developmental gap" (p. 21) between the dyadic states described above and the appearance of true triadic play around the infants' first birthday. Given that what they consider to be the two components of triadic play – that is, infant-mother interpersonal play and infant-object play – each predominate in earlier periods, it is not clear why infants do not readily or smoothly begin engaging in triadic or joint object play with caregivers. One sort of explanation for the late emergence of triadic play emphasizes a qualitative leap attributable to new conceptual and inferential resources. The explanation stipulates a dawning awareness that other people have "other minds" [Stern, 1985; Tomasello et al., 2005; Trevarthen & Hubley, 1978]. One claim of the work we will be reporting here is that the "gap," or discontinuity in the behavioral data, almost forces previous researchers to invoke an invisible representational shift to account for the development of triadic attention. Further, we suggest that the behavioral discontinuity is based on past researchers' choice of units of analyses and on how the resulting component parts that they consider limit their access to the processes involved in development.

Our embodied distributed cognitive account of a longitudinal sample of five infants at four, six, nine, and twelve months suggests that these new complex action and exploration patterns can emerge without the need for a conceptual "sea change."

By tracking each of the partners' access to others' activities in the world – their motions, words, and affect through space and time – we were able to identify a number of distinct action trajectories wherein activity builds on that seen at earlier sessions. This methodology is a boon to a developmental account in that it focuses on the changing processes of cognition that are visible rather than invisible. In doing so, it provides a basis with which to compare moments of interaction longitudinally across a developing dyad prior to and including the infants' first birthday [for a similar argument, see Johnson, 2001]. Our analyses lead us to argue that twelve-month complexity is not sudden or discontinuous but a culmination of continuous changes across the first year.

Before detailing our approach and our account of triadic development, we first review relevant past research into two categories: macro-level measures and micro-level measures.

Macro-Level Analyses

The majority of previous studies view the development of triadic attention in terms of "macro"-level changes in mother-infant face-to-face interactions. These can be considered macro both in the timescale at which phenomena of interest are tracked as well as in the unit of analysis. Hsu and Fogel [2003] and Bakeman and Adamson [1984], in historically detailed studies of developing mother-infant interactions, annotated their video with a single dimension – that is, they used a single "layer" of mutually exclusive state variables to classify relatively large time units within the interactions at the level of the dyad. For example, in their classic longitudinal study, Bakeman and Adamson [1984] use a one-dimensional coding scheme that distinguishes between the following six states, each referring to the focus of infants' atten-

tion during face-to-face interaction with their mothers: *unengaged, onlooking, persons, objects, passive joint,* and *coordinated joint*. Similarly, Fogel's "relational system" [e.g., Hsu & Fogel, 2003] codes at the level of the attentional coordination of the dyad. From that approach, Fogel notes, for example, whether the attention the dyad members display relative to one another is *symmetrical* (both attending to the same thing "actively"), *asymmetrical* (one partner viewing the other actively attending to an object, as when a mother might gaze to her infant as he manipulates a toy), or *unilateral* (one partner engaged in an activity and the other attempting to engage them in a second activity).

While these studies reveal systematic changes in attention across development, they do not indicate how such changes occur [for a discussion, see also Fogel & DeKoeyer-Laros, 2007; Forster & Rodriguez, 2006; Johnson, 2001].

Macro-studies indicate the high-level *products* of the interaction: what the dyad accomplishes during each episode of interaction. The categories are qualitatively different from one another such that we simply do not see anything similar to triadic interactions at earlier months. This leads to behavioral discontinuities between dyads with infants of different ages. In turn, this behavioral discontinuity provides little traction for explaining the age-related shift from one state to another.

Distributed and embodied cognition provide an alternative. In conceptualizing the interaction as a rich temporal configuration of component parts, we can observe continuous progress in measures that span the entire age range. By providing continuity across behaviors observed across the first year, we no longer need a discontinuous representational shift to explain the development of triadic attention.

Micro-Level Analyses

A number of more recent empirical studies track attention at the "micro" level, specifying the particulars of how the mother and the infant attend to one another and to available toys. Micro-level studies can be differentiated from macro-level studies in a number of dimensions, including the timing, specificity and comprehensiveness with which they code attentional behavior. Generally, timing refers to the units of time at which changes in attention are identified. By specificity, we refer to the precision with which attentional behavior is indicated via a particular sensorimotor modality such as gaze. Macrostudies often code a high-level construct of attention akin to the traditional psychological definition of attention as a unitary amodal "spotlight." This renders attention as an invisible, internal process. Instead, microstudies often specify the particular sensorimotor modality that comes into contact with the targets of attention. Finally, the majority of microstudies of infant activity specify gaze as the single sensorimotor modality by which their subjects attend. However, the utility of coding a wider range of modalities (e.g., hand, mouth, and gaze) and their targets in fine detail is becoming evident. Comprehensiveness refers to the degree to which studies code a variety of sensorimotor behaviors. Below, we review microstudies of attention relevant for our study. Overall, we argue that we need high resolution in timing, specificity, and the comprehensiveness of modalities in order to capture the development of sharing actions between mother and infant.

Many studies have shown the critical importance of tracking at the millisecond level when accounting for changes across longitudinal time. The majority of the mac-

ro-level studies described above code at relatively large temporal scales of once every second or even once every three seconds [Bakeman & Adamson, 1984; Cohn & Tronick, 1987]. However, attention to social information can occur at the much finer timescale of tens of milliseconds. This is relevant, for example, in that recent evidence from Yoshida and Smith [2008] suggests that older infants' gaze to caregivers might shift from longer periods of fixation to shorter but more frequent "checking-in" fixations. More generally, Deák, Krasno, Triesch, Lewis, and Sepeta [in press] found that dyadic attention states between caregivers and infants from three to eleven months of age changed an average of 31.7 times per minute. This suggests that coding intervals of any period longer than 1 s would certainly miss important changes in social attention; even with the largest acceptable interval of 1 s, many other events will be missed. However, many previous efforts to code attention-sharing and triadic attention used coding unit durations of several seconds. Thus, developmental changes of attention distribution within the ongoing social interaction were simply not captured by many past coding schemes.

A number of studies have started to specify moment-to-moment changes in the targets of gaze during social interactions. Detailing attention in this way has led to the finding that infants spend relatively little time looking at the face of their caregivers during their interaction with objects. Instead, they spend the majority of time (up to 80%) looking at hands – either their own hands or their caregivers' hands while those hands are in some sort of contact with the objects [Fiser, Aslin, Lathrop, Rothkopf, & Markant, 2006; Krasno, Deák, Jasso, Lewis, & Triesch, 2007; Yoshida & Smith, 2008]. This holds true for infants of a variety of ages and in naturalistic settings with many potential looking targets [Deák et al., in press].

By combining high-resolution gaze coding with fine-grained temporal analyses, Deák et al. [in press] identified that it is the motion of mom's hand on a toy, rather than the gaze of the parent, that best predicts infant gaze shifts from one location to another [Deák et al., in press; Yoshida & Smith, 2008]. By precisely coding specific attentional behaviors as they unfold in real time, these studies have identified patterns that contradict the conventional wisdom on early infant attention.

However, we know of no studies that detail infant attention in a dyadic context in a comprehensive manner, coding the full range of sensorimotor behaviors by which infants attend to their surroundings. While gaze is the modality most commonly associated with attention, developmentalists have long commented on the attending functions of other sensorimotor modalities. Eleanor Gibson [1988], for example, has written extensively about the importance of the hands to infant sensory exploration: Infants can, for example, rotate an object to view different angles or squeeze it to receive the sensations about its density and internal makeup [see also Streri & Feron, 2005]. Additionally, they can use hands to bring an object to the mouth, another key modality in the first year [Rochat, 1989].

A large body of work from the lab of Holly Ruff has determined that multimodal attention to objects has different physiological and cognitive consequences from simply gazing at an object. Ruff and her colleagues differentiate between "casual" attention which involves gaze-only, and "exploratory" attention, which involves concentrated gaze coordinated with certain types of haptic manipulation such as slow rotating or fingering an object [for a review, see Ruff & Saltarelli, 1993]. In comparison to gaze-only attention, exploratory attention is associated with physiological indices of increased focus such as heart rate deceleration [Lansink & Richards, 1997].

It also diminishes with object familiarity, decreases the likelihood of distraction [Oakes & Tellinghuisen, 1994], and inversely predicts future distractibility [Lawson & Ruff, 2004]. Thus, we anticipate that specifying between these will be important for characterizing attention development across the first year.

