The Development of Coordination in Infancy
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Chapter 10

HAND-MOUTH COORDINATION IN THE NEWBORN: MORPHOLOGY, DETERMINANTS, AND EARLY DEVELOPMENT OF A BASIC ACT

Philippe Rochat

Emory University, Atlanta, USA

Abstract

The transport of hand(s) toward the mouth is manifested prenatally and remains a prominent behavior at birth. Hand-mouth coordination is indeed one of the earliest behavioral expression of an integration between different sensorimotor systems. It is a trademark of infancy, forming a basic act with obvious adaptive value all through the lifespan. This chapter discusses the morphology and determinants of hand-mouth coordination at birth, and presents its development in the course of the first semester of life. Recent empirical evidence suggests that changes in the motor patterns of hand-mouth coordination correspond to changing functional goals driving the transport of hand(s) to the mouth. Hand-mouth coordination in newborn infants is shown to be an integral part of the feeding system, controlled by particular oro-pharyngeal stimulation (i.e. sucrose). By 2 months, when infants start to bring objects to the mouth, sucrose stimulation vanishes as a robust predictor of this coordination. Hand-mouth coordination switches to a bi-manual involvement, with both hands moving in symmetry toward the mouth, from a one-handed action at birth. By 5 months, hand-mouth coordination appears to become an integral part of multimodal exploration and manipulation of objects. The motor expression of this coordination changes as hands come increasingly under the control of vision, and as haptic and manipulatory skills develop. This progression

is discussed in terms of rapid changes in the functional goals driving hand-mouth coordination at birth and in the course of the first semester.

Hand-mouth coordination in the newborn: Morphology, determinants, and early development of a basic act

At the origin of development, there are propensities to behave in ways that are unmistakable and predictable. Immediately after birth, babies engage in sucking, mouthing, grasping, rooting, visual tracking, waving and kicking, forming the behavioral repertoire of the newborn. This repertoire is commonly identified as a collection of "reflexes" (Bronson, 1982; Koupernik & Dailly, 1968; Piaget, 1952), sometimes viewed as part of a collection of "action systems" serving particular functions, such as the ingestion of food, communication, exploration or locomotion (Reed, 1982; Rochat & Senders, 1991). These different ways to account for the newborn's repertoire are predicated on particular assumptions regarding the organization of behavior at birth, and what develops in the course of the first months. For example, Piaget recognized the highly organized and functional nature of individual "reflex schemes", each involving the complex integration of different muscle groups. Beyond the appreciation of their intrinsic structure, he proposed that at birth and in the course of the first weeks, reflexes are not yet co-ordinated, but viewed as unrelated and separate in their functioning. According to Piaget, reflexes have to be progressively coordinated to form new (larger) functional actions, such as reaching or bringing grasped objects to the mouth.

Recent research demonstrates the existence of complex sensorimotor coordinations at the origin of development, prompting a different account of what needs to develop early in life. Patterns of action that integrate various sensorimotor systems are shown to be manifest from birth. The studies of Bower, Broughton, & Moore (1970), von Hofsten (1982), and Trevarthen (1984), demonstrate that eye-hand coordination is at work in the newborn. When presented with a visual target moving in front of them, newborns manifest the rudiments of visually-guided reaching (pre-reaching) by moving their hand towards

the object-target. This precocious behavior, shows that contrary to Piaget's assumption, visual and manual schemes are not independent in their functioning, but are integrated from birth. Similar facts are now well established in relation to a variety of sensorimotor systems. There is ample evidence of the newborns' ability to turn their head towards a sound source (Clifton, Morrongiello, Kulig & Dowd, 1981; Weiss, Zelazo & Swain; 1988), to reproduce (imitate) the facial expression of an adult model (Meltzoff & Moore, 1977; Vinter, 1985), or to visually recognize an object that one-month-old infants had previously explored with their mouths only (Gibson & Walker, 1984; Meltzoff & Borton, 1979). This evidence demonstrates that various sensorimotor systems are potentially organized and coordinated in their functioning from birth. Current theories on perceptual and cognitive development rely on empirical evidence of an initial behavioral organization, assuming that infants come to the world attuned and organized, rather than disconnected and unstructured (Gibson & Spelke, 1983; Karmiloff-Smith, 1991; Mounoud, 1984; Spelke, 1991; Thelen & Fogel, 1986).

