Developmental Psychology
1989, Vol. 25, No. 6, 963–975

0012-1649/89/$00.75

Sensorimotor and Motivational Determinants of Hand–Mouth Coordination in 1–3-Day-Old Human Infants

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Hand–mouth coordination was studied in 1–3-day-old human infants by delivering 0.2 ml of sterile 12% sucrose solution intraorally once every 2 min. Sucrose was extraordinarily calming and caused sustained hand-in-mouth contact. The calm state persisted well beyond sucrose termination. Hand-in-mouth behavior, however, stopped upon sucrose termination, demonstrating stimulus control over this integrated behavior. In subsequent studies we demonstrated that hand-in-mouth behavior was not attributable to calming per se. Moreover, hand activity could be prevented by placing a pacifier in the mouth. This demonstrates that the behavior was under intraoral somesthetic control and was not necessarily the expression of a motor pattern triggered by the sweet taste. These findings are interpreted within the contexts of sucrose (a) calming through an endogenous opioid system and (b) activating suckling–feeding mechanisms, causing the expression of integrated hand, mouth, and head motor patterns.

In human development, hand–mouth contact is among the earliest cases of a sustained behavioral pattern that integrates two separate motor systems. Studies of human fetal activity have placed this phenomenon as early as 18 weeks menstrual age (Humphrey, 1968). The behavior remains prominent, appearing within the first hours after birth (Kravitz, Goldenberg, & Neyhus, 1978). According to Korner and her associates (Korner & Beason, 1972; Korner, Church, & Dontchos, 1968; Korner & Kraemer, 1972), it occurs up to 20% of the time in awake infants lying prone or on their sides.

Hand–mouth integration changes developmentally, coming under the control of perceptual systems by 5 months of age when infants start to reach for (Hofsten, 1979, 1982), then to grasp (Yonas & Granrud, 1985), and finally to bring objects to the mouth (Piaget, 1952; Rochat, 1985; Ruff, 1984; see Gibson & Spelke, 1983, for review). The transitional phases between the early behavior that is independent of eye–hand coordination and the later aspects that integrate reaching and grasping have not been identified or analyzed in any systematic fashion.

The early expression of hand–mouth contact, its increased frequency during the pregrasping and prereaching months, its expansion during the period when all grasped objects are brought into the mouth, and its eventual contraction to actions supporting ingestive behavior reflect changing elements of control among integrated perceptual, motor, and affective systems. Analyses of these transitions, and particularly of the circumstances underlying the development of restrictions on what is brought to the mouth, could reveal some of the characteristics of perceptual and affective systems determining gustatory and haptic identification of objects, motivational systems concerning ingestive behaviors, and those concerned with affect. The eventual smoothing of hand-to-mouth actions and the ultimate ability to substitute one motor pattern for another (reflecting the initial position of the limb, its relationship with the body, and the characteristics of the grasped object) in the service of bringing an object to the mouth is of interest to students of motor development.

Scientific interest in this phenomenon, however, had not moved much beyond Korner and her colleagues' earlier descriptions in newborn infants, largely because a method had not been discovered to bring hand–mouth contact under experimental control. Recently, however, Rochat, Blass, and Hoffmeyer (1988) have overcome this barrier. They obtained experimental control over the incidence of hand–mouth behavior in 2-day-old human infants by delivering 0.2 ml of a 12% sucrose solution to the mouth once every 2 min. Rochat et al. (1988) found a marked shift toward hand–mouth contact at the beginning of sucrose administration and a return to baseline levels when sucrose was no longer presented to the infants.

The goal of this article is to expand on our recent findings (Rochat et al., 1988) by providing a detailed analysis of hand–mouth coordination in 1–3-day-old human infants and by testing hypotheses, arising from these analyses, concerning the basis of this action. In so doing, we provide a point of departure for future studies that can identify isomorphism in motor patterns and their changing perceptual and motivational controls during development.

Experiment 1

Experiment 1A consisted of a more detailed analysis of the Rochat et al. (1988) data, paying particular attention to the temporal relationships among the components of hand–mouth

This research was supported by Grant in Aid of Research HD 19278 and Research Scientist Award MH 00524 to Elliott M. Blass. Support for Philippe Rochat was provided by the Swiss National Science Foundation (FNRS) Fellowship 81.082-0.83.