As a final motivation for a comprehensive tracking of attentional modalities, we note that we saw important differences in the way that infants responded to the mothers' actions on toys, but only when we considered the infants' manual activity in addition to their patterns of gaze. In the study by Deák et al. [in press] described above, all infants throughout the study period (from three to eleven months) showed similar patterns of shifting gaze towards a toy following maternal manipulation. In our own analyses (described below), we have found that there are indeed longitudinal changes from four to twelve months in infants' responses to maternal bids. However, these changes are in the nature of infants' multimodal contact with the object and how that unfolds over timescales of five to thirty seconds, rather than solely on their gaze immediately following the bid.

Embodied affect is another important dimension for characterizing the developing social attention in the dyad [Adamson & Bakeman, 1991]. Affect is studied via general arousal levels as well as facial expressions, especially relative to similar activity in the other. That affect and attention have an important relationship in infancy is clear from previous work showing, for example, that infants use gaze aversion and negative affect to regulate overarousal [e.g., Field, 1981]. Additionally, affect has been shown to have its own developmental course in coordination with other components of attention. For instance, by twelve months, infants have developed patterns of affect that are precisely timed with actions on an object and associated with the gaze to the mother [Eckerman, Whately, & McGehee, 1979]. Additionally, affect from the mother is important for the development of attention and later learning, perhaps via the social reinforcement that the infant is receiving for particular actions [Dodici, Draper, & Peterson, 2003]. In our study, we further observe that affect in the infants shifted from being attached to immediate events – the mom's smiling face, a toy tossed in his/her lap – to occurring within a larger routine – at the denouement of a game, at the recognition of an imitation, at the accomplishment of (or frustration with) a task, etc.

Summarizing, the current micro-level literature shows the relevance of the microanalysis of affect and attention, including the targets of gaze of both participants, as well as their manual actions. However, contemporary work is still too piecemeal to account for the emergence of triadic attention at twelve months. For this, we need a distributed analysis that situates analyses of embodied attention in the social interaction as we detail below.

Our Approach: Reconceptualizing Interaction

Our definition of attention for this work is based on theories of distributed and embodied cognition wherein activity of the body is considered cognitive activity [Clark, 2008; Hutchins, 1995]. Perception is not a passive process in which sensory information is displayed on the retinas. Instead, infants move and adjust their bodies in real time in order to identify and explore dynamic features of their environment [Gibson, 1988; Noë, 2004; Suchman, 1987]. Furthermore, infants do not just sense wavelengths of light, but they actively seek out differences in their surroundings via many types of sensory receptors.

This leads us to define attention as an effortful change in the sensory access of one individual to objects or other individuals [Johnson & Karin-D'Arcy, 2006]. Consistent with the neurobiological organization of human sensorimotor systems, we distinguish different types of sensory access including visual, oral, and haptic. Thus, changes in the targets of gaze as well as in manual and oral contact with toys and partner were all regarded as important in characterizing the attention of our participants. Furthermore, we distinguished between reaching towards a toy, grasping a toy, and manipulating a toy since each of these motor activities differs in the type and timing of the tactile and proprioceptive access that they afford.

Above we reviewed a number of benefits to operationalizing attention in this way. Moreover, by tracking dynamics of sensorimotor modalities as individuals gain access to targets, attention becomes a process that unfolds over moment-to-moment time. Studying the changing process of how infants' modalities become organized to attend to their caregivers and objects in the world around them provides a new window into the development of infants' attention. For example, we can characterize the dynamics of sensorimotor modalities as they become coordinated with a toy: How many modalities are on the toy; what order do they get there; how long does gaze remain on the toy given concurrent maternal elaboration, given concurrent infant manual elaboration, or given maternal elaboration of another toy? To give an example, our qualitative results show that gaze typically leads relative to other modalities in infants of all ages but that younger infants (four months) maintain gaze contact with the toy for the full duration that any modality is in contact with that toy, whereas older infants (six to nine months) may begin to look away once the hand has made contact with the toy, or even look away during the reach (at nine and twelve months). Thus, while reaching is visually guided at all ages, it depends on a decreasing level of gaze involvement as infants come to decouple their sensory modalities [see also Bushnell, 1985]. In this way, by documenting the microdynamics of how infants organize their sensorimotor modalities over developmental time, we can observe the variety of cognitive changes involved in the emergence of triadic attention.

Drawing from distributed cognition, we embed this analysis of embodied, multimodal attending in a triadic context of the mother-infant-object. From a distributed perspective [Forster, 2002; Hutchins, 1995; Johnson, 2010], the focus of research is not just on the elements of a system but on their configuration. A distributed account of ontogeny, then, is one of configural change. Given, for example, the multimodal data generated by embodied analyses, we can observe a set of elements that reconfigure as the infant ages. Many of these elements (such as touch, eye contact, visually tracking a proffered object, etc.) are common to all ages. However, at each age, these elements organize relative to each other and to new behaviors (like "reach" or "stack") in a distinctive way. By characterizing such changes in organization, the distributed approach can help provide a coherent account of the transitions involved in the development of triadic attention.

The distributed approach is well adapted not only for data that are multimodal but also for those that are multiparty. In the development of triadic attention, there are many critical relationships such as eye contact, imitation, altering the other's access to the toy, etc. that cannot be specified by the behavior of one subject alone. For example, when a mother "presents" a toy, the criteria for scoring that event include both the mother's grasp and extension of the object as well as the infant's available line of sight to that object. Taking interaction as the unit of analysis is a key characteristic of the dis-

tributed approach. From this view, the infant's ontogenetic challenge is not to perform particular, prespecified actions but to adapt to the conditions embodied by the mother's activity, which in turn are adjusted in response to the infant's current behaviors.

Furthermore, we can describe pronounced individual differences in the mother's tendency to act contingently with her infant that help shape how and when the infant engages. Thus, rather than assigning binary performance scores (e.g., whether the infant does or does not "attend" at a given age), distributed analyses produce "profiles of participation" [Forster & Rodriguez, 2006] that reflect the coregulation of activity within a dyadic interaction. Assessed longitudinally, such analyses can reveal the developmental course of changes in mother-infant-object coordination.

The study of cognition from this approach also highlights a tenet of the distributed cognition approach: Cognitive events are multiscalar – i.e., unfolding simultaneously at the micro-, macro- and historic-developmental timescales [Hutchins, 1995]. To produce a coherent distributed account of cognitive development, information must be collected at all these timescales. At the microsecond scale, we observe shifts of gaze, facial expression (e.g., gleeful smiles), and hand movement. At the macroscale, a particular look or grasp is positioned within an ongoing routine where, for example, it may repeat (as in peek-a-boo), or change, or organize with other events. At the historic-developmental timescale, the dyad's long-term experience with such routines (e.g., a playful father's tendency to initiate exciting games) comes into play.

In the study reported here, a monthly six-minute sample of free play was recorded from infant-mother dyads at home. For the current analyses, we observed episodes from when the infant was four, six, nine and twelve months of age. By tracking the details of these interactions across months, we can capture relevant changes at both the micro- and macro-levels. Of course, making inferences about these historic shifts requires interpolation and induction. We do not know how often and at what ages a given mother-infant dyad has played, for example, "peek-a-boo" or "build-up/knock-down" games. Nonetheless, some historic relations are directly observable, by comparing configural change across months. For example, we can describe long-term changes in the extent and nature of scaffolding by the mom by observing how her bids for the infant to attend to objects vary over developmental time. That is, the level and placement of motor activity by the mom clearly changes as the infant ages, from elaborate movements and expressions repeatedly directed at the infant's immediate frontal space in the earlier sessions to only a distal object touch and glance at the infant by twelve months. Together, assessments at these different timescales enable us not only to see cognition in action but to watch it develop as well.

While a multimodal, multiparty, multiscalar account can become very complex very quickly, its grounding in the embodied activity provides a straightforward approach that can reveal both significant pattern shifts and unexpected continuities. At each age, we will describe the same set of variables and participatory event types. These include the type and number of attentional modalities directed to each target, the order and rate of modality-specific transitions between targets, the contingencies between the participants' activities, and the type and timing of accompanying affect. We can thereby document how the organization of these elements changes as triadic attention develops. Each description will also include how "maternal bids" in which the mother directs the infant's attention to a different object are coordinated at each age. As we shall see, these interactions *and* their constituent microbehavioral elements configure differently over time as they become organized into routines that are

increasingly prolonged, attentionally divided, and eventually embedded. Through this approach, we can observe how constraints on the infant's motor development – for example, decoupling the hands to simultaneously contact multiple objects – shape how the infant responds to maternal toy bids. In this way, we argue, an embodied developmental change (i.e., manual action behaviors) directly feeds into developmental changes in distributed, dyadic-participatory changes. This provides an illustration of how this approach, using embodied and distributed analysis to parse complex social interactions at multiple temporal and behavioral units, can address the cognitive and behavioral complexity that emerges in very elaborate social interactions such as infants' triadic interactions with caregivers.

