Mother-Infant Interaction in the Emergence of a Tool-Using Skill at Mealtime: A Process of Affordance Selection

Nonaka, Tetsushi

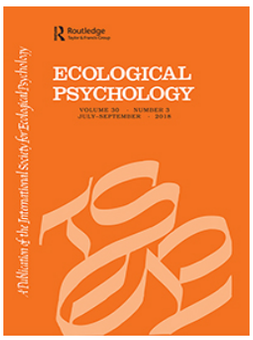
Goldfield, Eugene C.

(Citation)
Ecological Psychology,30(3):278-298

(Issue Date)
2018-03-09

(Resource Type)
journal article

(Version)
Version of Record



Ecological Psychology

ISSN: 1040-7413 (Print) 1532-6969 (Online) Journal homepage: http://www.tandfonline.com/loi/heco20

Mother-Infant Interaction in the Emergence of a Tool-Using Skill at Mealtime: A Process of Affordance Selection

Tetsushi Nonaka & Eugene C. Goldfield

To cite this article: Tetsushi Nonaka & Eugene C. Goldfield (2018) Mother-Infant Interaction in the Emergence of a Tool-Using Skill at Mealtime: A Process of Affordance Selection, Ecological Psychology, 30:3, 278-298, DOI: 10.1080/10407413.2018.1438199

To link to this article: https://doi.org/10.1080/10407413.2018.1438199

Accepted author version posted online: 12 Feb 2018.
Published online: 09 Mar 2018.

ECOLOGICAL PSYCHOLOGY
2018, VOL. 30, NO. 3, 278–298
https://doi.org/10.1080/10407413.2018.1438199

Routledge
Taylor & Francis Group

Mother-Infant Interaction in the Emergence of a Tool-Using Skill at Mealtime: A Process of Affordance Selection

Tetsushi Nonaka[a] and Eugene C. Goldfield[b,c]

[a]Graduate School of Human Development and Environment, Kobe University; [b]Program in Behavioral Science, Boston Children's Hospital; [c]Wyss Institute for Biologically Inspired Engineering, Harvard University

ABSTRACT

This study provides a detailed description of the process of the emergence of the utensil-using skill of infants to control encounters with food and mother-infant joint action that surrounds the emergence of this context-specific skill. Longitudinal observations from the first contact with a utensil to the beginning of successful self-feeding with a utensil found that there was an extended period of exploratory utensil use that precedes the use of the utensil for the goal of feeding around which adults organized the environment where such feeding-irrelevant activities of the infants were tolerated. Subsequently, adults gradually introduced and highlighted the opportunities for infants' functional feeding encounters, often by adjusting the position of objects on the table. Overall, we found the process of what may be called affordance selection—in which a definite set of opportunities for action among many available were selected by adults to invite certain spontaneous behaviors of developing infants. This study adds to the growing realization that normally occurring experiences of rich affordances matter in the development of specific behavior in a given cultural context.

The Shah of Persia was the guest of Napoleon III and insisted on eating with his fingers. The Emperor urged him to use a golden fork. "You don't know what a pleasure you are missing," the Shah replied (Mauss, 1935/1973). Gesell and Ilg (1937) long ago indicated the complexity underlying the story of feeding behavior, where the whole process is indissolubly linked with the cultural history of the techniques of feeding (see also Bril, Hombessa-Nkounkou, Bouville, & Ocampo, 2001). The use of hands and fingers is often sufficient for transporting food to the mouth (Valsiner, 1997). However in some cultures, an infant who is finger feeding would show willingness to abandon this effective strategy to transport food directly to the mouth in favor of the mode of feeding using a utensil, at sometime around the 2nd year of life when the infant is still incapable of using it. Connolly and Dalgleish (1989) reported that in the early phase of spoon use, infants put their spoon into and out of the dish repeatedly while taking food from the dish with the other hand. Infants hold the spoon in the way that

CONTACT Tetsushi Nonaka tetsushi@people.kobe-u.ac.jp Graduate School of Human Development and Environment, Kobe University, Tsurukabuto 3–11 Nada-ku, Kobe, 657–8501, Japan.

does not permit the manipulation of the spoon by movements within the hand and take the empty spoon to the mouth with the hand approaching from the side of the head by rotating the shoulder instead of the wrist. Obviously, a feeding utensil is a tool that affords important activities involved in eating food on a table. However, given to an individual who has never been encouraged to attend to those feeding-relevant properties of the utensil, and who has little experience of mealtime, a utensil cannot, of itself, create a feeder (Reed, 1993). The question of interest is what motivates infants to attend to those properties of the utensil that are relevant to the peculiarities of the mealtime setting.

Recent studies on the development of skills to use feeding utensils have been concerned more with using spoon feeding as a paradigm to assess the ability of children to plan action than with studying the process of developmental change in mealtime practices (Clifton, Collard, & McCarty, 1999, 2001; Adolph, & Keen, Lee, 2014). Because a spoon has to be functionally related to hand, food, and mouth, users are required to prospectively adjust the manner of grasping a spoon depending on the kind of encounters to be made. In these studies, children were presented with a spoon loaded with food whose handle pointed away from their dominant hand and encouraged to pick up the spoon to eat. The data showed a general progression from the youngest children, who used an awkward grip that causes food to spill, to the oldest, who exhibited efficient grips that indicate better planning for the end goal (McCarty et al., 1999, 2001). In addition, Keen and colleagues found a striking amount of inter- and intraindividual variability in grip patterns as children develop toward adopting efficient strategies (Keen et al., 2014). The development of ability to plan action is, no doubt, an important topic of research. Yet, because the task structures of these experiments were designed to assess the infant's planning ability, it is difficult to interpret what underlies such variability and the process of development in the usual context of practices during mealtime.

In one of the very few longitudinal studies on spoon feeding in mealtimes, Connolly and Dalgleish (1989) provided a detailed description of the development of operational aspects of spoon-using skills and observed that individual infants show considerable variability in the ways of using a spoon before they begin to exhibit increased consistency of grip coupled with a shift toward more flexible and appropriate patterns. The relevant concept in this instance may be that of exploration (E. J. Gibson, 1988; Lockman, 2000). E. J. Gibson (1988) drew attention to the fact that infants spend a large amount of time exploring to find out what can be done with things in the environment prior to the acquisition of their skills of controlling the encounters with them. Subsequent research has confirmed E. J. Gibson's idea that self-initiated exploratory activity plays a leading role in the acquisition of various skills, from which new insights have also emerged (e.g., Kahrs & Lockman, 2014; Nonaka & Bril, 2014; Perry, Samuelson, & Burdinie, 2014; Wu, Miyamoto, Castro, Ölveczky, & Smith, 2014). Among the new insights is the profound impact of the embedded context of infants on the pattern of spontaneous activities initiated by the infants in the process of acquiring object manipulation skills (e.g., Lockman, 2005; Corbetta, Williams, & Haynes, 2016; Needham, Wiesen, & Libertus, 2015; Soska & Adolph, 2014). A series of studies where infants wore "sticky mittens," which stuck to the toys and allowed the infants to pick up the toys without grasping, serve to illustrate this point well. The original study showed that the infants who had experienced parent-led training with "sticky mittens" contacted and tried to pick up the presented toy in the following experimental sessions significantly longer and more frequently than the controls who did not have such an experience (Needham, Barrett, & Peterman, 2002). However, the subsequent research found that the effects of "sticky

mitten" training depended on social encouragement for infants to engage in spontaneous exploration offered by the infants' parents and that the effect of the "sticky mitten" experience disappeared when the training sessions were led by the experimenter (Williams, Corbetta, & Guan, 2015; Corbetta et al., 2016). These new works direct us to think about the development of daily skills of infants in a different light. This view suggests that those who are seriously intent on understanding the process by which individual infants develop their daily skills must take a wider system of infant behaviors in the environment, including a caregiver, as subject matter of observation and description.

What is important, but has not been studied, is how the mealtime environment, which includes caregivers and a range of supporting objects, entrains the perceiving and acting involved in the utensil using skills of infants. To explore this issue, the present study investigates the process by which individual infants come to control encounters with food using feeding utensils in relation to the mealtime environment in which the development literally takes place. In doing so, we focus on one key factor: opportunities for action available to infant (*affordances;* J. J. Gibson, 1979/1986) following the studies on the development of tool use from the perspective of an ecological approach to perception and action (Lockman & Kahrs, 2017; Smitsman, Cox, & Bongers, 2005; Steenbergen, Van der Kamp, Smitsman, & Carson, 1997). The overarching hypothesis that motivates this study is that the process by which a definite set of opportunities for action were selected to invite spontaneous behaviors of developing infants is critical to the emergence of utensil-using skills specific to the mealtime context.