This chapter will discuss the morphology, determinants and early development of a complex behavior that appears to be organized from birth: hand-mouth coordination, or the early propensity to bring hand(s) in contact with the mouth. This propensity is among the earliest behavioral expression that integrates different sensorimotor systems. It is an interesting challenge to developmental theories as it demonstrates the existence of a highly organized pattern of action at birth that finds new functional expressions throughout the lifespan in various activities such as self-feeding, non-verbal communication, self-calming, self-stimulation or "oral eroticism", object manipulation and exploration. This chapter presents studies that account for hand-mouth coordination, and rapid changes in what determines this behavior in the course of the first six months. Based on these studies, important features of early development are tentatively outlined.

Pre-natal expression of hand-mouth coordination

Dramatic pictures taken by medical photographer Lennart Nilsson (1966) of the developing human embryo and fetus, illustrate that fetuses

display complex patterns of behavior such as thumb sucking by the third trimester of pregnancy. Bruises from intense fetal sucking are commonly found on the hand, thumb or wrist of the newborn (Murphy & Langley, 1963). This shows that hand(s) and mouth are brought into contact by the fetus, and points to prenatal precursors of the activities observed in the neonate. Ultrasound studies of human fetal behavior show that hand-face contacts are common and frequently observed from 12 weeks gestational age (GA) (de Vries, Visser & Prechtl, 1985). Utrasonic observations reveal movements of the hand slowly touching the mouth, the fingers frequently extending and flexing (de Vries, Visser & Prechtl, 1982). Although the ultrasound technique captures fetal behavior in the natural environment of the womb, it is not accurate enough to document systematically instances of fingers' insertion into the mouth, once hand-face contact occurs (de Vries et al., 1982).

Studies of human fetal activity using direct observations of fetuses placed in a fluid bath to reproduce the relative state of weightlessness in the amniotic sac, show that there is a link between manual and oral activities in fetuses (Humphrey, 1970). Following palmar stimulation, Humphrey (1970) reports mouth opening, tongue protrusion, ipsilateral face turning and finger closure in fetuses as young as 14 weeks GA. Humphrey (1970) notes that following palmar stimulation, no other movements than those of the fingers, the head and the oral area are observed. This early prenatal link between oral and manual activities is probably the precursor of Babkin and palmomental reflexes displayed by the newborn approximately 25 weeks later (Humphrey, 1969c). In the Babkin reflex, pressure on the infant's palm is followed by the opening of the mouth (Illingworth, 1987; Peiper, 1962; Prechtl & Beintema, 1964). Such responses are robust enough that pressure on the infant's palm is often applied by skilled nurses to stimulate feeding and facilitate the introduction of the nipple inside the infant's mouth (personal observation).

An important feature of fetal behavior is that from the earliest stage of prenatal development, mouth and hand(s) are often in contact. Humphrey (1970) notes that self-stimulation is an important component and a potential factor of prenatal development. In addition to the fact that hand-mouth contacts cannot be avoided in the confined

space of the womb, during the early stage of fetal development (8.5-9.5 weeks of gestational age), the perioral region is the only sensitive area of the whole skin surface (Humphrey, ibid, p. 43). After 14 weeks GA, the mouth of the fetus is found to be frequently open and swallowing activities are observed (Hooker, 1952). By 24 weeks GA, sucking activities in the fetus are reported, and by 29 weeks, it is strong enough to be audible (Hooker, ibid; reported by Humphrey, 1970). Although sucking behavior emerges by the end of gestation, pictures document that the thumb is inserted inside the mouth as early as 18 weeks GA (Nilsson, 1966). It is thus feasible that swallowing of amniotic fluid and thumb insertion inside the oral cavity precede the actual establishment of sucking and thumb sucking, this latter activity observed only by the end of gestation (Murphy & Langley, 1963).

In summary, there is good evidence of a prenatal link between oral and manual behavior. Although it is yet unclear what function such a link might serve, it is probably at the origin of the coordination between manual and oral actions found immediately after birth. Developing in utero, the functional link between the hand and mouth continues at birth, particulary in the newborn.