Method

Participants

We selected a random sample of five mother-infant pairs from the corpus created for the Modeling the Emergence of Shared Attention project [for more information about PI, NSF SES-0527756, see Deák et al., in press]. The full corpus included data from 40 mother-infant pairs who were assessed twice monthly, once at home and once in the lab, from three to nine months, and then at twelve months. For the study described here, we used video recordings of home session free play interactions occurring at four, six, nine, and twelve months.

All infants were tested within two weeks of turning four, six, nine or twelve months. All primary caregivers were the biological mothers of their infants. All were married and living with a secondary caregiver. The caregivers' mean age was 31.9 years (range = 28–38) and the mean education was 15.6 years (range = 14–18). Four of five infants were first-born, one was later-born. Their ethnic backgrounds were Caucasian (80%) and multiethnic (20%). No infant had significant medical or cognitive problems.

Procedure for Free Play Interaction

At months four, six and nine, infants were placed in modified walkers in order to control for individual differences in postural stability and height of young infants. At the twelve-month session, mother and infant were both seated on the floor. Floor seating was preferable at this age because twelve-month infants become fussy at being confined to the chair. Furthermore, all infants were able to sit upright at this age, so it was no longer necessary to provide additional stability to control for upright posture. This was important for the younger infants since it affects their ability to reach [Fogel, Messinger, Dickson, & Hsu, 1999]. In all cases, the mothers were seated on the floor facing and within reach of their infants.

At each session, a set of three toys were placed between the mother and the infant. All mothers were instructed to "play as they normally would" with their infants, using the toys as they felt fit. At four- through nine-month sessions, two of the toys were placed in specially mounted cup holders at the sides of the walker tray. At these sessions, mothers were instructed to leave only one toy on the tray at a time, and to return the others to the cup holders. At twelve-month sessions, there were no cup holders, and mothers were not given further instructions to constrain the number of toys in active play. Thus, while there were some differences in the setup and instructions between the four- through nine- and the twelve-month sessions, at all ages multiple toys were simultaneously accessible to both mother and infant, both visually and manually.

At each session, three cameras recorded the interaction simultaneously: one directed at each of the faces of the participants, and one positioned in order to capture a side or "contextual" view of the dyad interacting with the toys. The free play session was recorded for six to seven minutes at each session.

Observational Methods

For approximately nine months, de Barbaro and Johnson spent between three and four hours each week viewing and discussing the subsample of twenty free play sessions (five dyads times four longitudinal sessions). We observed each video many times, occasionally viewing the sessions of a single dyad in longitudinal order and occasionally viewing all dyads at a single session as befitted clarifying individual observations into a pattern of results. During the process of writing, we frequently returned to the videos for additional verification. For the reasons described above, we watched the tapes with the explicit goal of characterizing the interactions as organizations of multimodal, multiparty components in real time and focused on the mothers' and infants' attentional resources as they engaged with each other and the toys. In particular, we paid close attention to the targets of attention of gaze, mouth, right hand, and left hand of the infant and the mother as well as the position of each of the objects as they were manipulated and transported by the participants. We also noted displays of affect in both the mother and infant and, to some extent, their vocalizations. We were particularly concerned with identifying variability across the longitudinal sample as well as regularities that occurred within sessions. Our descriptions were highly detailed and thorough and revealed multiple developmental trajectories of interest (described below). These trajectories function as results in their own right; additionally, we used these results to ground a more systematic, quantitative account of some elements of the development of triadic attention [see de Barbaro, Johnson, Forster, & Deák, under revision; for methodological considerations for pursuing the distributed approach we describe here quantitatively, see de Barbaro, Johnson, Forster, & Deák, in press].

Results

For each group of sessions at each age, we will first describe the pattern of sensorimotor coordination that we observed in the infants and then describe the nature of the dyads' interactions at that age. The latter will focus, in particular, on maternal bids for the infant's attention to objects and the infants' responses to them.

Four-Month Sensorimotor Coordination

Sensorimotor coordination in four-month-olds can be characterized as "convergent." That is, all the infant's attentional streams tended to converge on one single target at a time. Vision generally leads, followed by hands, then mouth. If only one hand made contact, it might rhythmically slap at the object, repeatedly rub all five fingers on it, or sweep it toward the body. Often, two hands working in concert, mirroring the same motions, would clasp the object. Gaze to the object cooccurred for the full duration of such contact. Often the hands then brought the object to the mouth, allowing oral attention to supplant visual attention. Alternatively, infants would bend their bodies to make direct oral contact with an object on the tray, even if one or both hands were already touching the object. Visual fixations on targets were relatively prolonged at this age. When a change in target did occur, the transition was fairly slow, with all of the infant's modalities shifting to the new target, with eyes leading hands, and the previous target being fully abandoned. If the attentional shift was to the mother's face, the hands might release a previously held object.

Four-Month Dyads

Mothers engaged in their most active scaffolding at this age. This commonly included grasping an object and moving it to loom in the infant's near visual field. The mother would often also pivot or rhythmically shift the object. While mothers showed individual differences in their tendency to engage their infants, all mothers presented objects, and all smiled and talked when they did so. The mothers were also most likely, at this age, to swoop their own faces into their infant's near visual field, soliciting and usually achieving eye contact. Although infants individually varied in how prone they were to look toward their mother's face, when that did occur, both eye contact and joint positive affect (smiling) tended to be prolonged.

When mothers made objects loom near the infant's face, this also brought the objects within the infant's reach. However, at this age infants seldom extended their arms; they kept their hands relatively close to the body, although their hands, and especially their fingers, were continuously active and highly responsive to opportunities to touch the objects. Thus maternal scaffolding at this age was critical for infant haptic contact with toys. Mothers were most likely at this age to place an object in contact with the infant's hand or even to move the infant's hand to an object. Infants most often responded positively to such bids, immediately clasping the object and sometimes adding visual, haptic, and oral attention to it.

At all sessions, mothers instigated a high number of object switches. An object switch was characterized by the mother's bid interrupting an ongoing bout of multistream attention to a previous object which the mothers would often remove before introducing the novel object. In response to maternal bids, four-month-old infants would readily shift all of their attentional streams to the novel object. This shift was gradual but complete, even if the infant had gazed towards or reached for the departing object. The infants showed little of the negative affect that they would display at later ages in response to such object exchanges. In fact, we characterize flow of attention following the bid at this age as *well-coordinated,* with mothers making frequent bids and the infants complying.

Six-Month Sensorimotor Coordination

Infants at this age frequently reach, grasp, and retrieve nearby objects. Reaching was visually guided, with eyes leading the reaching hand to within grasping distance. The infant's capacity to grasp and manipulate an object was better developed. Once grasped, the object was often brought closer to the body in a bimanual grasp. As at four months, infants often mouthed the object, although typically by using the arms to lift the toy to the mouth rather than bending the torso. As objects were being reached for, infants often opened their mouths as if in anticipation of oral contact.

Unlike at four months, infants were not as bound to look at whatever object they were touching. That is, the infants visually guided their reach for an object but thereafter could decouple their gaze (e.g., to a novel object) while they continued to grasp the original object. The grasping hand would often be passive while the eyes and other hand haptically explored a novel object. At other times, the grasping hand would position the object where it could be easily accessed by the other modalities. For example, both gaze and the active hand could be directed at the object, the latter

doing exploratory contact while the grasping hand continued to position the object. These infants would not, however, grasp two objects simultaneously. On the relatively few occasions when they both grasped and gazed at a novel object, the original object would tend to be left behind as the divided system "collapsed" into a new configuration of convergence on the novel target. Thus some visual and exploratory haptic attention could be directed at one target while a grasping hand maintained contact with another, but there was a strong tendency for such divided attention to shift such that all the attentional streams returned to the object that was being, or had been, grasped.

Most strikingly, six-month-old infants more consistently tracked and maintained prolonged attention to a target. Even after haptically exploring a novel object, infants tended to return their gaze to the previously held object. When previously attended objects were removed by the mother, the infants often tracked the object during removal and redirected hands (and mouth) to it once relocated.