Traditionally, the issue of mother-infant interaction and that of the development of tool use have been studied separately in psychology (see Boyer & Bril, 2001; Lockman, 2005; Valsiner, 1997, for a few important exceptions). Nevertheless, to address the issue of how the former entrains the latter, the analysis of both social context and individual development is inevitably required. The originality of the article lies in the attempt at finding a connection between these different aspects of the development of infants. To reveal the details of the process by which individual infants come to selectively attend to a set of relevant opportunities offered by feeding utensils in the mealtime environment, this article analyzes both (a) development of the ways feeding utensils are used by infants and (b) mother-infant joint action that surrounds the use of utensils in the mealtime environment.

Method

Observation materials

The work reported in this article is based on a longitudinal videotaped observation of 2 male Japanese infants (Kota and Daiji) whose everyday behavior was videotaped by caregivers at home on a weekly basis for "*Akachan* (infant) Movie Database"—a movie database of niches of the 2 infants published in Japan (Nonaka & Sasaki, 2009; Sasaki, 2008). Both infants were healthy and developing normally, and their mothers had no medical problems. From the 160 hr of recorded video materials, the clips that captured feeding situations during the following period were extracted for the analysis: from the first meal where the infant was observed to contact a utensil to the first observed instance of successful self-feeding with a utensil (the complete sequence of loading food onto a utensil followed by bringing food on the utensil to the mouth without the help from the mother). In total, 15 mealtime

observations were conducted for Kota and 19 observations for Daiji. All the extracted videos captured the whole duration of mealtime. Due to the nature of the video materials used, the observation period differed across the 2 infants, and the intervals between observations were not of equal length. Mean duration of the meal (from the first contact with food or utensils by children to the last contact before leaving the table) was 16 min 31 s (*SD*: 6 min 41 s) and 23 min 43 s (*SD*: 5 min 55 s) for Kota and Daiji, respectively (Table 1). Additionally, Kota's video was available for the period after the onset of self-feeding with a utensil, which made it possible for us to follow the development of action after the onset of self-feeding with a utensil. Although the analysis of development after the onset of self-feeding with a utensil has not been the primary focus of this study, part of this observation is briefly reported in the section discussing action sequence.

Data coding

Using *Datavyu* coding software (www.datavyu.org), a primary coder scored 100% of video data of natural mealtime situations of the two mother-infant dyads. Each mealtime video was segmented into a series of 15-s windows (30-min mealtime would result in 120 windows). Next, for each window, (a) manners of utensil use by the infant, (b) assistance by the mother, and (c) tabletop layout within reach of the infant were coded. The reason behind the choice of 15-s windows for the analysis was that food intake by infants appeared to occur with roughly 15-s intervals when they were fed with a spoon by their mothers. A trained second coder independently scored 25% of each mealtime data (i.e., one 15-s window per each minute). Interrater agreement was high for the observed windows of utensil use ($k = .85$),

Table 1. Summary of longitudinal observations of the two infants.

		Kota	Daiji
First contact with utensil during meal		7:2 (month:day)	8:19
Onset self-feeding with a utensil		16:6	15:7
Number of observed meals		15	19
Mean mealtime duration (*SD*)		16 min 31 s (6 min 41 s)	23 min 43 s (5 min 55 s)
Number of 15-s windows	Total	991	1,793
	Utensil in hand	499	663
Food intake (frequency)	Passive feeding	541	975
	Finger feeding	84	178
	Utensil with assistance	38	63
	Utensil without assistance	4	3
Use of utensil (number of windows)	Nonfood mouthing	9	89
	Exploration at utensil	63	263
	Utensil directed at surfaces	36	109
	Utensil directed at food	130	157
	Self-feeding with a utensil	4	3
Assistance by caregiver (number of windows)	Help with utensil	64	100
	Adjust posture	17	4
	Adjust layout	159	80
	Steady dish	144	78
Tabletop layout (number of windows)	No dish	438	1,209
	Dish held by mother	65	140
	One food dish	300	444
	Multiple dishes	188	0

Note. Additionally, five meals of Kota (17:10, 17:20, 17:24, 17:27, and 18:13) after the first successful self-feeding with a utensil were observed, whose episodes are briefly reported in the section discussing action sequence.

assistance by the mother ($k = .85$), and tabletop layout ($k = .90$). In addition, for every intake of food by infant during each meal, (d) manners of food intake were classified, as to which coders agreed 100%.

Manners of utensil use. The number of 15-s windows in which infants had utensils in their hands was used to estimate the duration of infants' contact with utensil during each meal. The manners of spontaneous (i.e., self-initiated) utensil use by infants in mealtime contexts was coded for each 15-s window of the mealtime video according to the following five categories: (a) *nonfood mouthing of a utensil*: a child put a utensil into the mouth not for the purpose of eating food, (b) *manual exploration at a utensil*: a child manipulated a utensil without directing it to other surfaces (e.g., running fingers over a utensil), (c) *directing a utensil at objects*: a child directed a utensil at nonfood surfaces (e.g., tapping on a table), (d) *directing a utensil at food*: a child directed a utensil at food (including loading food onto a utensil or transporting food to another dish), and (e) *self-feeding with a utensil*: a child performed a complete sequence of loading food on a utensil and then bringing food to the mouth with the utensil. Whether a given behavior was observed during a given 15-s window was coded, and the number of the windows where a given behavior was observed was counted for each meal. When two or more categories were observed within the same 15-s window it was coded as such. To avoid redundancy, *self-feeding with a utensil* was not counted as *directing a utensil at food*, although self-feeding with a utensil naturally involves directing a utensil at food.

Manners of food intake. For each food intake by the infants, how the food reached the mouth was classified into the following four categories, whose frequency was measured over the course of each meal: (a) *passive feeding*: a child was fed passively by the mother, (b) *self-feeding with fingers*: a child ate food with fingers, (c) *assisted feeding with a utensil*: a child ate food with a utensil with the help of the mother contacting the child, and (d) *self-feeding with a utensil*: a child ate food with a utensil on his or her own.

Mother's assistance. To examine whether and how the mother organized the environment of the infant, objects placed within reach of the child on the tabletop were coded for each 15-s window of the mealtime according to the following categories: (a) *no food dish*: no dish with food was placed within reach of the child, (b) *food dish held by a mother*: a food dish held by the mother was presented within reach of the child, (c) *one food dish*: a food dish was placed within reach of the child without being held by the mother, and (d) *multiple food dishes*: multiple food dishes (typical of Japanese food) were placed within reach of the child. Furthermore, the following assistance by the mother was coded in each of the 15-s windows of the mealtime: (a) *assistance with a utensil*: a mother guided the child's use of a utensil by contacting the utensil or the child's body, (b) *adjustment of posture*: a mother adjusted the posture of the child, (c) *adjustment of the tabletop layout*: a caregiver adjusted the arrangement of objects within reach of the child on the table during the meal (e.g., moving a dish closer to the child or moving away a cup in the way), (d) *steadying the dish*: a mother steadied the dish in front of the child.

Dynamics of mother-infant interaction. In addition to the overall changes in the relation between the behavior of mothers and that of infants, we looked into the real-time effects of the adjustments provided by the mothers on the attention of the infants by measuring the rate of coincidence between assistance provided by the mother and the following two types of infant behavior: (a) *exploratory utensil use* (nonfood mouthing of a utensil, manual exploration at a utensil, or utensil use directed at nonfood surfaces) and (b) *feeding-relevant utensil use*

(touching food or bringing food to the mouth with a utensil). In other words, we looked into the temporal matches between the mother's assistance and each of the infant's utensil-use categories (*exploratory* and *feeding relevant*). This part of analysis included both self-initiated and mother-led utensil use by infants. To capture the interaction dynamics at a finer temporal resolution, mealtime videos were further divided into 5-s bins to create the following three sets of binary spike trains for the mothers and infants. First, a binary spike train of mother's assistance was created by coding whether or not either one of the four types of assistance described earlier occupied a time bin. Second, spike trains of exploratory utensil use by the infant were created by coding whether or not exploratory utensil use defined earlier occupied a time bin. Third, spike trains of feeding relevant utensil use by the infant was created by coding whether or not feeding-relevant utensil use defined earlier occupied a time bin. Then, a diagonal cross-recurrence profile (DCRP; Abney, Warlaumont, Oller, Wallot, & Kello, 2016; Warlaumont, Richards, Gilkerson, & Oller, 2014)—the rate of co-occurrence of events across the spike trains of the mother and the infant—was used to characterize the contingency between each of the two types of utensil-using behavior of an infant and the assistance provided by the mother in order to examine whether a particular type of utensil-using behavior of an infant selectively occurred close together in time with the mother's assistive behavior. DCRP height, which measures the quantity of the co-occurrence of mother's assistance and infant's utensil use at a range of lags, was computed by finding the total area under the DCRP curve between lag –15 s and lag 15 s for each of the two types of infant's utensil-using behavior (exploratory utensil use and feeding-relevant utensil use). This part of analysis was done only to the meals where the infants had utensils in their hands (9 meals for Kota, 14 meals for Daiji), 25% of which was subjected to scoring by a second coder. Interrater agreements for assistance provided by mothers, exploratory utensil use by infants, and feeding-relevant utensil use by infants were $k = .80$, .71, and .78, respectively. The methods of cross-recurrence quantification analysis used in this part of the investigation have been described in detail elsewhere (Cox, van der Steen, Guevara, de Jonge-Hoekstra, & van Dijk, 2016; Warlaumont et al., 2014).