Hand-mouth coordination at birth

The apparent continuity between fetal and newborn behaviors is particularly remarkable in light of the drastic contrast between the confined, liquid environment of the fetus, and the expanded, aerial milieu of the neonate. The womb constrains the fetus' degrees of behavioral freedom, but provides a relative state of weightlessness favoring movements. By contrast, the open environment of the neonate frees behavior from the spatial restraints of the womb, but makes it effortful as movements require antigravitational forces. Despite this drastic environmental change, behavioral continuity is maintained as patterns of fetal behavior are observed immediately after birth, such as sucking, grasping, orienting, and eye movements (Prechtl, 1985).

Simultaneous recordings of sucking and grasping behavior in the neonate reveal that these activities co-vary rather than function independently (Brown & Fredrickson, 1977; Buka & Lipsitt, 1991).

Brown et al. found that sucking is dominant, and once engaged, drives newborn grasping. Despite this dominance, both appear to participate and contribute to hand-mouth coordination as an integrated system. The significant increase in behavioral degrees of freedom at birth, leads to an increase in the probability of random contacts between hands and mouth. In reality, this change does not prevent neonates, like fetuses, from manifesting protracted contacts of the hand(s) with the mouth. Korner and Kraemer (1972) observed that neonates spend up to 20% of their waking hours with their hands contacting the oral region. Recently, Butterworth and Hopkins (1988) systematically documented instances where newborn infants brought their hand(s) in contact to their mouth. These authors performed a frame-by-frame analysis of the spontaneous upperlimb, facial and head movements in a group of newborns, their analysis focusing on hand movements towards the mouth. They observed instances of hand-mouth coordination that do not appear to be driven by reflex mechanisms such as the rooting and the Babkin reflex. Butterworth et al. found instances where the hand is brought directly to the mouth, without prior contact to the perioral region. They report remarkable episodes in which newborns open their mouths as the hand approaches the face, in what appears to express anticipation of contact. Further observations reported by these authors suggest that hand-mouth coordination in newborns is somehow independent of reflex mechanisms. A fine grain analysis of hand trajectory reveals flexibility and variability, rather than spatio-temporal rigidity and fixedness. It is assumed by Butterworth et al., that if reflex mechanisms were involved in controlling such coordination, the spatio-temporal configuration of behavior should be highly predictable; their analysis shows that it is not.

Recent investigations have pushed further the study of hand-mouth coordination in the newborn, trying to capture the mechanisms of its control and the functions that this behavior might serve. Different hypotheses have been developed about the function of early hand-mouth coordination. Kravitz, Goldenberg and Neyhus (1978) suggested that hand-mouth and hand-face contacts are a form of primary haptic self-exploration. Feldman and Brody (1978) have proposed that hand- and finger-sucking by the neonate serves a self-calming function, linked to

hunger mechanisms. Others have interpreted hand-mouth coordination in the newborn as a precursor of self-feeding activities and an early form of oral capture (Rochat, 1987b; Butterworth & Hopkins, 1988; Rochat & Senders, 1991). Recent studies have addressed this issue based on the results of experiments designed to substantiate these interpretations. They originated from accidental observations made by Blass, Ganchrow and Steiner (1984), as they were doing classical conditioning of sucking and head turning in newborn infants. In these experiments, they used oral delivery of a small dosage of sucrose as reinforcement. They observed that following sucrose delivery, as the newborn started engaging in mouthing and tonguing activities, that they frequently brought one hand to the mouth and maintained it in contact with the oral and perioral region for long periods of time. This accidental observation suggests that hand-mouth coordination could be enhanced following sucrose delivery. Rochat, Blass and Hoffmeyer (1988) confirmed this phenomenon in a controlled experiment, demonstrating that hand-mouth coordination in the newborn was indeed under the control of sucrose stimulation. Following the delivery of 0.2 ml of sterile water with 12 % sucrose, both duration and frequency of hand-mouth contact increased by 50 %, returning to baseline levels when sucrose stimulation ended. Following sucrose delivery, the proportion of hand-mouth contacts clearly increased in comparison to hand-face contacts, and once in contact with the mouth the hand rested there for protracted periods of time.