Six-Month Dyads

Infants initiated their own haptic access to objects, even if their mother had redirected their attention. This impacted the dyad's social coordination. As at four months, gaze was the first modality to shift to an object that the mother moved in the infant's frontal field [see Deák, et al., in press]. However, infants were then less likely to reach for that target. Rather, they looked back at their own still-grasped object. As a result, infants less often converged their attention on a novel object presented by the mother. Also, overall there was less mutual cogaze between the partners at this age. Finally, infants occasionally showed negative affect when their mothers attempted to remove an object of their attention. Negative affect was expressed as frowning or by rearing back the body or gaze [Field, 1981].

Mothers did less active scaffolding at this age, perhaps, in response to the infants less often accepting new objects. Mothers also abandoned their bids at this age and followed infants' attention back to their current object of attention. Nonetheless, maternal bids sometimes succeeded, typically if the mother persisted and especially if she managed to remove the original object. In either case, we classified the dyad's coordination as *disrupted*. That is, maternal bids tended to disrupt the infants' ongoing, directed activity, and attentional resources were thus actively and variably negotiated rather than all smoothly following the mother's lead as they had at four months. Note that "disrupted" is not meant as an evaluative label – indeed, it appears to indicate a more mature strategy – but rather describes that the flow of infant's attention does not consistently follow the mother's bids as it did at four months.

Nine-Month Sensorimotor Coordination

Sensorimotor coordination at nine months was marked by rapid, fluid transitions, reiterated routines, and an increased tendency to handle two objects at once. Compared to earlier months, the progression from gaze to reach to grasp to manipulate was fluid and facile. Unlike at six months, infants could divert their attention (including grasp and manipulate) to a novel object, but quickly return full attention

to the prior object. Furthermore, infants' tendency to look back and forth between two objects, and then commit attentional streams to one of the objects appeared more controlled and less compelled by exogenous, "in the moment" salience.

The exploratory routines at this age also changed in type and redundancy. At six months, infants maintained possession of an object for longer periods and used a consistent basic set of simple manipulations (e.g., shake, hit, mouth). In contrast, at nine months, although infants switched objects more frequently, they tended to repeat object-specific routines (e.g., bang the toy or make it spin) many times in succession, sometimes punctuated by looking at their mother (see below). This is reminiscent of Piaget's description of secondary circular reactions [Piaget, 1954] but interleaved with gaze to partner. Also, nine-month-olds tended to "follow through" by directing a focused gaze to the objects when their action had an effect (e.g., dropping an object and then leaning to stare at it on the floor; slapping an object to make it rock, then pausing to watch). Also, infants' manipulations were more diverse and seemingly selective as well as more articulate. For example, infants touched one object with another or carefully stroked, rubbed, or pinched a part of an object, sometimes contacting the object with only one or two extended fingers or lifting with precision (e.g., forefinger to thumb grip). These actions were suited to the specific affordances of the object [Bourgeois, Khawar, Neal, & Lockman, 2005; Lockman, 2000].

Most markedly in the videos at this age, the infants frequently had two hands engaged at once, with a different object in each hand. Similar to six months, one hand would passively maintain contact with (usually grasp) one object while the other actively manipulated the other object. However, although at six months the active hand did not grasp the object being haptically explored, at nine months the active hand would grasp, lift, and manipulate this object. Gaze was usually directed at the active hand but shifted to the passive hand soon before they started manipulating that hand's object. Both hands were simultaneously active only when jointly manipulating one object or bringing it to the mouth.

Nine-Month Dyads

Infants' transitions between objects were based both on their own initiative and mothers' presentations of new objects. Infants did not always take up their mother's bids, but when they did, they fully engaged the new object. However, unlike at six months, they did not then abandon the original object. Also, infants stopped showing negative affect to mothers' bids, although they often tried to retrieve the object that she had removed. We characterize the flow of attention in these interactions as a *divergent* or *distracted trajectory* following the mother's bid. That is, the mother's bid did not disrupt the infant's momentum in attending to the previous object; instead, the infant could coordinate multimodal attention to the mother's bid for extended periods of time without losing track of their previous activity.

Perhaps because of infants' increased tendency to initiate and repeat particular object manipulation routines, mothers presented new objects less frequently. They also tended to shift their own attention to the object of the infant's engagement, and, for the first time, even imitate or facilitate the infant's actions. Alternation of actions was more common at this age, and infants sometimes paused to watch their mothers and then resume their own activity.

Although mothers did most of the imitation, infants occasionally imitated mothers. This involved actions the infant had produced earlier (e.g., banging an object) but now repeated immediately after the mother and sometimes followed by smiling at the mother. Also, bouts of turn-taking were sometimes followed by mutual gaze and positive affect. Although such events were infrequent, every infant had at least one such sequence.

Twelve-Month Sensorimotor Coordination

At twelve months, infants showed improved bimanual organization, more differentiated articulation, and longer, more elaborate routines.

As at nine months, the two-hands/two-objects pattern was common, as was the one-active/one-passive pattern. Infants still sometimes directed both hands to a single object. However, at twelve months, infants were bimanually coordinated. That is, at nine months, when both hands were active, they were only directed to a single object. By contrast, now each of the hands would grasp *and* manipulate separate objects. In this case, their hands most often mirrored one another, resulting in activities such as clapping the objects together or touching or rubbing them together.

This active bimanual coordination was also visually mediated in a new way. At nine months, when each hand grasped an object, whichever one the infant looked at was the active hand. At twelve months, infants looked rapidly back and forth between the two objects or gazed between them, viewing both simultaneously during bimanual activity. Infants also seemed to visually attend to particular parts of the objects. For example, we observed an infant repeatedly "run" a toy ladybug along a surface, then turn it over and visually examine the wheels on its underside. Such focused "inspection" often entailed holding the object with one hand and actively probing it with the other.

Twelve-month-old infants continued to repeat action routines, but routines were longer and included more different actions and foci of attention. For example, an infant might pick up and squeeze an object, then shake it, and then repeat the more elaborate sequence. Infants at twelve months also began to embed subroutines into longer manipulative sequences. For example, we observed an infant who was holding two blocks adjust one to align its face to the other before clapping them together. Some routines resembled the experiment-like "tertiary circular reactions" described by Piaget in which the infant explored a variety of actions both novel and familiar, each producing the same specific effect on the object. For example, we observed an infant squeezing a rubber toy using one hand, two hands, a full fist, just the fingers, and by pressing it against the floor. Finally, at this age, infants often verbalized, both while handling objects and while watching their mothers (see below).

Twelve-Month Dyads

The most pronounced change at this age was in the coordination between mother and infant, mediated by changes in both the infant's and the mother's behavior.

Mothers' actions on toys appeared to have a novel appeal. If the mother and infant performed a similar action in synchrony, the infant could show a ratcheting-up

of his/her arousal, eye contact, and an exchange of positive affect. For example, one infant lifted an object with two hands. The mother then raised her two (empty) hands, and this mirroring action captured the infant's attention and led to eye contact and mutual laughter. Thus, at twelve months, synchronous similar coactivity appears pleasant for both participants.

Infants often paused their haptic activity to watch their mother perform particular actions with an object. This response was now embedded in a new sequence. Whereas nine-month-olds would manipulate their objects, pause to watch the mother, and then resume their original manipulation, at twelve months, infants sometimes modified their activity upon resumption. For example, the infants might return their gaze to the held objects and engage in the observed activity with those objects. Alternatively, infants could engage with the mother with the same objects she had manipulated by alternating possession of the object. Finally, the infant might pick up a new object or two and engage in the observed activity with those objects instead. Occasionally, infants engaged in considerable effort and multiple strategies in the process of reproducing the outcomes of the mothers' activity. For example, one infant spent many minutes unsuccessfully "stacking" blocks, first balancing one on top of the other vertically and then horizontally, and only eventually succeeding by placing the first block on the ground and placing the other on top. The infants' persistence at and variability within such routines gave them the feel of "projects" in which the infants now incorporated elements of the forms of the mother's manipulations.

Oftentimes during these efforts, infants stopped to return their gaze to the mother's hands. When this occurred, mothers tended to respond contingently by repeatedly demonstrating the target action in the infant's field of view. While frustration in these settings typically led the infant to look at the mother's hands, success led the infant to look at the mother's face and show positive affect, or, alternatively, success did not lead to changes in affect or shared gaze [for similar observations, see Ross & Lollis, 1987].