Results

Manners of utensil use

Kota was given a spoon briefly during the mealtime at age 7:2 (month:day) and 9:12 (Figure 1a) and Daiji at age 8:19 and 9:17 (Figure 2a). In these first observed instances of contact with a utensil, without an exception, it was the infant who first reached for the spoon used for feeding in the mother's hand, and the mother gave a spoon to the infant in response. Subsequently, the infants placed a utensil in the mouth, biting one of the ends but not for the purpose of feeding, and manually explored a utensil by running fingers over the spoon. From around the beginning of the 2nd year, both infants consistently had a spoon, fork, or both in their hands for most of the mealtime (Figure 1a and Figure 2a). Yet, successful self-feeding with a utensil—a complete sequence of spontaneously loading food onto a utensil and the bringing it to the mouth—was never observed until 16:6 and 15:7 for Kota and Daiji, respectively (Figure 1b and Figure 2b). An interesting issue is what these infants were doing with utensils that were not yet functional for the purpose of feeding for such a long time.

A series of observations revealed that both infants used utensils in a variety of ways within the context of mealtime. The list of behavior of infants with utensils observed included

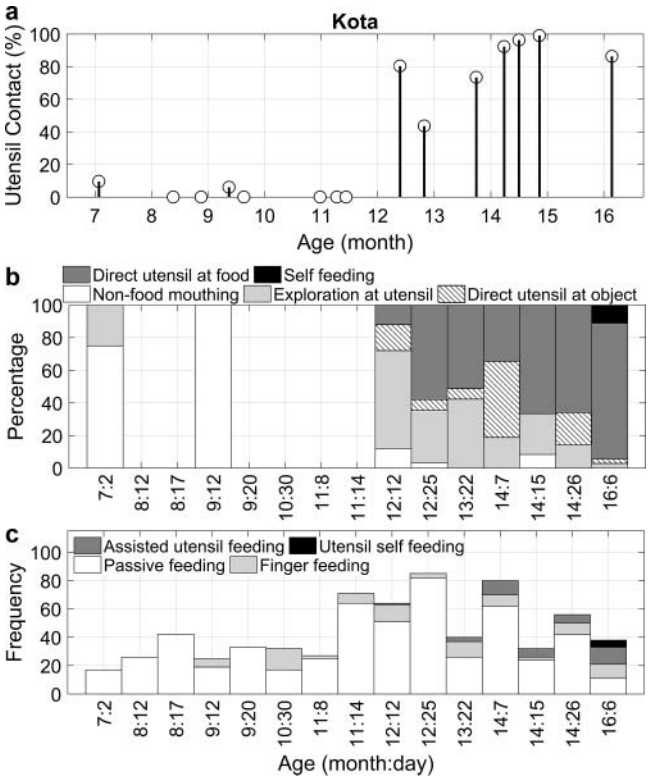


Figure 1. (a). Percentage of duration of contact with a utensil within each meal, (b). percentage of 15-s windows in which each of the five patterns of spontaneous utensil use was observed, and (c). frequency of each of the four ways of food intake as a function of age in Kota.

mouthing a utensil, running fingers over a utensil, banging two utensils against each other, bouncing the end of a utensil on the table, twisting a utensil with fingers, passing from hand to hand, rolling on a surface, shaking, dropping, throwing, touching own head, rhythmical tapping on a surface, probing food, poking at food, loading food onto, transporting food to another place, smearing food onto a surface, and finally, bringing food to one's mouth. The ways utensils were used by the infants spontaneously (i.e., without the mothers contacting them) in the context of mealtime are presented in Figure 1b and Figure 2b, which depict the proportion of the windows where each of the five categories of utensil-using behavior was observed. In the first contacts with a utensil, infants often placed a utensil in the mouth, biting one of the ends but not for the purpose of feeding. This behavior became rare later in the observation period (Figure 1b and Figure 2b). Manual exploration of a utensil such as running fingers over a utensil or passing the utensil between hands was also frequently seen in young infants. As infants became older, they increasingly spent more time on directing a utensil at other surfaces, especially at food surfaces, instead of mouthing and exploring the utensil itself. The functions of a utensil appeared to have changed meal to meal, which differed between one child and another (Figure 1b and Figure 2b). For example, one child (Daiji) often exhibited stereotyped rhythmic movement when a utensil was in his hand such as shaking a utensil, scratching a table surface, or tapping on a dish. As such, "exploration at a utensil" and "directing a utensil at nonfood surfaces" were more frequently observed in

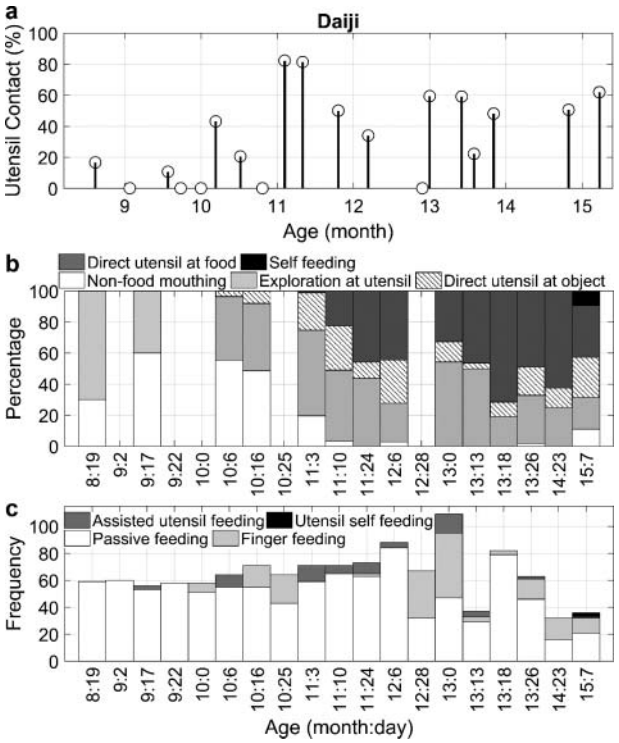


Figure 2. (a). Percentage of duration of contact with a utensil within each meal, (b). percentage of 15-s windows in which each of the five patterns of spontaneous utensil use was observed (relative to the total number of windows where utensil-using behavior was observed), and (c). frequency of each of the four ways of food intake as a function of age in Daiji.

Daiji compared with Kota. However, underlying such interindividual variability, there also seems to have been commonality across the developmental paths of the 2 children where the variation in the functions of a utensil at mealtime gradually changed over time. Although the timing of change differed across the 2 infants, after several months of utensil-in-hand experience in feeding situations, the utensils began to be directed at other surfaces, especially at food surfaces, whereas the occurrence of nonfood mouthing of a utensil became rarer compared with the early contacts with a utensil during mealtime (Figure 1b and Figure 2b).

Manners of food intake

The crux of the functional act of feeding is the intake of food. During the period when the infants exhibited playful exploration at utensils, the function of bringing food to the mouth was almost entirely under the control of the mother. Before the 13th month, passive feeding where the food is brought to the infant's mouth by the mother accounted for 89% of food intake for both Kota and Daiji (Figure 1c and Figure 2c). When the infants became increasingly focused on food in their 2nd year of life, in addition to being fed by the mother, both infants began to finger feed themselves occasionally before they finally used a utensil to feed themselves a few times. Yet, in both infants, overlapping the coexisting cycles of finger

feeding and utensil manipulation, a separate stream of feeding by a caregiver was steadily found even when the infants began to use utensils to eat successfully (Figure 1c and Figure 2c).

Mother's assistance

Mothers were occasionally observed to directly hold the infant's hand or the end of the utensil to provide guidance, although it was not very frequent (observed only in 6% of all windows). Such assistance was limited to the situation where mothers help scoop or bring the utensil up toward the mouth of infants. Assistance with the scooping process was most frequent, accounting for 65% and 50% of all the observed instances of such direct intervention for Kota and Daiji, respectively. Mothers were never observed to hold the infant's hand on the utensil to guide other behavior such as nonfood mouthing of a utensil, exploration of a utensil itself, or touching nonfood surfaces with a utensil.