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interactions in 13 infants. These infants had served as part of an ongoing project in our laboratory on auditory conditioning in which sucrose was preceded by the sound of "psst" or "shh." Experiment 1B partially replicated the analysis in an additional 18 infants who were participating in an olfactory conditioning study in which a chocolate or lime odor preceded sucrose administration.

We undertook the more detailed analysis to gain a fuller understanding of the circumstances under which hand–mouth contact would occur and to establish distinctions among different classes of contact. Informal observations had revealed significant variability among infants in the frequency of hand–mouth contact, the likelihood of the hand actually being engaged by the mouth, and the intensity with which these behaviors occurred. This analysis has yielded a number of mutually exclusive classes of hand–mouth integration, and has provided insights into the control of the behavior and hypotheses to evaluate its determination.

Method

Subjects

Subjects were 31 healthy full-term infants (12 boys, 19 girls) studied in the well-born nursery of Sinai Hospital in Baltimore, Maryland. Twenty-five of the infants were the products of normal vaginal delivery, whereas 5 were delivered by Caesarian section and one by forceps. Mothers of 12 infants received an epidural block during delivery, 1 a pudendal block, and the rest either no anesthesia or analgesia, or a local anesthetic only. Sixteen of the infants were Black and the remainder White, except for 1 Asian infant. All infants had 1 + 5 min APGAR scores of 8 or above. They were studied 15–240 min after their last feeding (M = 76 min).

Procedure

After parental permission was obtained, the infant was brought in its own bassinet from the mother's room to the test area, located in a quiet room in the nursery. The infant's diaper was changed and its blanket arranged loosely, leaving the arms free for movement. The bassinet was tilted to a 25° angle that placed the infant *en face* with a Panasonic camera for videotaping.

Experimental Design

Each infant in the first experiment (N = 13) was studied for a total of 28 min, divided into three phases: presucrose (initial baseline), sucrose, and postsucrose (second baseline). The initial baseline period lasted for 5 min, with the "psst" or "shh" sounds presented during Seconds 11–20 of each minute. This was followed immediately by seven 2-min trials in which 0.2 ml of a 12% (weight/volume) sterile sucrose solution was delivered to the oral midline via a sterile syringe during Seconds 21–30. Sound was presented during Seconds 11–20 as above. The postsucrose phase was identical to the initial phase except that it consisted of nine 1-min trials. The second study (N = 18) was identical except that the presucrose phase lasted 9 min, no postsucrose period was obtained, and an odor was presented instead of the sound.

Sessions were videotaped and scored at a later date. Scoring categories were established that best captured infant states and behaviors during the experiment. After considerable preliminary analyses, we selected a number of measures that adequately represented both state and behavior, as well as their transitions during the test session. Because the behaviors were particularly clear-cut, we used relatively broad classificatory categories and were not concerned with more subtle nuances within a behavior unless specified. Interobserver reliability for these measures was above .95 according to Pearson's product-moment correlation. The categories and their definitions are as follows.

Crying. The infant had to vocalize with a crying face. This behavior is unmistakable. We did not distinguish among categories of crying, so both a full-throated cry and a simple whimper were classified as "cry."

Sleep. Sleep was scored when children slept with closed eyes, regular respiration, little or no movement other than spontaneous startles, and little or no behavioral response to stimulus (sound) presentation. This corresponded approximately to Brazelton States 1–2.

Awake. Awake was scored when an infant was not asleep as defined above. Movement intensity was not distinguished.

Hand in mouth (HIM). HIM was scored when any part of an infant's hand was *inside* its mouth as defined by the mucous membrane demarcation inside the lips. The origin of connection was not important for classificatory purposes (i.e., HIM was scored whether the hand was brought directly into the mouth with open fingers, the head turned to the hand after face contact, or the hand moved into the mouth following contact with the face; origin was analyzed in detail later to shed light on mechanisms of coordination).

Hand at mouth (HAM). HAM was recorded when a hand was touching the lips but not inserted beyond the mucous membrane boundary.