Projects fit the classic characterization of *triadic* interactions. Other triadic interactions at this age included a new configuration of activity in which infants grasped an object and then extended it toward either the mother's hand or, less often, her face. Mothers seemed familiar with this behavior, as they readily held out a hand to receive the object, often looking between it and the infant's face, and even anticipated it with a "requesting" gesture, positioning a hand to receive the object even before the infant extended it. Such "giving" routines never occurred at nine months. Another type of triadic interaction was turn-taking bouts, in which alternating actions would be repeated by the dyad with the particular actions changing little over the repetitions of the sequence. These often involved infants replicating the mother's action. Such actions encompassed object manipulations, changes in posture, and vocalizations (e.g., nonverbal sounds or "sound effects" for the objects). Finally, triadic interactions emerged as complementary actions within a shared routine. One mother, for example, put a cover over a toy, turned to the infant, and performed a gesture complex that included spreading her hands, shrugging her shoulders, and asking, "Where is it?" The infant watched her, then pulled off the cover, looked up at the mother, and expressed positive affect. The dyad then repeated this sequence.

The increasingly formalized alternation of sequences of coordinated activity, or "roles," were demonstrated in a number of ways. First, the infant's activity did not go forward unless the mother performed her particular behavior. If the mother failed to

repeat her actions, the infants could respond to this situation with negative affect. Alternatively, infants performed their next actions in the routine as a way to "solicit" the mother's further participation. For example, we observed that a mother squeezed a toy to blow air on the child's cheek. After several iterations, when the mother refrained, the infant looked toward the mom, then turned his cheek toward her and vocalized a "whooshing" sound. In this way, the infant supplies many elements of the absent routine, including positioning his body in a way that previously afforded engagement (i.e., lifting and turning his cheek) and simulating the sound the toy would produce if the mother did her part.

While the infants were clearly initiating many of these interactions, mothers continued to play an active role. As at nine months, mothers imitated their infants' actions. Mothers also facilitated infants' ongoing activity as in the past but with new subtlety. Because the infant's activities were now more elaborate multipart sequences, mothers could shape and time their contributions to particular aspects of an activity. For example, upon seeing her child's difficulty in squeezing a block, one mother demonstrated a two-handed squeeze. When she had got the infant's attention, she briefly froze her hands in an exaggerated fingers-spread position, closed them slowly on the object, and then slowly reopened them. She then asked, "Can you do that?" and allowed the infant to take it from her.

Mothers also used more directive language, gestures and symbols with their infants. Patterns of maternal speech to one-year-old infants have been documented in many studies [e.g., Adamson & Bakeman, 1984; Bates, 1979; Goldfield, 1993]. We are preparing a report of speech and gesture content during these interactions and their contextual embedding in dyadic interaction. For the present, we note that mothers used speech in more elaborate ways than in previous sessions: They drew infants' attention to objects and actions, named specific objects and "shaped" their verbalizations to fit the current activity. Also, mothers more often pointed to objects to direct infants' attention. At earlier months, mothers would occasionally point to objects that their infants were already attending. In contrast, at twelve months, mothers pointed to novel objects or configurations not currently being handled, sometimes not even within the infant's reach. For the first time, mothers pointed to details or parts of objects to which the infant was attending, as if to show the infant particular features [see Zukow-Goldring & Arbib, 2007]. Finally, mothers now began to use other manual gestures – for example, extending the hand palm up in a "requesting" gesture or waving while saying "bye-bye." The mothers made a special effort to align these gestures with the infant's gaze or waited until the infant turned toward her to perform them. Moreover, these gestures were coordinated with speech and with the current activity (e.g., holding up two fingers while saying "two," clapping while singing "If you're happy and you know it …"). Thus, rather than only positioning objects where they could best be visually (and haptically) accessed by the infant, the mothers were now commonly positioning gestures and acting in such a way as to make them especially salient. Certainly mothers were driving all of these symbolic embeddings, but infants occasionally made efforts to copy a gesture or to vocalize in synchrony or alternation. Thus, at around twelve months, we saw dramatic increases in what Adamson, Bakeman, and Deckner [2004] have called "symbol-infused joint attention."

Altogether, these changes show a mutual adaptation: of scaffolding on the mother's part to the infant's growing abilities, and of attention and action on the infant's part to the opportunities afforded by the mother.

In sum, at twelve months, infants' attention was neither *disrupted* nor *distracted* by the mothers' bids but, rather, they often incorporated the mothers' activity during the toy bid into their own object activities. Both participants in the dyad showed more adaptive readiness and behavioral range to engage in and promote collaborative activity. The conjunction of mothers' use of speech and gestures, their refined tactics for scaffolding, and their engagement in ritualized activities produced distinctive triadic interactions. As a result, we characterize these interactions as *well coordinated.* Note that we *also* characterized interactions at four months as *well coordinated* due to how highly labile infants' attention was to maternal bids. At twelve months, infants also readily followed their mother's bids for attention, but the dyadic coordination shows a very different level of complexity.

Discussion

Developmental Trajectories

Based on our observations, we propose a set of developmental trajectories that characterize the increasing sophistication of mother-infant-object sensorimotor coordination over the first year (table 1). These trajectories include an increasing number of loci of attention, refining haptic articulation, the emergence of routines, and increasing continuity between episodes of activity. By contrast, we propose that some elements were present from the youngest age: shared interest in dyadic activities and the dyads simple-yet-coordinated attention to objects. Changes in dyadic social interaction parallel changes in infants' attending to objects across the first year. As infants show more complex behaviors with objects, they produce ever more complex responses to their mother. Mothers' behaviors towards the infant and the objects also changed and diversified. By altering the infant's environment and the affective expressions she associates with it, she too helps shape each interaction and thus contributes to how triadic attention develops. Our analyses led us to argue that twelve-month complexity is not sudden or discontinuous but a culmination of continuous changes along these trajectories.

Consistent Properties of Interactions across the First Year

Coordinated Arousal and Attention. From the earliest months, infants show positive affect including smiling and laughing during play with their mother. At four months, mothers often initiate reciprocal affect [Hsu & Fogel, 2003]. The joint positive affect of interactions at the earliest months foreshadows the more complex interweaving of affective exchanges and shared activities in later months.

Dyads also coordinated their actions and attention to objects from the first months. Four-month-old infants found their mother's object in hand highly salient, and mothers used objects to deliberately draw infants' haptic and visual attention. While such *well-coordinated* attention does not reappear until twelve-month sessions, this "you touch, I touch" might be a rudimentary pattern that leads to mirroring a partner's actions at the end of the first year.

Table 1. Developmental trajectories

Co-arousal	Loci of attention	Haptic articulation	Emergence of routines	Continuity of actions	Maternal scaffolding
4 months					
Eye contact pleasantly arousing for both	All modalities converge on one target, abandon previous	Bimanual, symmetrical clasping, bring to mouth; undifferentiated fingering	One simple activity at a time	One simple activity at a time	Mom looms own face, initiates eye contact and positive affect; waggles object in hand in line of sight, touches infant's hand (give)
6 months					
Infant directs some negative affect, esp. when mother removes attended object	Can passively gasp one target, while looking to/touching another; returns to grasped object; too much active attention shifts all modalities to new target	Extend arm, grasp, retrieve object; simple exploratory manipulations (hit, rub, grasp, push away, etc.)	"Meander" through a series of simple exploratory manipulations on a single object	Track object over delay, but at return begin a different type of manipulation rather than return to prior	Mom follows infant's attention to object and facilitates its further access
9 months					
Mom initiates positive co-arousal over "co-same" (when imitating infant's action)	Fluently alternate between loci; easy transitions between active/passive manipulation	More elaborate sequences and more precise, affordance-dependent handling of object; simple embedding (e.g. hit with object in hand)	Multipart sequences; iterate rapidly with overlapping timing; follow-through, actively observe consequences	Routines retained over time, including over active handling of a different object	Mom imitates infant sequences, w/exaggeration and positive affect; mom complements familiar routines
12 months					
Infant initiates positive affect upon his/her own imitation of mom's action; infant looks to mom's hands in frustration, to mom's face in success; infant initiates giving	Multiple loci: e.g., infant gazes to mom's object in hands, then manipulates own objects with elements of mom's form incorporated	Refined embedding (e.g., adjust object in hand to suit act with other object in hand); variable actions that have same effect on object; extend object in hand (give)	Games involve repeated sequences of actions across dyad performed in alternation; longest persistence, esp. at outcome-based "projects"	Repeat not only own actions, but also mom's (i.e., infant imitates mom)	Mom precise demonstrations, some performed in viewing but not touching distance from infant, consistent with infant's "project"; mom point and gesture

Note that all earlier stages are also seen at later ones.