Assistance provided by the mother at mealtime was not only through the mechanical contact with the infant with a utensil. In particular, we highlight the kind of joint action where mothers rejigger and restructure the environment in ways that have consequences for infants' behaviors. Throughout the period of observation, the mothers were observed to adjust and prepare the environmental contexts so as to provide opportunities for action to the infants. Looking longitudinally at the tabletop environment, we found that there was a change over time in the arrangement of objects placed in front of the infants (Figure 3a and Figure 4a). Before the infants began to reach for food with a utensil consistently, no food dish was left within reach of the infants for most of the duration of mealtime. Subsequently, when the infants began to reach for food with utensils, one or multiple food dishes were made available within reach of the infants.

The opportunities for action available for the infant during mealtime were not fixed within each meal but were adjusted dynamically by the mother online. The mothers were frequently observed to steady and adjust the position of the dish during mealtime (Figure 3b and Figure 4b). For both Kota and Daiji, the frequency of windows in which the mother was observed to adjust the position of the dish or steadied the dish in front of the infant was consistently greater than the frequency of windows where the mother directly held the infant's hand or the end of the utensil to provide guidance (Table 1). In addition, although not frequent, the mother was occasionally observed adjusting the posture of the infant to the feeding task by changing the spatial orientation of the infant on the chair (Figure 3b and Figure 4b).

Dynamics of mother-infant interaction

The coincidence of assistive behavior by mother and utensil-using behavior by infant was measured by DCRP height (Abney et al., 2016; Warlaumont et al., 2014), defined as the total area under the DCRP curve between lag –15 s and lag 15 s (see Figure 5 for the average DCRP curves). Higher DCRP heights suggest more co-occurrence of mother's assistance and infant utensil use. We compared the DCRP height for each original pairings of infant and mother behavior series with a distribution of the DCRP heights for 50 randomly shuffled surrogates (i.e., a new distribution of 50 DCRP heights for each original pair). Because shuffled DCRP height differed as a function of age and infant behavior type, we normalized the original DCRP height by subtracting the corresponding shuffled DCRP height from the

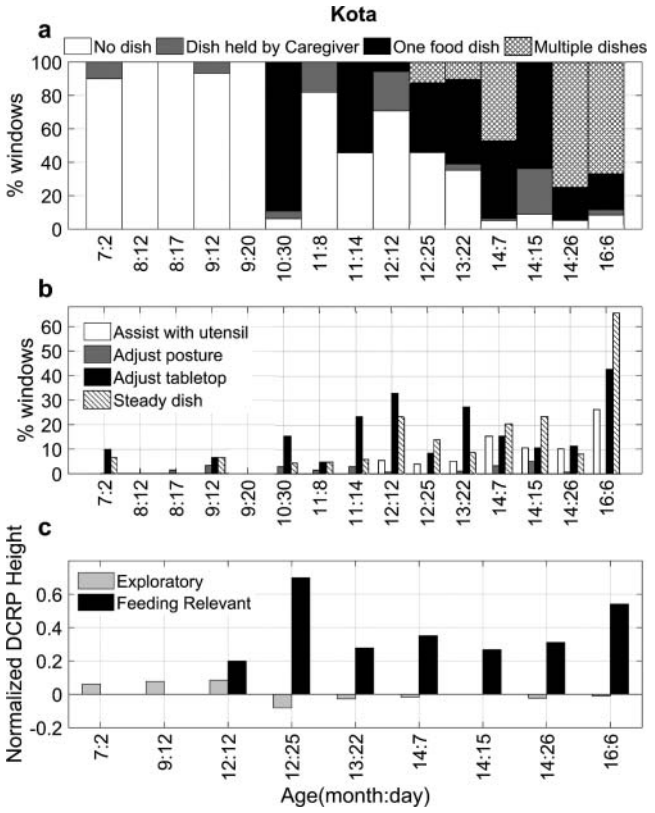


Figure 3. (a). Percentage of 15-s windows in which each of the four patterns of layout of objects on the table within the reach of the infant was observed, (b). percentage of 15-s windows within each meal in which each of the four patterns of assistance by the mother was observed, and (c). normalized diagonal cross-recurrence (DCRP) height in which the mean shuffled DCRP height was subtracted from the original DCRP height for each infant behavior type as a function of age in Kota.

original DCRP height for each infant behavior type (Figure 3c and Figure 4c). We evaluated the differences between the DCRP height for each original time series and the DCRP heights for each corresponding comparison distribution using one-sample *t* tests with the original DCRP height as a test value. Throughout, the DCRP height of cross-recurrence quantification analysis between mother's assistance and infant's feeding-relevant utensil use were significantly higher than that of shuffled copies, *t*s ranging from –154.76 to –15.21, $p < .0001$, suggesting that the rate of coincidence between assistance by the mother and feeding-relevant utensil use by the infant was higher in the original series than in the shuffled series (Figure 3c and Figure 4c). The DCRP height for interaction between mother's assistance and infant's exploratory utensil use was also significantly different from that of shuffled copies, $|ts|$ ranging from 4.69 to 89.76, $p < .0001$, except one meal of Daiji at 13:18, $t = 1.15$, $p = .26$. However, though almost always significantly different, the rate of co-occurrence of mother's assistance and infant's exploratory utensil use were neither generically higher nor lower than those for shuffled surrogates. For Kota, the rate of co-occurrence of exploratory behavior and mother's assistance was higher in the first three meals compared with the shuffled data, whereas after 12:25, the rate of co-occurrence of exploratory behavior and mother's

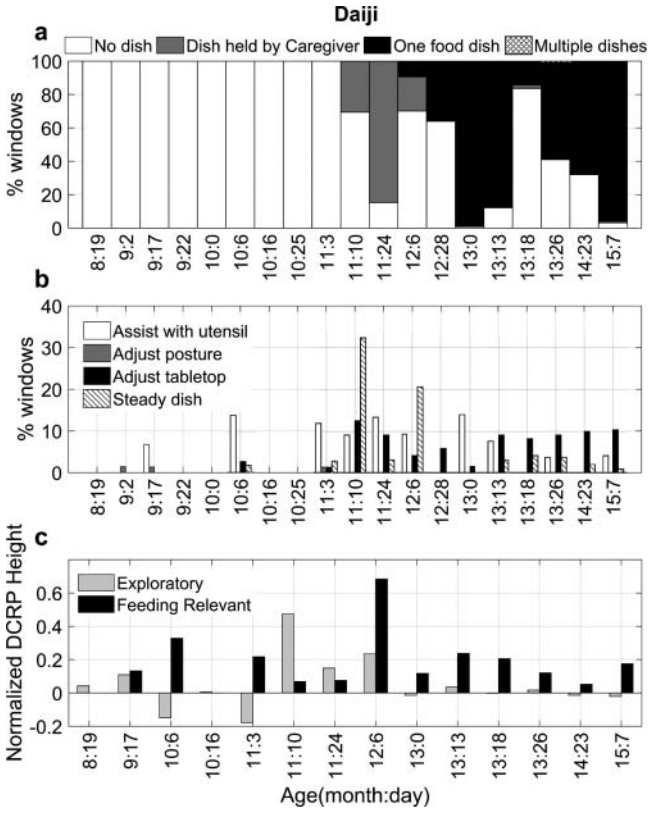


Figure 4. (a). Percentage of 15-s windows in which each of the four patterns of layout of objects on the table within the reach of the infant was observed, (b). percentage of 15-s windows within each meal in which each of the four patterns of assistance by the mother was observed, and (c). normalized diagonal cross-recurrence (DCRP) height in which the mean shuffled DCRP height was subtracted from the original DCRP height for each infant behavior type as a function of age in Daiji.

assistance was close to that of the shuffled data (Figure 3c). For Daiji, although there are a couple of exceptions, the rate of co-occurrence between mother's assistance and infant's exploratory utensil use tended to be higher than the shuffled data before the 13th month, whereas after the 13th month, it was close to that of the shuffled data (Figure 4c). The rate of co-occurrence between exploratory behavior and mother's assistance was exceptionally lower compared with the shuffled series in Daiji's meals in 10:6 and 11:3, partly due to the fact that Daiji was constantly playing when he had a utensil in his hand, in between which his mother occasionally guided the utensil toward food.