A qualitative analysis of the videotapes revealed that sucrose delivery generally had a calming effect on the newborn, thus decreasing the probability of a random encounter of the hand to the mouth. One could suppose that as a consequence of sucrose delivery, infants became agitated, increasing random contacts of the hand with the mouth. These type of contacts would comply with Piaget's assertion that hand-mouth contacts in early infancy are merely accidental, genuine coordination emerging by the second month only (Piaget, 1952). In our study, it was clearly not the case, as hand-mouth contacts were fleeting during baseline periods, and protracted after sucrose stimulation.

In a follow-up study, Blass, Fillion, Rochat, Hoffmeyer and Metzger (1989) investigated whether it is the calming effect of sucrose

stimulation that determines hand-mouth coordination in newborns, or whether other factors might be involved. Infants who cried during a first baseline observation period were used in this study. Attempts to soothe the infant were first performed by the experimenters for 5 minutes with gentle stroking, quieting sounds, and rocking (vestibular) stimulations. Following this soothing period, the neonate received 5 deliveries of 0.1 cc plain water at a rate of one delivery per minute. The infant received then 5 sucrose deliveries, followed by 5 water deliveries at the same rate of one per minute. Testing ended with a final 5 minute observation baseline in which no stimulation was administered to the infant. Blass et al. observed that soothing, water and sucrose stimulations all had a calming effect on the newborn. Analysis of upperlimb movements revealed a significant increase in hand transport to the mouth only after sucrose delivery. Although all manipulations had an effect on changing the newborn's state (i.e., crying reduction and reduced upperlimb movements), only sucrose stimulation appeared to control hand(s) transport to the mouth, confirming the observations made by Rochat et al. (1988). These results suggest that it is not the calming effect, per sé, that controls for an increase of hand transport to the mouth in the newborn. Furthermore, it is not any kind of oral stimulation that causes enhanced hand-mouth behavior, sterile water not being effective compared to sucrose solution. Other experiments have shown that olfactory stimulations (chocolate or lemon odor) as well as water at room temperature delivered on the infant's hand, did not increase significantly hand-mouth coordination in the neonate (Rochat, Hoffmeyer and Blass, 1987).

The effect of sucrose on sucking behavior has been well documented in numerous studies (see Crook, 1979, for a review). In general, following sucrose delivery, newborns change their sucking pattern, engage in longer bursts of sucking combined with reduced frequency of sucks, as if they were "savouring", possibly linked to a "hedonic response" (Lipsitt, 1979). Note that this interpretation is based on multiple measures recorded simultaneously with the sucking response, such as heart rate, respiration and mouthing activities (expression) (Lipsitt, ibid). Sucrose stimulation appears to tune the neonate into a particular oral mode linked to the feeding system. In the

experiments presented above (Rochat et al., 1988; Blass et al., 1989), sucrose stimulation first typically engaged newborn's sucking, followed then by the movement of the hand to the mouth. This timing, together with the specific effect of sucrose over other stimulations, suggest that sucrose engages the feeding system of the neonate, which in turn recruits hand-mouth coordination (Blass et al., 1989; Rochat & Senders, 1991).

Following sucrose stimulation and the establishment of hand-mouth contact, upperlimb movements tend to stop and overall calming takes place, the action apparently brought to completion once hand-mouth contact occurs (Blass et al., 1989). This fact indicates that hand-mouth coordination in the neonate might serve the function of providing the infant with something to suck on, once the sucking (feeding) system is engaged. This interpretation is supported by a study in which immediately following sucrose delivery, the infant was presented with a rubber pacifier inserted in his/her mouth. Pacifier insertion is shown to suppress hand-mouth coordination typically following sucrose delivery. The pacifier appears to facilitate and bring to balance the newborn's sucking system (Blass et al., 1989). Once the pacifier is introduced in the newborn mouth, a dramatic inhibition of upperlimb movements towards and around the mouth is observed, confirming the idea that hand-mouth coordination, at birth, is an integral part of the feeding/sucking system. Once engaged, this system appears to orient the newborn toward objects that afford sucking. Hand-mouth coordination in the newborn, like the rooting response predicted by cutaneous stimulation of the perioral region, is among the earliest expression of a goal oriented action. Note that the term "oriented action" is restrictive compared to the view interpreting hand-mouth coordination at birth as a first manifestation of "intentionality" (Butterworth, 1986; Butterwoth & Hopkins, 1988). Whether oriented or pre-intentional, hand-mouth coordination is part of the behavioral repertoire of the neonate, and an integral part of the feeding system as it is shown to be brought under control of sucrose stimulation.