Changing Properties of Interactions across the First Year

Multiple Loci: Decoupling Attentional Streams. Over the first year, infants gradually came to attend to several objects simultaneously [for a similar pattern of results, see Belsky & Most, 1981; Bruner, 1973; Fenson, Kagan, Kearsley, & Zelazo, 1976; Kotwica, Ferre, & Michel, 2008]. At four months, attention was "all or none" towards a single object whereas, at six months, infants could grasp one object while gazing at and reaching for another. Yet when mothers presented another object, six-month-olds looked like an unstable dynamical system, teetering on a ridge between one object and the other. Their difficulty seemed to be reflected in overarousal (e.g., gaze aversions) and negative affect. By nine months, all infants easily alternated activity between two targets of attention without negative affect. However, they held objects apart and did not gaze at them simultaneously.

The transition to attending to multiple loci also involved a gradual decoupling of the visual and haptic modalities. At four months, when exploring an object, gaze and touch were virtually inseparable. At six months, infants visually mediated their reach until the object was collected but could then direct gaze elsewhere. At nine months, they could shift gaze rapidly between objects and even look and reach to the next object while still examining the current one. Thus, changes in the timing of coordinated actions allowed the incorporation of an increasing number of loci within a behavioral routine. The mother's face, a focus of interest from the beginning, also shifted from being a separate, momentarily all-consuming focus of attention to one among several attended targets.

Haptic Articulation. Within episodes of object exploration, several changes were observed. In terms of hand shapes and adaptation of actions to object properties, there was predictable refinement. At four months, object handling was bilateral and symmetrical; at six months, infants often "meandered" through a variety of simple, exploratory manipulations; at nine and twelve months, they produced small elaborations and precise, affordance-dependent touches.

Emergence of Routines. Between the fourth and ninth sessions, we saw a slow emergence of repeated multipart sequences of actions within the infants' object play, which we called "routines." At four months, the undifferentiated fingering provides little evidence for organization of actions. At six months, manual actions are more differentiated, but organization is still simple: infants appear to meander through a variety of simple, exploratory manipulations on an object. At nine months, infants were able to chain together a series of simple actions into sequences which they fluently repeated. The repetition of the sequence of behaviors indicates that the infants have learned that each action is preceded by and follows another. They also began to show "follow-up" attention to objects upon which their own actions had had a visible impact – for example, gazing at objects that had fallen off the tray. Here again, the infant has chained together a sequence of activities wherein falling is followed by the outcome of being on the ground. By twelve months, these multipart sequences evolve to be performed across the dyad such that some elements of the chain are enacted by the mother, and some are enacted by the infant.

Human Development 2013;56:223–248
DOI: 10.1159/000351313

Extending Continuity of Action. At four months, infants' convergence of attention on one object and utter distractibility by the mother's face suggest that there is little continuity between one action and the next. At six months, infants did not manipulate objects in a consistent way over time. In contrast, at nine months, upon returning to a previously attended object, infants tended to repeat their previous actions on that object even after a delay or intervening activity. At twelve months, infants not only repeated their routines but also incorporated their mother's actions. Thus twelve-month continuity entails not only attending to multiple loci but also parsing or recognizing the mother's activity on an object and reproducing this activity on another object.

Parsing Action Trajectories. In order to imitate their mothers' actions, infants must take what is available from the visual input of their mothers' actions and translate that into motor commands that they can perform with their own bodies. We conceive of actions as a complex, dynamic input pattern that must be recognized and segmented (parsed) into a sequence of simpler actions (e.g., reaching for an object, shaping the hand, grasping it, bringing it towards oneself, and manipulating it). Typically each step has a nested substructure of very specific moves (e.g., reorienting blocks in a series of small adjustments in order to align them). The complexity of this structure that usually looks smooth and effortless becomes apparent when it is compromised by neurodegenerative disorders [Sainburg, Poizner, & Ghez, 1993]. Moreover, recognizing motor sequences from visual input is a challenging task. Indeed, it is considered one of the most difficult problems in machine vision [Jhuang, Serre, Wolf, & Poggio, 2007]. In order to imitate, infants must recognize these actions despite differences in orientation, body size and available motor skills [Wohlschläger, Gattis, & Bekkering, 2003]. The infants' experiences over the first year might contribute to progress in infants' recognizing their mothers' actions from visual input.

Over the first year, infants have repeated experiences of reaching, grasping, and manipulating. Eventually, they combine these actions into repeated multipart sequences of actions. Additionally, as their articulation becomes more refined, infants increasingly modify their behavior to the affordances of the objects. We suggest that the infants' observation of self-generated actions may contribute to their attunement to the refined, multipart actions of their social partners and to the infants' recognition, differentiation, and organization of this activity into elements that they can replicate.

Changing Maternal Scaffolding. Mothers also showed a developmental trajectory in the scaffolding that they provided. All mothers played a dominant role with four-month-olds: They delivered objects to infants' hands, waggled them or made them loom, etc. At six months, mothers' bids were often rebuffed by their infants, and they shifted to following the infant's attention. By nine months, when infants had established solo play routines, the mothers began to imitate and temporally coordinate with these, often with exaggerated motion and positive affect. Indeed, the mothers used positive affective displays in temporal synchrony with turn-taking actions, as if to punctuate the subevents of the game. Moreover, as mothers began repeating infants' actions, they provided a new selective environment: They showed infants repeated examples of their own manipulative actions performed by another.

At twelve months, the mothers' actions changed further, to fit the infants' refined manual skills and capacity to organize action. For example, because infants could attend to multiple loci, mothers no longer needed to loom or statically present objects. Instead they could scaffold infants' activity by demonstrating it at a distance, in an exaggerated manner [Zukow-Goldring & Arbib, 2007] while the infant watched.

The Emergence of Twelve-Month Triadics

At twelve months, we see a number of novel high-level configurations of mother-infant-object engagements. We focus on three main types of triadic engagement at twelve months: projects, imitation, and games. We also note developments in infant gesturing. Our descriptions acknowledge a significant jump in complexity in our dyads between the nine- and twelve-month videos. The high-level configurations observed at twelve months are simply not present in earlier months. However, rather than resorting to postulating a novel representational ability as the cause of this activity, we can view their novel presence as a continuous developmental outcome of a number of developmental trajectories.

In both imitation and games, infants divided their attentional modalities between two independent loci: objects in their possession and activities and/or objects of the mother. Infants incorporated elements of their mother's actions and objects to their own ongoing object activities. As the infants' haptic differentiation becomes further refined, and they become more proficient with performing their own multipart sequences, we suggest that they become more attuned to the actions of their mothers' hands and better able to parse the manipulations she performs. The attentional continuity the infants now maintain across multiple loci may also facilitate their translation of the activity parsed from actions upon objects within their mothers' possession to the objects within their own possession.

Our infants showed a slowly developing propensity to continue sequences of manipulations across spatially distributed targets. At twelve months, this develops to allow infants to incorporate elements of the actions on objects manipulated by their mothers into their own ongoing manipulations with objects.

We assert that the bridging of these sensorimotor ontogenies with interest in shared activities with the mother transforms the early "you touch, I touch" into a replication of the particulars of mother's actions. This manifests as either imitation or experimentation.

The changing social ontogeny also plays a role in this transition. For some time before infants became so proficient, they had been immersed in an imitative environment with repeated opportunities to observe their own actions (and their own vocalizations) being reproduced and given value with positive affect by their mothers. The mothers' excited expressions might have cemented infants' attentiveness to this action mirroring and enhanced their enjoyment of the reciprocity of the interaction.

Games share the above elements of imitation. Additionally, they have accrued additional structure – repeated patterns of alternating activity between the mother and infant marked by negative affect at moments of disruption – that enables us to identify participant-specific actions, or "roles," in the joint activity. Above we describe how by nine months infants establish and perform routines (repeated se-

quences of actions) on objects in their own possession. Experience with these solo routines likely provides additional structure to the imitated or complementary actions that have emerged by twelve months, leading to the emergence of codependent routines. The mothers' actions at nine months also likely help. By performing their part of the routines on cue, readily reciprocating their infants' positive affect, and acting surprised when something went awry, the mothers of nine-month-olds helped establish regularity in the dyad's turn-taking cycles and helped highlight their disruption. This would lead, at twelve months, to the further elaboration of games and to promoting the infants' parsing of their own and their mothers' activities.