Figure 5 presents the diagonal cross-recurrence profile averaged across infant behavior and age period (before and after the 13th month, both infants pooled). Although the segmentation at the 13th month is admittedly arbitrary, Figure 5 indicates the general trend where the exploratory, feeding-irrelevant utensil use coincided with mother's assistance in the early period of utensil use, whereas later the mother's assistance was increasingly focused on the functional use of utensil for the goal of feeding. The difference between the nonnormalized DCRPs and the normalized versions reflected the overall frequency of each type of infant behavior in the two periods. For example, before 13th month when feeding-relevant

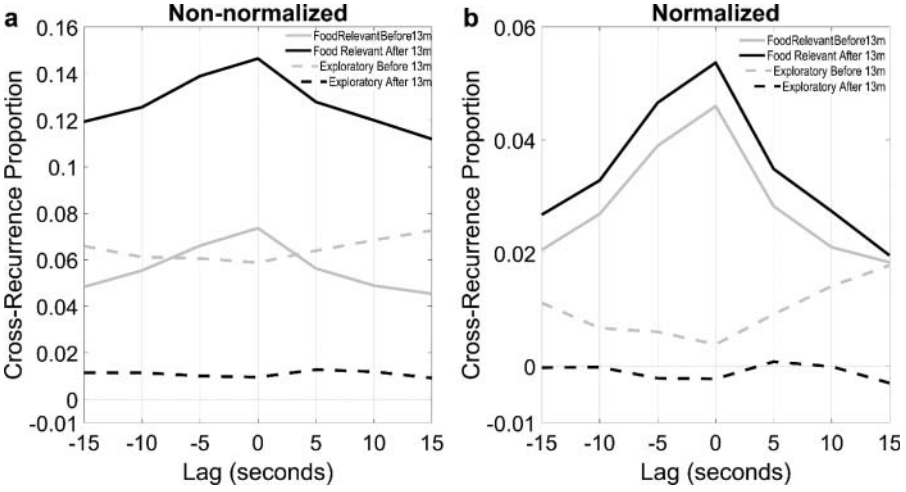


Figure 5. Diagonal cross-recurrence profile (DCRP) averaged across infant behavior type as a function of age period (before and after 13 months of age). (a). Average DCRPs before normalization. (b). Average DCRPs normalized for shuffled DCRPs.

utensil use by infants was rarely observed, the rate of co-occurrence between this type of behavior and mother's assistance was low compared with the later period (Figure 5a).

We found several interesting episodes that show the details of such interactions as indicated by the aforementioned quantitative measures. For example, in Kota's meal at age 12:12, on seeing her child directing the tool awkwardly to an empty dish, Kota's mother moved closer and steadied the empty dish rather than restricting Kota's nonfeeding movement. But of course, because the dish was empty, Kota's mother was not doing this in order to feed her child. Indeed, there were other food dishes on the table, but they were carefully kept out of reach of the infant, from which the mother fed the infant occasionally. A little later, the mother was frequently observed to introduce opportunities for the infant to access food on the tabletop, often by physically modifying the layout of the environment (Figure 3b and Figure 4b). For example, in Kota's meal at age 13:22, on seeing Kota picking up a spoon placed in front of him, his mother moved the dish just in front of him and went on to steady the dish to provide opportunities for getting the food on the spoon. When Kota was probing food on the dish with the spoon, the mother again moved the dish closer to him and adjusted the position of Kota's chair in relation to the table. When Kota attempted to reach for another dish with the spoon, his mother moved away the nearby dish that was in the way and moved the reached-for dish closer. These dynamic adjustments by the mother seem to have highlighted the aspects of the environmental relation that were functionally relevant to the goal of feeding.

Sequential action

Sequential action refers to a series of actions that are functionally distinct, such as loading, transporting, and emptying a portion of food, and are performed in a coherent manner (Schwartz, Reed, Montgomery, Palmer, & Mayer, 1991). Prior research on the emergence of utensil use at mealtime has indicated that the young infants who grasp spoons tend to place the spoon either in the mouth or into the bowl but not both, and the emergence and

consolidation of organized action sequences occurred later (Connolly & Dalgleish, 1989). The repeated viewing of the videos in the present study suggested that change in action sequence reflects not only the ability of the infant but also the change in mother-infant interaction that occurs during mealtime, which is described diagrammatically in Figure 6. Before a utensil was consistently oriented toward food, the action sequence of mother-infant dyads typically followed a basic cycle in which the mother monitored the infant and brought food to the infant's mouth while the infant was playing with a utensil or with what was available on the tabletop (Figure 6a). With respect to the function of feeding, the responsibility of the infant was minimal, limited to maintaining a stable upper body and opening the mouth to take food from the spoon brought by the mother. Loading food onto the spoon, transporting food from dish to mouth, and most of the subsidiary activities required to achieve the function of feeding were taken care of by the mother through the constant monitoring of the state of the infant. Somewhat later, the occasional cycle of finger feeding was inserted into the preexisting cycle of the mother bringing food to the infant's mouth (Figure 6b), and the infants began to spend most of the mealtime with utensils in their hands (Figures 1 and 2). And finally, Kota and Daiji succeeded in loading and bringing food to the mouth with a utensil for the first time at 16:4 and 15:17, respectively, after several attempts at loading food on a utensil with help from their mothers (Figure 6c)

As mentioned previously, a utensil was initially used for a variety of purposes even in the definite mealtime context (Figure 1b and Figure 2b). After the infants had come to consistently direct a utensil toward food, several episodes were found where the competition among multiple possibilities of action afforded by a utensil was apparent. When Kota was at age 14:14, the mother helped Kota to catch the seaweed in the soup with a fork. However, Kota's attention was distracted by the spilled food on the tray, and the fork with a piece of seaweed was relinquished as Kota ran his fingers on the tray. Shortly after, Kota looked at the fork left on the tray, still with seaweed, and picked it up, then transported the seaweed on the fork to one dish, but seaweed did not come off the fork. He then moved the fork-

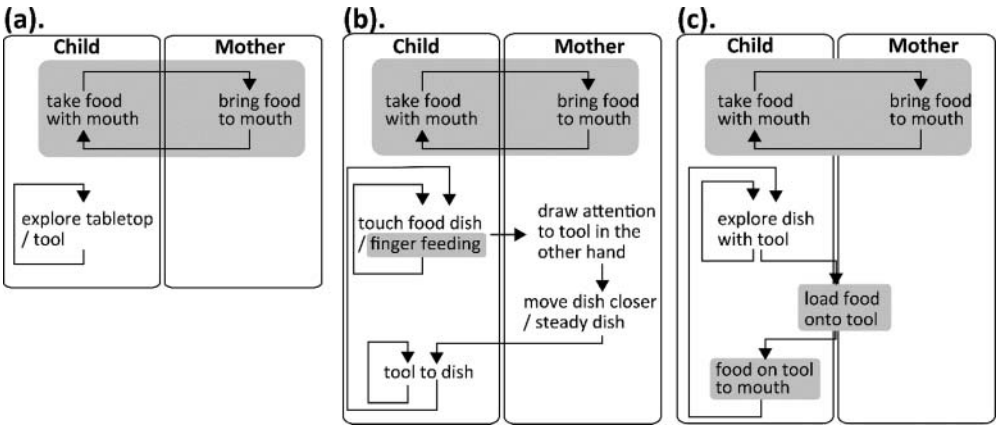


Figure 6. Examples of action sequence of a mother-child dyad actually observed in the early stages of utensil use at mealtime. (a). Passive feeding cycle where food is brought to the child's mouth by the mother while the child plays with a utensil (e.g., Kota, 9:12; Daiji, 10:6). (b). Overlapping cycles of passive feeding, finger feeding, and exploratory utensil use encouraged by the mother (e.g., Kota, 12:12; Daiji, 13:0). (c). Overlapping cycles of passive feeding and the occasional attempt by the infant to feed himself with a utensil with the assistance from the mother (e.g., Kota, 14:26; Daiji, 15:7).