The question that will be addressed now pertains to the future of such organized pattern of behavior, beyond birth. In particular, can the phenomena observed in the neonate be replicated in older infants, and

what changes in the morphology and determinants of hand-mouth coordination?

Hand-mouth coordination in early development

The expression of hand-mouth coordination develops rapidly during the months following birth. To illustrate and discuss this development, observations are first presented showing that the mechanisms controlling hand-mouth coordination at birth are not the same two months later. A second body of observations documents morphological changes in hand-mouth-coordination between 2- and 5-months, as infants start to transport objects to the mouth. Finally, based on observations reported in the literature, and on a longitudinal study regarding the development of infant reaching behavior, the early development of hand-mouth coordination is shown to be closely related to the development of other sensorimotor systems, in particular eye-hand coordination.

Hand-mouth coordination in 1- to 4-month-old infants

Recently, observations were collected suggesting that the organization and determinants of hand-mouth coordination in the newborn rapidly changes. Hand-mouth coordination, calming of the infant, and sucking engagement found in the neonate following sucrose stimulation was not found in a group of eight healthy infants aged between 4 and 14 weeks (one four-week-old infant, five eight-week-olds, one twelve-week-old, and one fourteen-week-old). Each infant was filmed while placed supine on a floor mat in the laboratory. After a three minute baseline period, the infant received 5 deliveries of 0.1 cc sterile water with 12% sucrose at a rate of one delivery per minute. Testing ended with a final three minute observation baseline in which no sucrose stimulation was administred to the infant. Following this design, five behavioral variables were scored and analyzed, including behavioral state (sleeping, quiet alertness, fuss/cry), facial expression (relax, frown, anger/pain), mouthing activity (quiet mouth, mouthing movements such as tonguing, sucking, or puckering), frequency and type of hand movements

(random, towards face and mouth), duration of hand-face contacts (with face or head, with the mouth). Again, the main question guiding this study was whether the hand-mouth phenomenon observed in the newborn could be replicated in older infants. Following sucrose stimulation, will they calm down, become more relaxed, engage in sucking, or show increased transport of their hand to the mouth?

Analysis of the five dependent measures in all infants indicated that none of the above happens. Following sucrose delivery, the most noticeable fact is a reversal of the calming phenomenon found in the neonate. In one infant (eight-week-old), sucrose did not suppress crying, and in another (eight-week-old), sucrose stimulation was followed by crying. In still another eight-week-old, sucrose stimulation was followed by an unmistakable expression of displeasure (instances of anger/pain expression). None of the tested infants showed any significant increase in the frequency of hand transport to the mouth, nor any increase in the duration of hand-mouth contact.

Two conclusions can be drawn from this study. First, sucrose stimulation has different behavioral consequences in the 1- to 3-month-old infant in comparison to the newborn. It suggests that the mechanisms mediated by sucrose in the newborn are altered few weeks later. Second, the account of hand-mouth coordination in the newborn as an integral part of the sucking/feeding system does not hold a few weeks later. Rapid changes occur regarding the determinants of hand-mouth integration.

To interpret these changes, it is important to consider the progress of the infant in exploring and manipulating objects in the environment. A major characteristic of sensorimotor development is the transition from body-oriented to object-oriented activities (see for example the development from primary to secondary circular reactions depicted by Piaget (1952), borrowing from Baldwin (1906)). This general trend of early development matches the apparent changes in the determinants of hand-mouth coordination. Two-month-olds start to manifest hand-mouth coordination when grasping an object, bringing it to the mouth for oral contact and oral/haptic exploration (Rochat, 1989). Various attempts to observe such behavior in younger infants failed. Once an object is introduced in the hand of the newborn for

grasping, there is no evidence of consecutive transport of the object to the mouth (Rochat, 1987; Rochat & Senders, 1991).