Triadic activities are also characterized by face-to-face expressions of affect and mutual gaze which occur at action-dependent moments during prolonged routines. This is an elaboration of a pattern of coarousal that has existed since the earliest months. What has developed is the integration of affective exchanges into increasingly complex exchanges. For example, in the case of games, the regularities produced by the corepetition of mother-infant routines can also make a break in that pattern salient. Thus, a repeated, fun-filled exchange, disrupted by the mother's failing to play her role, provokes a display of negative affect in the twelve-month-old infant. While the timing and conditions of such affective displays has changed, their occurrence at twelve months is interpretable as the outcome of mother-infant coarousal embedded in the elaboration of routine.

Finally, gesture became an important component of twelve-month dyadic activity. Infants' first gestures were recreations of portions of their imitative activity or game that the dyad had recently played. Now, however, the action was repeated without the mother's participation. Thus, an action that had been organized around a material outcome seemed to be replicated with a social motive: to influence the mother. Infants had already, for many months, provoked distal effects on their mothers with facial expressions. At twelve months, they extended that by producing manual and postural actions that evoke responses. When mothers responded, infants showed gleeful satisfaction. In this way, mothers' scaffolding might contribute to motivating further adaptive selection for communicative actions that are "once removed" – that is, taken outside of their immediate object or game context.

What about conventionally symbolic gestures? Most of these, even at twelve months, were produced by mothers. Mothers' pointing (deictic) gestures compelled infants to shift their gaze to a target and thus focus at least partly on particular aspects of her target object or activity. Mothers' iconic gestures (for example, reaching out to receive a toy) scaffolded infants' participation, even to initiate a game. By making their gestures slow, simple, and visible, parents might further have scaffolded infants' own budding use of nonverbal symbolic gestures [Bates, 1979]. Thus, although still a "new frontier" for twelve-month-olds, the production of scaffolded symbolic gestures by collaborative mothers suggested an impending foray into new social-communicative territory.

Complexity and Continuous versus Discontinuous Development

As in many previous studies of triadic interaction, we too saw a significant jump in complexity in our dyads between the nine- and twelve-month videos. This radical shift in the complexity of behavior has led many researchers to propose a discontinu-

ous mechanism to explain that complexity, namely the appearance of a novel cognitive ability.

Discontinuous accounts are characterized by their supposition that it is a novel representational capacity that is responsible for the apparently unprecedented behavior. A common such supposition in the twelve-month literature is the capacity to represent ''goals'' [e.g., Gergely & Csibra, 2003; Tomasello et al., 2005; Woodward, 2005]. It is this new capacity that is required, for example, for infants to understand what their mothers are "trying to do,"and further underlies their ability to produce a similar "attempt" [e.g., Meltzoff, 1995]. Intersubjectivity would be held responsible, for example, for infants gazing up at their mothers after imitating her or succeeding at a task that she had just demonstrated. In such situations, the gaze alternation is taken as an acknowledgment of the fact of their joint engagement [e.g., Carpenter, Nagell, Tomasello, Butterworth, & Moore, 1998]. It would also lie behind the gaze alternations or negative affect infants show when their mothers do not complete their part in a routine. That is, it is the infant's representation of the mother's violation of their tacit agreement to coengage in the routine that is invoked to account for the infant's displeasure [e.g., Ross & Lollis, 1987]. A final supposition of many discontinuous accounts of twelve-month triadics is the notion that communication is ''intentional'' [Grice, Cole, & Morgan, 1975]. It is the participants' representation of gestures and vocalizations as ''intended'' that is said, for example, to enable the infant to understand the mother's pointing at an object [e.g., Bates, Benigni, Bretherton, Camaioni, & Volterra, 1979; Bruner, 1975].

These accounts provide an intuitive scheme for organizing the interactions that were observed in this study, fitting our folk-theoretic accounts of such interactions. However, positing the appearance of these novel representational abilities still leaves the cognitive origins of these activities a mystery. Many of the papers on triadic attention that have postulated mental representations like goals, intentions, or intersubjectivity have been insightful and informative. However, they run the risk of committing the ''nominal fallacy'' in which the description of an event is taken as isomorphic with its mechanism. They also keep the individual at the center of the account, which causes problems for any explanation of social phenomena. For example, this minimizes the role of contributions from social partners who continually adapt their own behaviors in response to those of the infant. Finally, traditional accounts privilege the maturation of internal or individual conceptual capacities over changes in sensorimotor development.

An alternative approach is to focus on how bodies engage with the world and with each other. By remaining focused on activity, and by viewing the dyad as a system, our account can identify changes in the organization of that activity across developmental time. Over the four- through twelve-month period, we observed that our infants demonstrate increasingly complex routines involving increasingly haptic differentiation, more loci of attention, as well as multipart sequences and embedding. Infants changing behaviors elicit novel behaviors from the mom which in turn reinforce and provide novel opportunities for twelve-month triadics.

The focus of the traditional account on internal cognitive processes has led researchers to neglect such changes in dyadic activity across development. In turn, lack of attention to changes in the organization of dyadic behavior reinforces the need for an internal cognitive shift to account for developmental change. Our description acknowledges the emergence of novel collaborative triadic activities at twelve months.

However, when we track the interaction as a multimodal, multiparty configuration, we no longer need to resort to postulating a novel representational ability to explain the emergence of these new activities. Instead we observe that the actions at each session build on those viewed at the earlier sessions. In this way, an embodied and distributed approach provides an alternative account of triadic attention that is based on continuous changes in the activity of our participants rather than a simple shift in internal structures.

Acknowledgements

We owe great thanks to the mother-infant dyads that participated in the study, as well as to Jordan Danly and the students in UCSD's Cognitive Development lab for their work in collecting the video data used for this study. We thank Deborah Forster for her contributions including, but not limited to, her advice to focus on how micro components get organized differently at moments that regularly occur within the social system. Finally, we thank NSF for funding the collection of these data, part of the MESA Project (Modeling Emergence of Shared Attention; NSF SES-0527756) as well as NSF grant #SBE0542013 to the Temporal Dynamics of Learning Center, an NSF Science of Learning Center.

References

Adamson, L.B., & Bakeman, R. (1984). Mothers' communicative acts: Changes during infancy. *Infant Behavior and Development, 7,* 467–478.

Adamson, L., & Bakeman, R. (1991). The development of shared attention during infancy. *Annals of Child Development, 8,* 1–41.

Adamson, L.B., Bakeman, R., & Deckner, D.F. (2004). The development of symbol-infused joint engagement. *Child Development, 75,* 1171–1187.

Bakeman, R., & Adamson, L. (1984). Coordinating attention to people and objects in mother-infant and peer-infant interaction. *Child Development, 55,* 1278–1289.

Bates, E. (1979). The emergence of symbols: Ontogeny and phylogeny. In A. Collins (Ed.), *Children's language and communication: The Minnesota Symposium on Child Psychology. Vol. 12* (pp. 121–157). Hillsdale: Erlbaum.

Bates, E., Benigni, L., Bretherton, I., Camaioni, L., & Volterra, V. (1979). *The emergence of symbols: Cognition and communication in infancy*. New York: Academic Press.

Belsky, J., & Most, R.K. (1981). From exploration to play: A cross-sectional study of infant free play behavior. *Developmental Psychology, 17,* 630.

Bornstein, M., & Tamis LeMonda, C. (1989). Maternal responsiveness and cognitive development in children. *New Directions for Child and Adolescent Development, 1989,* 49–61.

Bourgeois, K.S., Khawar, A.W., Neal, S.A., & Lockman, J.J. (2005). Infant manual exploration of objects, surfaces, and their interrelations. *Infancy, 8,* 233–252.

Bruner, J. (1973). *Beyond the information given: Studies in the psychology of knowing*: New York: Norton.

Bruner, J. (1975). From communication to language – A psychological perspective. *Cognition, 3,* 255–287.

Bruner, J.S. (1983). *Child's talk: Learning to use language.* New York: Norton.

Bushnell, E.W. (1985). The decline of visually guided reaching during infancy. *Infant Behavior and Development, 8,* 139–155.

Carpenter, M., Nagell, K., Tomasello, M., Butterworth, G., & Moore, C. (1998). Social cognition, joint attention, and communicative competence from 9 to 15 months of age. *Monographs of the Society for Research in Child Development, 63,* i–vi, 1–143.

Clark, A. (2008). *Supersizing the mind: Embodiment, action, and cognitive extension*. New York: Oxford University Press.

Cohn, J.F., & Tronick, E.Z. (1987). Mother-infant face-to-face interaction: the sequence of dyadic states at 3, 6, and 9 months. *Developmental Psychology, 23,* 68.