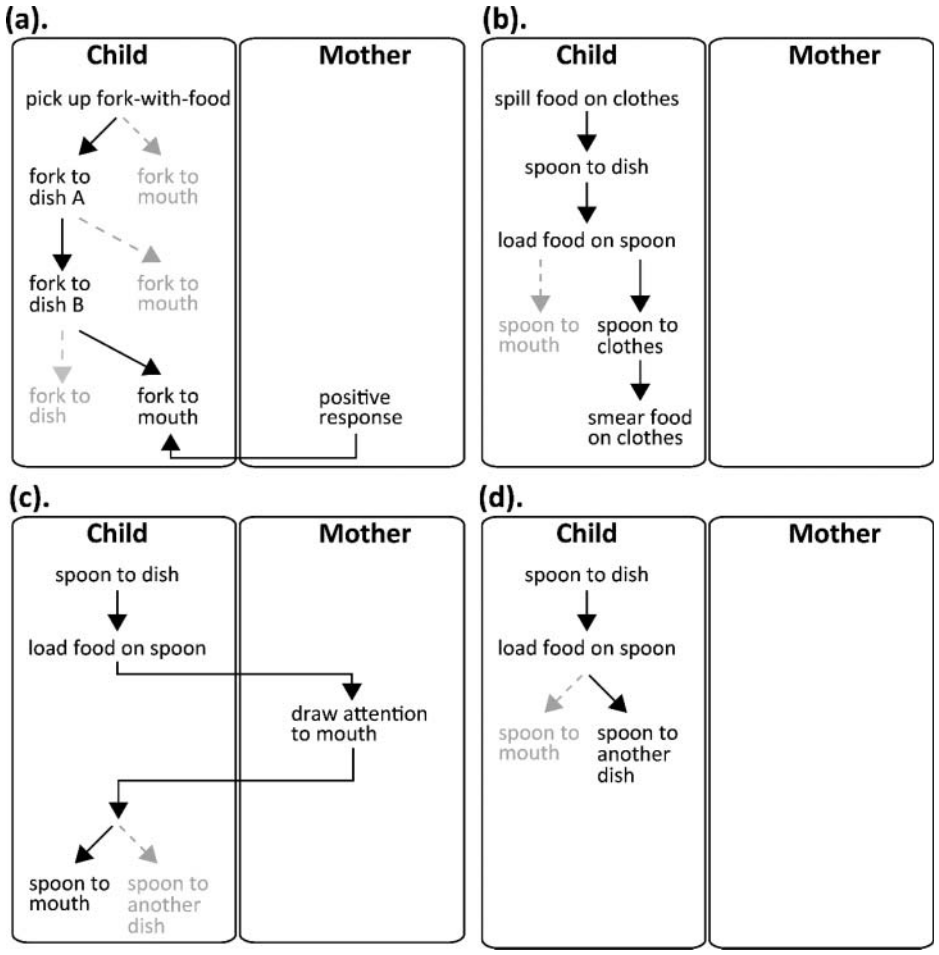


Figure 7. Problem of sequential action. Black arrows represent the sequence of action that was actually selected. Gray dotted arrows represent action that was possible but not selected. (a). Kota attempted to transport the fork-with-seaweed to other dishes before bringing it to his mouth (14:14). (b). Selection of action irrelevant to the goal of feeding just after loading the food onto the spoon (Kota, 17:24). (c). Intervention by the mother at the transitions between subsidiary tasks (Kota, 18:13). (d). Selection of action irrelevant to the goal of feeding during the mother's absence from the table (Kota, 18:13).

with-seaweed to another dish and finally brought it to his mouth, to which his mother exhibited a positive response, saying, "You are very good" (Figure 7a). Therefore, Kota tried out different possibilities of action afforded by the fork-with-seaweed before finally bringing it to his mouth. The additional five videos of Kota after the onset of self-feeding with a utensil further provided episodes where similar problems were observed. During his mother's absence from the table, Kota spilled yogurt on his clothes (Figure 7b, age 17:24). After this event, Kota resumed scooping yogurt with a spoon from a cup. Having scooped yogurt with a spoon, although it was possible to bring it to his mouth, Kota instead smeared yogurt on the clothes where the yogurt had been spilt previously (Figure 7b). How might we understand such behavior? Bringing food to the mouth with a spoon depends on having loaded food onto a spoon, but loading food on a spoon creates the condition that enables multiple

actions to occur. In this example, after having scooped yogurt, an alternative action route was selected among the multiple possibilities that opened up after scooping yogurt.

There were situations where the mother played a role in selecting a particular function of utensil from among the many possibilities. For example, when Kota was at age 18:13, immediately after he independently scooped the food with a spoon, his mother remarked "open your mouth" so that Kota would take a particular route in bringing the food to the mouth (Figure 7c). Yet, right after this event in the same meal, when his mother briefly left the table to go to the kitchen, the goal of the child's behavior with the spoon deviated from its feeding function. This time, after having successfully scooped food with a spoon, Kota transported food on the spoon to another dish and repeated this sequence several times (Figure 7d). Albeit anecdotally, such episodes illustrate a challenge faced by children learning to use utensils robustly for a particular function in a mealtime context, where multiple possibilities of action and potential sources of perturbations, such as spillage of food, are present.

Discussion

This study provided a detailed description of the process of emergence of a utensil-using skill of infants to control encounters with food and mother-infant joint action that surrounds the emergence of this context-specific skill. Longitudinal observations found a systematic pattern of change in the way a utensil was used by infants at mealtime and a concomitant change in the organization of the environment by their mothers over time. In summary, the following characteristics of mother-infant dyads were found in the development of utensil use in the specific context of mealtime:

Child

1. There was an extended period of non-goal-directed, exploratory use of a utensil before the infants used the utensil for the goal of feeding.
2. Variation in the ways a utensil was used by infants gradually shifted toward a specific set of functions that are appropriate to the mealtime setting.
3. Even after the infants have learned to catch food with a utensil, or to transport food to the mouth, these subsidiary activities were often not organized into a coherent sequence that affords the intake of food.

Caregiver

1. Assistance provided by the mother to the infant at mealtime included various adjustments of the subsidiary components of functional act of feeding, such as the adjustment of spatial arrangement of objects surrounding the infant.
2. In the early phase of utensil use by the infant at mealtime, the mother constructed a spatial arrangement, or a "field" around the infant, within which various non-feeding-relevant acts were tolerated and even promoted.
3. Subsequently, the mother gradually increased the opportunities for the infant's functional feeding encounters, often by changing the arrangement of objects on the table in front of the infant.
4. When an infant had learned to perform part of the feeding activity independently, the mother was observed to intervene at the transitions between subsidiary activities in such a way to highlight an action possibility relevant to the function of feeding.

Ecology of skill learning

The two foci of this study have been as follows: (a) emergence of a utensil-using skill of infants to control encounters with food and (b) mother-infant joint action that surrounds the emergence of this context-specific skill. Regarding the former, the present study could help situate recent laboratory findings by focusing on the details of the process by which individual children come to use utensils in the specific context of mealtime. This study found that, at least in the two mother-infant dyads observed, there was an extended period in infancy where the utensil-using behavior of infants was not yet directed at the goal of feeding (Figure 1b and Figure 2b). What constituted the natural starting points of the development of utensil-assisted feeding in these infants were not the rudimentary versions of self-feeding with a utensil but rather playful manipulation of a utensil that was quite irrelevant to the immediate goal of feeding. In the beginning, infants just seemed to do whatever may come up while playing with a utensil and their behavior fluctuated without a clear goal. The data are in line with the view that tool-use development may entail a gradual process involving exploratory attempts that afford opportunities for perceptual learning (Lockman, 2000). However, the fact that having a utensil in the hand would not provide the opportunity for eating for several months is quite astonishing. What makes it possible for infants to persist with using the utensil that does not immediately serve the purpose of feeding but instead requires prolonged experience and learning?

One possible key to answering this question we found is the fact that mothers organized environment so as to provide changing opportunities for developing infants. This is where another focus of the present study—mother-infant joint action—comes in. So far, most studies on mother-infant joint action involved in feeding predominantly focused on the direct dyadic interaction between an infant and his or her caregiver, such as give-and-take responses involved in feeding (van Dijk, Hunnius, & van Geert, 2012), coordination between infant's food-intake motions and mothers' food-carrying movements (Toyama, 2013, 2014), or mother's intervention to guide the infant's hand or the utensil (Valsiner, 1997). Unlike earlier work, we presented a broader perspective that takes into account not only the direct interaction but also the indirect adjustment of the environment by the mother in ways that have consequences for the spontaneous behavior of infants. This study found that the mother actively organized the environment of infants in such a way to encourage infants according to different phases of the development of utensil feeding. Qualitatively, structuring the environment of the infant by the mother seemed to have followed each of the following two steps.