Between 2 and 5 months, there is an interesting change in the tendency to either bring a grasped object *first* to the mouth for oral contact, or *first* to the field of view to look at it. Rochat (1989) found that at 2 and 3 months, infants show an overwhelming tendency to bring the object first to the mouth. At 4 and 5 months, they show an overwhelming tendency to transport it first in the field of view for a visual inspection (see also Rochat & Senders, ibid). It appears that during the first semester, infants progress from oral (proximal) preference to visual (distal) preference in contacting a novel object. Studies of infants' free play indicate that such developmental trend continues beyond the first semester. By the end of the first year, instances of oral exploration decrease, as fine object manipulations in coordination with vision increase (McCall, 1974; Mc Quiston & Wachs, 1979; Ruff, 1984).

What determines hand-mouth coordination in the newborn appears to change by the second month. These changes participate to a general transition from body-oriented to object-oriented actions that are increasingly under the control of vision. The emergence of fine manipulations in coordination with vision by 4-5 months parallel changes in the functional orientation of oral activity. In the course of the first semester, the mouth and its activity is progressively oriented by the control of solid food processing (i.e., chewing), developing also as a major system of non-verbal (i.e., smiling) and verbal (i.e., babbling) communication.

Object transport to the mouth in 2- to 5-month-old infants

When neonates show hand-mouth coordination, it typically involves moving the hand facing their head (en face), and in particular the ipsilateral hand relative to head orientation in the assymetrical posture they often favor when placed prone or supine (Rochat & Senders, 1991). A few months later, when the infant starts to transport grasped objects to the mouth, the morphology of the manual engagement is different. The infant will typically transport the object by using *both*

hands. This development enhances changes in the expression of hand-mouth coordination at around 2 months. It replicates a progression observed in studies of eye-hand coordination in 4-to-6-month-old infants (Rochat, 1992; Rochat & Stacy, 1989; Rochat & Senders, 1990; 1991).

In a recent investigation conducted in collaboration with Jody Avery, we have analyzed instances of object transport to the mouth in forty 2- to 5-month-old infants (divided into 4 age groups of 10 infants each). Infants were placed in an upright infant seat facing a video camera and a novel object was placed in either their left or right hand for grasping (see Rochat, 1989, for details of the procedure used). Once the infant had a good grasp on the object, s/he was free to explore the object up to 90 seconds, or until the object was dropped. The first sequence of object transport to the mouth was analyzed frame-by-frame (rate of 5 images per second) starting two seconds prior to oral contact with the object, and ending one second after (N=15 images per transport pattern). Projecting the video image onto a computer monitor, and based on the X and Y coordinates of a cursor (see Page, Figuet & Bullinger, 1989, for further technical details), we calculated on each successive image the distance between hands, as well as the distance between each hand and the mouth. This analysis allowed us to quantify the morphology of object transport to the mouth in terms of the relative engagement of the hands, and in particular whether the transport involved one or two hands. One-handed transports corresponded to a progressive decrease of the distance between one hand and the mouth, and a progressive increase of distance between hands. By contrast, a two-handed transport corresponded to a simultaneous decrease of the distance between the mouth and both hands, and a decrease in the distance between hands. In qualitative terms, a two-handed transport corresponded to a synergistic inward racking ("crabbing") of the hands joining at the mouth, one hand holding the object during the movement.

Results show that at 3-months, seven out of ten infants (7/10) manifest a *bi-manual* transport of the object to the mouth. By contrast, at 2-, 4- and 5-months, infants show a majority of *one-handed* transport to the mouth (respectively 7/10, 6/10 and 8/10). Comparison of the

relative distance between hands at the beginning of the transport movement and when it ends at the mouth confirms these results. There is a significant decrease of the distance between hands (bi-manual transport), only for the group of three-month-olds ($F(1,36)= 9.229$, $p<.004$). Three-month-olds express a transition from a predominantly one-handed action at two months, that reappears at four and five months. It seems that two-month-olds replicate the morphology of hand-mouth coordination observed in the newborn when transporting only a single hand to the mouth. The fact that there is again a dominant one-handed transport at four and five months does not mean that the infant has "regressed" to an old pattern. Rather, the action of the older infant could be the expression of a novel organization controlled by different variables (see for example the formulation of Mounoud & Vinter, 1981). The synergistic involvement of both hands in transporting the object to the mouth at three months corresponds to a transitional phase, older infants breaking away from these synergies to show more differentiated actions of the hands. The emergence and disappearance of synergistic movements of the hands is an important feature of sensorimotor development. An analogous progression is observed regarding the development of reaching behavior in 4-to-6-month-old infants.