Deák, G.O., Krasno, A., Triesch, J., Lewis, J., & Sepeta, L. (under review). Watch the hands: Infants learn to follow gaze by seeing adults manipulate objects.

de Barbaro, K., Johnson, C.M., Forster, D., & Deák, G.O. (in press). Methodological considerations for investigating the micro-dynamics of social interaction development. *Transactions on Autonomous Mental Development*.
de Barbaro, K., Johnson, C.M., Forster, D., & Deák, G.O. (under revision). Infant sensory-motor decoupling contributes to 12 month social "revolution": A longitudinal investigation of mother-infant-object interactions.
Dodici, B.J., Draper, D.C., & Peterson, C.A. (2003). Early parent-child interactions and early literacy development. *Topics in Early Childhood Special Education, 23,* 124.
Eckerman, C.O., Whately, J., & McGehee, L. (1979). Approaching and contacting the object another manipulates: A social skill of the 1-year-old. *Developmental Psychology, 15,* 585.
Fenson, L., Kagan, J., Kearsley, R.B., & Zelazo, P.R. (1976). The developmental progression of manipulative play in the first two years. *Child Development, 47,* 232–236.
Field, T.M. (1981). Infant gaze aversion and heart rate during face-to-face interactions. *Infant Behavior and Development, 4,* 307–315.
Fiser, J., Aslin, R., Lathrop, A., Rothkopf, C., & Markant, J. (2006). *An infants' eye view of the world: Implications for learning in natural contexts.* Presentation at the biennial meeting of the International Society on Infant Studies, Kyoto, Japan.
Fogel, A., & DeKoeyer-Laros, I. (2007). The developmental transition to secondary intersubjectivity in the second half year: A microgenetic case study. *Journal of Developmental Processes, 2,* 63–90.
Fogel, A., Messinger, D.S., Dickson, K.L., & Hsu, H. (1999). Posture and gaze in early mother-infant communication: Synchronization of developmental trajectories. *Developmental Science, 2,* 325–332.
Forster, D. (2002). Consort turnovers as distributed cognition in olive baboons: A systems approach to mind. In M. Bekoff, C. Allen, & G.M. Burghardt (Eds.), *The cognitive animal: Empirical and theoretical perspectives on animal cognition* (pp. 163–171). Cambridge: MIT Press.
Forster, D., & Rodriguez, P.F. (2006). Social complexity and distributed cognition in olive baboons *(Papio anubis):* Adding system dynamics to analysis of interaction data. *Aquatic Mammals, 32,* 528–543.
Gergely, G., & Csibra, G. (2003). Teleological reasoning in infancy: The naive theory of rational action. *Trends in Cognitive Sciences, 7,* 287–292.
Gibson, E.J. (1988). Exploratory behavior in the development of perceiving, acting, and the acquiring of knowledge. *Annual Review of Psychology, 39,* 1–42.
Goldfield, B. (1993). Noun bias in maternal speech to one-year-olds. *Journal of Child Language, 20,* 85–99.
Grice, H.P., Cole, P., & Morgan, J.L. (1975). Syntax and semantics. *Logic and Conversation, 3,* 41–58.
Hay, D.F. (1979). Cooperative interactions and sharing between very young children and their parents. *Developmental Psychology, 15,* 647.
Hsu, H.C., & Fogel, A. (2003). Stability and transitions in mother-infant face-to-face communication during the first 6 months: A microhistorical approach. *Developmental Psychology, 39,* 1061.
Hutchins, E. (1995). *Cognition in the wild.* Cambridge: MIT Press.
Jhuang, H., Serre, T., Wolf, L., & Poggio, T. (2007). A biologically inspired system for action recognition. In *Proceedings of the 11th International Conference on Computer Vision* (pp. 1–8). Rio de Janeiro: IEEE Press.
Johnson, C.M. (2001). Distributed primate cognition: A review. *Animal Cognition, 3,* 167–183.
Johnson, C.M. (2010). Observing cognitive complexity in primates and cetaceans. *International Journal of Comparative Psychology, 23,* 587–624.
Johnson, C.M., & Karin-D'Arcy, M.R. (2006). Social attention in nonhuman primates: A behavioral review. *Aquatic Mammals, 32,* 423.
Kaye, K., & Fogel, A. (1980). The temporal structure of face-to-face communication between mothers and infants. *Developmental Psychology, 16,* 454.
Kotwica, K.A., Ferre, C.L., & Michel, G.F. (2008). Relation of stable hand use preferences to the development of skill for managing multiple objects from 7 to 13 months of age. *Developmental Psychobiology, 50,* 519–529.
Krasno, A., Deák, G.O., Jasso, H., Lewis, J., & Triesch, J. (2007). *Watch the hands: Do infants learn gaze-following from parent's object manipulation?* Paper presented at the Society for Research in Child Development.
Lansink, J.M., & Richards, J.E. (1997). Heart rate and behavioral measures of attention in six-, nine-, and twelve-month-old infants during object exploration. *Child Development, 68,* 610–620.
Lawson, K.R., & Ruff, H.A. (2004). Early focused attention predicts outcome for children born prematurely. *Journal of Developmental & Behavioral Pediatrics, 25,* 399.
Lockman, J.J. (2000). A perception-action perspective on tool use development. *Child Development, 71,* 137–144.
Meltzoff, A.N. (1995). Understanding the intentions of others: Re-enactment of intended acts by 18-month-old children. *Developmental Psychology, 31,* 838.
Noë, A. (2004). *Action in perception*. Cambridge: MIT Press.

Oakes, L.M., & Tellinghuisen, D.J. (1994). Examining in infancy: Does it reflect active processing? *Developmental Psychology, 30,* 748.
Piaget, J. (1954). *The construction of reality in the child*. New York: Basic Books.
Piaget, J. (1962). *Play, dreams and imitation. Vol. 24.* New York: Norton.
Ratner, N., & Bruner, J. (1978). Games, social exchange and the acquisition of language. *Journal of Child Language, 5,* 391–401.
Rochat, P. (1989). Object manipulation and exploration in 2- to 5-month-old infants. *Developmental Psychology, 25,* 871.
Ross, H.S., & Lollis, S.P. (1987). Communication within infant social games. *Developmental Psychology, 23,* 241.
Ruff, H., & Saltarelli, L. (1993). Exploratory play with objects: Basic cognitive processes and individual differences. *New Directions for Child and Adolescent Development, 1993,* 5–16.
Sainburg, R.L., Poizner, H., & Ghez, C. (1993). Loss of proprioception produces deficits in interjoint coordination. *Journal of Neurophysiology, 70,* 2136–2147.
Stern, D.N. (1985). *The interpersonal world of the infant*. New York: Basic Books.
Streri, A., & Feron, J. (2005). The development of haptic abilities in very young infants: From perception to cognition. *Infant Behavior and Development, 28,* 290–304.
Suchman, L.A. (1987). *Plans and situated actions: The problem of human-machine communication*. New York: Cambridge University Press.
Tomasello, M., Carpenter, M., Call, J., Behne, T., & Moll, H. (2005). Understanding and sharing intentions: The origins of cultural cognition. *Behavioral and Brain Sciences, 28,* 675–690.
Trevarthen, C., & Hubley, P. (1978). Secondary intersubjectivity: Confidence, confiding and acts of meaning in the first year. In A. Lock (Ed.), *Action, gesture and symbol: The emergence of language* (pp. 183–229). London: Academic Press.
Tronick, E., Als, H., Adamson, L., Wise, S., & Brazelton, T.B. (1978). The infant's response to entrapment between contradictory messages in face-to-face interaction. *Pediatrics, 62,* 403.
Tronick, E.Z., Ricks, M., & Cohn, J.F. (1982). Maternal and infant affective exchange: Patterns of adaptation. In T. Field & A. Fogel (Eds.), *Emotion and early interaction* (pp. 83–100). Hillsdale: Erlbaum.
Wohlschläger, A., Gattis, M., & Bekkering, H. (2003). Action generation and action perception in imitation: an instance of the ideomotor principle. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences, 358,* 501–515.
Woodward, A.L. (2005). The infant origins of intentional understanding. *Advances in Child Development and Behavior, 33,* 229–262.
Yoshida, H., & Smith, L.B. (2008). What's in view for toddlers? Using a head camera to study visual experience. *Infancy, 13,* 229–248.
Zukow-Goldring, P., & Arbib, M.A. (2007). Affordances, effectivities, and assisted imitation: Caregivers and the directing of attention. *Neurocomputing, 70,* 2181–2193.