Creating a field of safe exploration. At the beginning of utensil use, we found that the mothers were prospectively creating the conditions where nonfunctional, playful utensil-using behavior of the infants was tolerated. We call those environmental layouts structured by the caregiver in such a way to allow for the safe exploration of the tool, objects, and environment *the field of safe exploration*, borrowing the field concept from Lewin (1936), Valsiner (1984, 1997), Reed, and Bril (Reed, 1993; Reed & Bril, 1996) with modification to emphasize that it is exploratory activities of the infants that are promoted in this field. In the context of feeding, the field of safe exploration was created around the infant by the mother in such a way to simultaneously allow for the playful, sometimes unpredictable behavior of the infant and the ongoing feeding cycle controlled by the mother. To do so, the mother would move the dangerous objects out of reach, steady the dish when the infant reaches for

it, provide an object (e.g., empty dish) to play with a utensil, highlight the part of the environment to be explored, and so on (Figure 8a). As was shown in the case of Kota, whose mother held out an empty dish for the infant to explore, in between bringing food to the infant's mouth, the mother invited the exploration with a utensil by the infant. By repeating such interactions over days, weeks, and months, infants may be given chances to gain knowledge about and discover a set of functional properties of the utensil. Previous studies also reported that the infant was frequently given a spoon to play with while being fed around the end of the 1st year (Connolly & Dalgleish, 1989; Gesell & Ilg, 1937). Although all activities can potentially yield some knowledge about the aspects of the environment, E. J. Gibson (1988) found it useful to distinguish performatory activity from exploratory activity that is knowledge gathering, primarily because the possibilities of performatory activities are minimal in young infants, whereas exploratory activities are available even in the newborn. E. J. Gibson considered this asynchrony between exploratory and performatory activities a key to understanding the development of skills in infancy, where exploratory activities provide a prerequisite for the later emerging performatory skills (E. J. Gibson, 1988). The characterization of the infant's activity as consisting of the two modes—exploratory activity and performatory activity—might allow viewing what has been frequently seen in the beginning of utensil use in a new light. Our observations, as well as the recent studies on skill acquisition in infancy, provide support for the idea that the exploratory activity of an infant precedes the emergence of later goal-directed use of the utensil. Not only that, but we found that in the early stages, the mother constructed a spatial arrangement around an infant within which the infant was given opportunity to play safely with a utensil.

Creating opportunities for functional encounters. At about the same time as the use of utensil by the infant became consistently food oriented, the mother started to introduce opportunities for functional feeding encounters. The mother may physically modify the arrangement of the objects within the child's reach so as to provide the opportunities relevant to the context of feeding (Figure 8b). The behavior of the child was motivated and constrained by the opportunities available in the environment, which mother was observed to attend to carefully, and the affordances for the improper use of the utensil at mealtime such as tapping on the table were realized less frequently compared with before (Figure 1b and

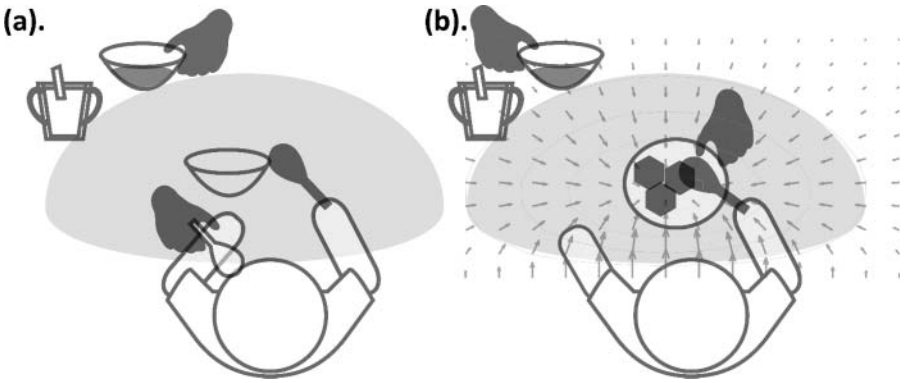


Figure 8. Schematic representations of (a) *the field of safe exploration*, where what is within reach of the child is carefully controlled, and (b) creating *opportunities for functional encounters*, where a food dish is moved closer and steadied by a caregiver to provide the opportunities for the child's feeding encounters. Gray shading indicates the reaching space of the child.

Figure2b). For example, when Kota reached for a spoon at age 13:22, his mother moved one dish close to the child, steadied the dish in such a way to increase the opportunities for getting food on the utensil, and moved away another dish that was in the way. The dish stabilized by the mother allowed the child to take advantage of the edge of the dish to load the food onto the utensil. The role of the caregiver here seems to be one of adjusting the opportunities so that good-enough solutions are available for the child with a tool to obtain feeding-relevant encounters (Loeb, 2012). Gradually, a single dish was replaced by multiple dishes typical of Japanese food, the bottle used for drinking was replaced by a cup, and the available opportunities gradually increased until the child would be given full opportunities for self-feeding. Yet, the online adjustments of opportunities by arranging the dishes by a caregiver long continued even after the child started taking the food with a utensil on his own.

Guiding sequential action. Previous studies on patients suffering from traumatic closed head injuries reported that some patients are typically quite successful in various activities subsidiary to eating (e.g., using a spoon to transport liquid) while being unsuccessful in organizing these activities into the coherent accomplishment of the overall goal of eating (Reed, 1993; Schwartz et al., 1991). A somewhat similar situation was observed in infants learning to use a utensil to eat. Even after the infants had learned to scoop food with a spoon, or to transport food to the mouth, these activities often failed to form a sequence in such a way to achieve the goal of bringing food to the mouth (Figure 7). The infants failed to select a relevant action among possibilities afforded at the transitions between these subsidiary activities. Something like a competition among multiple functions afforded by a utensil seemed to be at play, and an alternative course of action in waiting had surfaced at times. Interestingly, what was also observed in such a situation was that the mother's interventions were synchronized to the specific timing of the occurrence of such distraction of the infant's behavior. At these transitions between subsidiary activities, the mother was drawing the attention of the infant to a particular possibility of action among the myriad possibilities opening up, thereby facilitating the organization of sequential actions into a functional act. Through the mother-infant interaction situated in the mealtime context, the infants seemed to learn not only the affordances of the mealtime environment but also that sequencing can be very important in realizing those affordances.

Conclusion

Through the analysis of utensil-use development in the mealtime context of two infant-mother dyads, this study revealed the details of what may be called the process of affordance selection—in which a definite set of opportunities for action among many available were selected by adults to invite certain spontaneous behaviors of developing infants. Mealtime behavior of infants is much messier than the diagnostic tasks in the laboratory. The spatial context is often crowded with multiple opportunities of action available on the tabletop. Our study adds to the growing realization that normally occurring experiences of rich affordances matter in the development of specific behavior in a given population (Bril et al., 2001; Gottlieb, 1997/2014; Nonaka, Bril, & Rein, 2010; Nonaka, 2012, 2017; Reed, 1996; Turvey & Sheya, 2017). Spontaneous exploration by infants in the sea of affordances, when coupled with the selection of a set of opportunities by adults, may provide a directional effect that enables infants to attend to the relevant set of affordances of utensils, which in turn develops

their skills to realize them in a manner appropriate to a specific context in the populated environment.

Acknowledgments

This study was made possible by the cooperation of the two families and by Masato Sasaki and the members of the Sasaki Laboratory of the University of Tokyo who generously made available to us the videos collected for *Akachan* Movie Database (Sasaki, 2008). We sincerely thank them. The first author is grateful to Blandine Bril for drawing attention to the important issues concerning the development in a *populated* environment. We gratefully acknowledge the contribution of Karen Adolph to the design of the coding scheme using *Datavyu* (datavyu.org), although she is not responsible for the present interpretation of the data. We also thank Drew Abney for his helpful advice on cross-recurrence quantification analysis, Chihiro Nishio for her assistance with data coding, and the two anonymous reviewers for invaluable comments on earlier versions of this article.

Funding

This work was supported by JSPS KAKENHI Grant 15KK0009 from the Ministry of Education, Science, Sports and Culture, Japan, awarded to Tetsushi Nonaka and the Wyss Institute for Biologically Inspired Engineering.

References

Abney, D. H., Warlaumont, A. S., Oller, D. K., Wallot, S., & Kello, C. T. (2016). Multiple coordination patterns in infant and adult vocalizations. *Infancy*, *22*, 514–539. doi:10.1111/infa.12165

Boyer, I., & Bril, B. (2001). Structuring a child activity: A comparative study of mother-child interaction in a complex bimanual task. In J. van der Kamp, A. Ledebt, G. Savelsbergh, & E. Thelen (Eds.), *Proceedings of the International Conference on Motor Development and Learning in Infancy* (pp. 55–58). Amsterdam, The Netherlands: IFKB.

Bril, B., Hombessa-Nkounkou, E., Bouville, J-F., & Ocampo, C. (2001). From milk to adult diet: A comparative study on the socialization of food. *Food and Foodways*, *9*, 155–186. doi:10.1080/07409710.2001.9962110

Connolly, K., & Dalgleish, M. (1989). The emergence of a tool-using skill in infancy. *Developmental Psychology*, *25*, 894–912. doi:10.1037/0012-1649.25.6.894

Corbetta, D., Williams, J. L., & Haynes, J. M. (2016). Bare fingers, but no obvious influence of "prickly" Velcro! In the absence of parents' encouragement, it is not clear that "sticky mittens" provide an advantage to the process of learning to reach. *Infant Behavior and Development*, *42*, 168–178. doi:10.1016/j.infbeh.2015.05.001

Cox, R. F., van der Steen, S., Guevara, M., de Jonge-Hoekstra, L., & van Dijk, M. (2016). Chromatic and anisotropic cross-recurrence quantification analysis of interpersonal behavior. In C. Webber, C. Ioana, & N. Marwan (Eds.), *Recurrence plots and their Quantifications: Expanding horizons* (pp. 209–225). Cham, Switzerland: Springer.