In another study, we compared instances of object transport to the mouth in ten 3-month-olds and ten 4-month-olds. Infants were videotaped in a condition with normal illumination (light condition, as in the first study), and in a condition where the infant was plunged in total darkness (dark condition). In both conditions, the infant was sitting on his/her mother's lap, held gently by the hip, and the object was again placed in either the right or left hand for grasping. An infrared camera was used to film the infant in the dark. Again, the analysis focused on the relative engagement of the hands in the first transport of the object to the mouth by the infant. The question was whether infants would show different patterns in the light compared to the dark condition. This study was meant to control for the role of vision in determining the occurrence and morphology of object transport to the mouth in young infants. For both age groups, results indicated no differences between object transport to the mouth in the

light or in the dark. A (2(age)X2(condition)X2(distance)) ANOVA comparing the distance between hands at the onset of the movement (2 seconds before), and when it ends at the mouth, yields a significant effect of hand distance ($F(1,14)= 16.92$, $p<.001$), and no significant effect of age, or condition, nor any significant interactions between the three variables. These results indicate that both 3- and 4-month-olds tend to be bi-manually engaged in transporting the object to the mouth. Furthermore, they do so equally in the light and in the dark. With this sample of infants, 4-month-olds persist in a synergistic involvement of the hands, apparently stretching out the transition period and the timing of the progression described in the first study. The absence of a significant age-by-condition interaction suggests that it is unlikely that exposure to the dark condition inhibits the expression of one-handed transport of the object to the mouth by 4-month-olds. Rather, it shows that the timing of the progression from synergistic involvement of the hands to one-handed transport can potentially vary by few weeks. Longitudinal studies would be a good way to gather more information on the developmental timing of this progression and its relative variability. In relation to the question guiding this last study, results show that early on, transport of objects to the mouth is independent of vision. Although object transport to the mouth does not appear to be controlled by vision at the onset of development, other observations indicate that it rapidly becomes an integral part of visually controlled and triggered actions.

Hand-mouth and eye-hand coordination in early development

The fine grain observations made by Piaget over sixty years ago remain the most comprehensive account of the development of hand-mouth coordination between birth and 6 months (Piaget, 1952). This is not the place to review this account, but there are few aspects that are useful to consider here. First, of all, Piaget points to various levels of coordination, each corresponding to particular developmental stages. First instances of hand-mouth coordination are reported by Piaget starting the second month, when infants bring fingers to the mouth for sucking. This coordination is viewed by Piaget as yet incomplete,

because it does not entail a reciprocity between manual and oral action, nor an interaction with an object external to the body. According to Piaget, these early instances of hand transport to the mouth do not express a means-end differentiation, and thus no intentionality. More developed forms of coordination between hand and mouth are manifested by the third month, when infants demonstrate systematic transports of *grasped objects* to the mouth, as well as *away* from it (reciprocal action). This type of reciprocal and object oriented action qualifies what Piaget sees as a complete coordination. A second interesting aspect reported by Piaget is the developmental precedence of hand-mouth coordination over eye-hand coordination. This observation is confirmed in large scale cross-sectional studies (Bayley, 1933). Piaget does not view this chronological order in development as "a logical necessity", as he considers a reversed order feasible: "(...) the coordination between sucking and grasping is more precocious (...). But there is no logical necessity for this order of succession and it is possible to conceive of the existence of a partial reversal in the case of certain exceptional subjects." (Piaget, 1952, p. 99). Piaget is careful about making any causal inference linking the emergence of hand-mouth and eye-hand coordination. Neither does he view any logic behind the apparent developmental precedence of hand-mouth coordination over eye-hand coordination. This interpretation is debatable, based on observations suggesting that hand-mouth coordination is an integral part of reaching activities when they emerge at around 4 months.