Gesell, A., & Ilg, F. L. (1937). *Feeding behavior of infants*. Philadelphia, PA: Lippincott.

Gibson, E. J. (1988). Exploratory behavior in the development of perceiving, acting, and the acquiring of knowledge. *Annual Review of Psychology*, *39*, 1–42. doi:10.1146/annurev.ps.39.020188.000245

Gibson, J. J. (1986). *The ecological approach to visual perception*. Hillsdale, NJ: Erlbaum. (Original work published 1979)

Gottlieb, G. (2014). *Synthesizing nature-nurture: Prenatal roots of instinctive behavior*. New York, NY: (Psychology Press. Original work published 1997)

Kahrs, B. A., & Lockman, J. J. (2014). Building tool use from object manipulation: A perception–action perspective. *Ecological Psychology*, *26*, 88–97. doi:10.1080/10407413.2014.874908

Keen, R., Lee, M. H., & Adolph, K. (2014). Planning an action: A developmental progression in tool use. *Ecological Psychology*, *26*, 98–108. doi:10.1080/10407413.2014.874917

Lewin, K. (1936). *Principles of topological psychology*. New York, NY: McGraw-Hill.

Lockman, J. J. (2000). A perception-action perspective on tool use development. *Child Development*, *71*, 137–144. doi:10.1111/1467-8624.00127

Lockman, J. (2005). Tool use from a perception-action perspective: Developmental and evolutionary considerations. In V. Roux & B. Bril (Eds.), *Stone knapping: The necessary conditions for a uniquely hominin behavior* (pp. 319–330). Cambridge, UK: McDonald Institute for Archaeological Research.

Lockman, J. J., & Kahrs, B. A. (2017). New insights into the development of human tool use. *Current Directions in Psychological Science*, *26*, 330–334. doi:10.1177/0963721417692035

Loeb, G. E. (2012). Optimal isn't good enough. *Biological Cybernetics*, *106*, 757–765. doi:10.1007/s00422-012-0514-6

Mauss, M. (1973). Techniques of the body. *Economy and Society*, *2*, 70–88. (Original work published 1935 in *Journal de Psychologie Normal et Pathologique*, *32*, 271–293) doi:10.1080/03085147300000003

McCarty, M. E., Clifton, R. K., & Collard, R. R. (1999). Problem solving in infancy: The emergence of an action plan. *Developmental Psychology*, *35*, 1091–1101. doi:10.1037/0012-1649.35.4.1091

McCarty, M. E., Clifton, R. K., & Collard, R. R. (2001). The beginnings of tool use by infants and toddlers. *Infancy*, *2*, 233–256. doi:10.1207/S15327078IN0202_8

Needham, A., Barrett, T., & Peterman, K. (2002). A pick-me-up for infants' exploratory skills: Early simulated experiences reaching for objects using 'sticky mittens' enhances young infants' object exploration skills. *Infant Behavior and Development*, *25*, 279–295. doi:10.1016/S0163-6383(02)00097-8

Needham, A., Wiesen, S., & Libertus, K. (2015). Sticky mittens, prickly Velcro, and infants' transition into independent reaching: Response to Williams, Corbetta, and Guan (2015). *Infant Behavior and Development*, *41*, 38–42. doi:10.1016/j.infbeh.2015.05.009

Nonaka, T. (2012). What exists in the environment that motivates the emergence, transmission, and sophistication of tool use? *Behavioral and Brain Sciences*, *35*, 233–234. doi:10.1017/S0140525X11002056

Nonaka, T. (2017). Cultural entrainment of motor skill development: Learning to write *hiragana* in Japanese primary school. *Developmental Psychobiology*, *59*, 749–766. doi:10.1002/dev.21536

Nonaka, T., Bril, B. & Rein, R. (2010). How do stone knappers predict and control the outcome of flaking? Implications for understanding early stone tool technology. *Journal of Human Evolution*, *59*, 155–167. doi:10.1016/j.jhevol.2010.04.006

Nonaka, T., & Bril, B. (2014). Fractal dynamics in dexterous tool use: The case of hammering behavior of bead craftsmen. *Journal of Experimental Psychology: Human Perception and Performance*, *40*, 218–231.

Nonaka, T., & Sasaki, M. (2009). When a toddler starts handling multiple detached objects: Descriptions of a toddler's niche through everyday actions. *Ecological Psychology*, *21*, 155–183. doi:10.1080/10407410902877207

Perry, L. K., Samuelson, L. K., & Burdinie, J. B. (2014). Highchair philosophers: The impact of seating context-dependent exploration on children's naming biases. *Developmental Science*, *17*, 757–765. doi:10.1111/desc.12147

Reed, E. S. (1993). The intention to use a specific affordance: A conceptual framework for psychology. In R. H. Wozniak & K. W. Fischer (Eds.), *Development in context: Acting and thinking in specific environments* (pp. 45–76). Hillsdale, NJ: Erlbaum.

Reed, E. S. (1996). *Encountering the world: Toward an ecological psychology*. New York, NY: Oxford University Press.

Reed, E. S., & Bril, B. (1996). The primacy of action in development. In M. L. Latash & M. T. Turvey (Eds.), *Dexterity and its development* (pp. 431–451). Mahwah, NJ: Erlbaum.

Sasaki, M. (2008). *Ugoku Akachan Jiten (Akachan* Movie Database*)*. Tokyo, Japan: Shogakukan.

Schwartz, M. F., Reed, E. S., Montgomery, M., Palmer, C., & Mayer, N. H. (1991). The quantitative description of action disorganisation after brain damage: A case study. *Cognitive Neuropsychology*, *8*, 381–414. doi:10.1080/02643299108253379

Smitsman, A. W., Cox, R. F. A., & Bongers, R. M. (2005). Action dynamics in tool use. In V. Roux & B. Bril (Eds.), *Stone knapping: The necessary conditions for a uniquely hominin behavior* (pp. 129–147). Cambridge, UK: McDonald Institute for Archaeological Research.

Soska, K. C., & Adolph, K. E. (2014). Postural position constrains multimodal object exploration in infants. *Infancy*, *19*, 138–161. doi:10.1111/infa.12039

Steenbergen, B., Van der Kamp, J., Smitsman, A. W., & Carson, R. G. (1997). Spoon handling in two- to four-year-old children. *Ecological Psychology*, *9*, 113–129. doi:10.1207/s15326969eco0902_1

Toyama, N. (2013). Japanese mother-infant collaborative adjustment in solid feeding. *Infant Behavior and Development*, *36*, 268–278. doi:10.1016/j.infbeh.2013.01.008

Toyama, N. (2014). The development of Japanese mother-infant feeding interactions during the weaning period. *Infant Behavior and Development*, *37*, 203–215. doi:10.1016/j.infbeh.2014.01.002

Turvey, M. T., & Sheya, A. (2017). Non-obvious influences on perception-action abilities. *Psychonomic Bulletin & Review*, *24*, 1–7.

Valsiner, J. (1984). Construction of the zone of proximal development in adult-child joint action: The socialization of meals. In B. Rogoff & J. V. Wertsch (Eds.), *Children's learning in the "zones of proximal development"* (pp. 65–76). San Francisco, CA: Jossey-Bass.

Valsiner, J. (1997). *Culture and the development of children's action: A theory of human development*. New York, NY: Wiley.

van Dijk, M., Hunnius, S., & van Geert, P. (2012). The dynamics of feeding during the introduction to solid food. *Infant Behavior and Development*, *35*, 226–239. doi:10.1016/j.infbeh.2012.01.001

Warlaumont, A. S., Richards, J. A., Gilkerson, J., & Oller, D. K. (2014). A social feedback loop for speech development and its reduction in autism. *Psychological Science*, *25*, 1314–1324. doi:10.1177/0956797614531023

Williams, J. L., Corbetta, D., & Guan, Y. (2015). Learning to reach with "sticky" or "non-sticky" mittens: A tale of developmental trajectories. *Infant Behavior and Development*, *38*, 82–96. doi:10.1016/j.infbeh.2015.01.001

Wu, H. G., Miyamoto, Y. R., Castro, L. N. G., Ölveczky, B. P., & Smith, M. A. (2014). Temporal structure of motor variability is dynamically regulated and predicts motor learning ability. *Nature Neuroscience*, *17*, 312–321. doi:10.1038/nn.3616