Observations support the idea that the developmental precedence of hand-mouth coordination over eye-hand coordination is an important fact of sensorimotor development, hand-mouth coordination potentially driving early eye-hand coordination. Bruner (1969), suggests that the mouth is the terminus point or third element ("tertium quid") of early eye-hand coordination, infants starting to reach and grasp for objects they see in order to bring them to the mouth. This interpretation is based on the common observation of young infants' propensity to bring objects to the mouth. A similar interpretation can be drawn from a recent longitudinal study the present author did on the emergence of reaching behavior. In this study, infants were filmed from the time

parents reported that their baby showed first attempts to reach for a seen object (approximately 3 1/2 months). Within a week of this report, infants were seen bi-weekly until the age of 6 months. During testing, the infant was placed on the mother's lap and objects were presented to them frontally for reaching. At one point in the session, the mother was instructed to hold down by her sides both arms of the infant. This manipulation prevented the infant from reaching for the approaching object. In this condition, from the first session on, infants manifested an *oral capture* of the object, leaning their trunk forward to contact the approaching object with their mouth (Rochat & Senders, 1991). This striking behavior demonstrates that early eye-hand coordination (i.e., reaching) is part of a goal-oriented action that ends at the mouth. It generally includes visually guided reaching, hand-to-mouth transport, and in some particular instances, trunk-mouth coordination. It suggests that the emergence of reaching is not independent from pre-established abilities of the young infant to transport objects to the mouth. Because of the developmental precedence of object transport to the mouth, emerging eye-hand coordination feeds into this existing organization. The possibility of a causal link between the development of hand-mouth and eye-hand coordination cannot be discarded, and future studies should attempt to further substantiate this link. This could be achieved by longitudinal studies focusing on the emergence and development of eye-hand-mouth coordination.

Hand-mouth coordination and functional re-orientation

As mentioned at the beginning of this chapter, hand-mouth coordination is among the earliest expressions of a behavior that integrates different sensorimotor systems. It forms a basic act expressed in the confines of pregnancy, and all through life span. Like other precocious and basic acts such as imitation and reaching, it provides a rich paradigm for the study of development. In general, the developmental question raised by the precocious expression of basic actions that persist through out the lifespan pertain to the mechanisms of functional re-orientation, that is, the integration of basic actions within new behavioral organizations emerging in development. It is

obvious that the mechanisms underlying the neonatal expression of basic acts such as reaching, imitation or hand-mouth coordination, are not merely duplicated when expressed a few months or years later. So, what changes?

The observations on hand-mouth coordination reported in this chapter demonstrate that hand and mouth are functionally linked from birth. Newborns show a propensity to bring hands to the mouth, and to maintain hand-mouth contact for protracted periods of time. Developmental observations within the infancy period also indicate that there are rapid and clear changes in the functional orientation of hand transport to the mouth, as it becomes progressively integrated within new action systems, such as feeding, object exploration and manipulation. At birth, hand-mouth coordination appears to be an integral part of the feeding system. It revolves primarily around the body, rapidly becoming oriented towards objects in the environment, as part of a complex system of exploration and object manipulation. Beyond mere description, what are the control variables of this functional re-orientation? The question remains open but there are important factors to consider, among which the development of postural control, the freeing of the hands, and the emergence of vision as a dominant perceptual system.

At around 6 months, the infant's behavioral organization is dramatically affected by the emergence of self-sitting abilities, when the infant becomes capable of sitting for long periods of time without any external body support. This ability frees the hands from the encumbrance of maintaining balance, and marks the first conquest of verticality. This conquest allows the hands to explore freely, and enlarges the field of visual exploration by providing new degrees of freedom to eyes-head-neck, and trunk articulations (Rochat, 1991). Parallel to this conquest of verticality, hands become differentiated in their functioning and express new collaborations such as fingering (Rochat, 1989). It is also during this period that vision emerges as a dominant perceptual system, "supervising" oral and manual actions (Rochat, 1989; Rochat, 1992; Rochat & Senders, 1991).

This context is important and needs to be considered when trying to account for the functional re-orientation of a basic act such as

hand-mouth coordination. Rather than studying basic acts in isolation, research effort should focus more on the mechanisms of their interaction. As illustrated in this chapter, hand-mouth coordination in the newborn greatly contributes to the complex interactions between action systems that are shaping infant behavior and development.

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