Mouthing. Mouthing was scored when there was patterned oral movement. We did not distinguish among movement categories. Mouthing included chewing, sucking, lip puckering, and any other obvious mouth movements other than crying, sneezing, hiccuping, or yawning. These behaviors were recorded continuously on an Esterline-Angus event recorder. For purposes of tabulation, the unit of measurement was 1 s, and a behavior was tabulated if it occurred at all during the 1-s bin.

To evaluate conditioning of any of these behaviors to the sound, behavior in the 10 s immediately preceding the sound and behavior during the 10 s of sound were compared for the last 4 min of Phase 1, for an appropriate 4 min at the end of Phase 2, and for the last 4 min of Phase 3. Frequencies of occurrence of each of the five behaviors (HIM, HAM, mouth, sleep, and cry) were fit to log-linear models. There was no evidence of conditioning of any of the measures to the sound (described below).

Results

Coordination of Hand–Mouth Behavior: Group Data

Figure 1 presents the percentage time in which an activity was expressed during the three phases of Experiment 1A. With

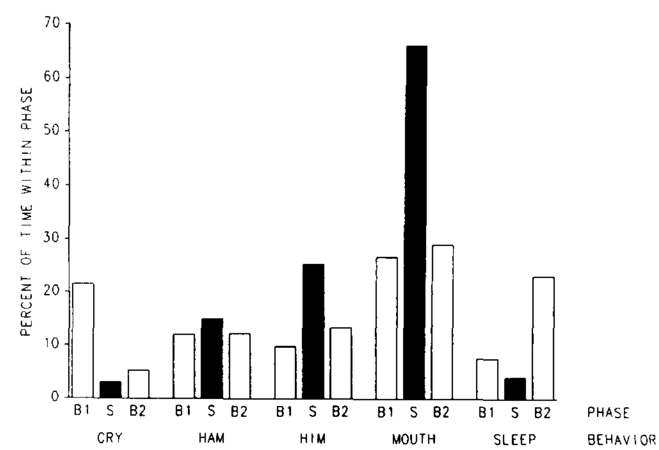

Figure 1. Mean percentage of time in which each of the five behaviors was expressed during each of the three phases of Experiment 1A. (Significant differences are as follows: between Baseline 1 and sucrose for crying, between sucrose and both baselines for HIM and mouthing, and between sucrose and Baseline 2 for sleep. HIM = hand in mouth; HAM = hand at mouth.)

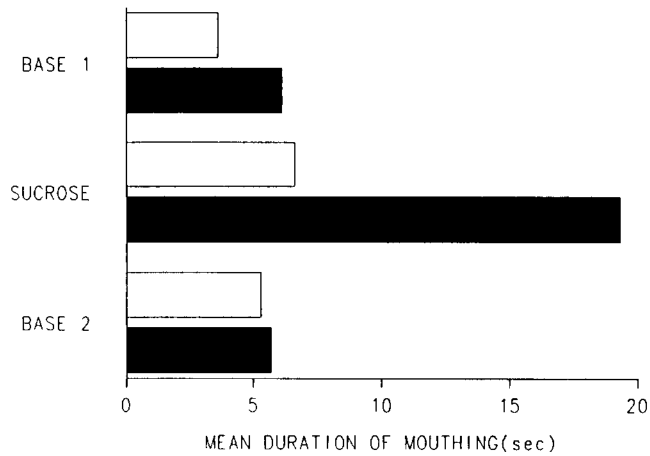

Figure 2. Mean durations, by experimental phase, for two classes of mouthing behavior: Mouthing bouts that did not incorporate hand–mouth contact behavior (HIM or HAM) (□) and mouthing bouts that did (■). (Mouthing bouts with hand contact were longer during the sucrose phase, $F(2, 21) = 25.97$, $p < .01$. HIM = hand in mouth; HAM = hand at mouth.)

the exception of HAM, there were substantial, differential changes in all behaviors recorded in this study. The magnitude of the effects is impressive to us because the analysis includes all of the infants studied and not only those later classified as hand-in-mouth infants.

Crying was dramatically reduced by sucrose administration from occupying 22% of the time to essentially none of the time. This almost always occurred within the first two sucrose administrations, so that a total volume of 0.4 ml of 12% sucrose was all that was necessary for initial quieting. The quiet state attained after the seven 2-min trials extended into the second baseline period. Indeed, as shown in the extreme right portion of Figure 1, 22% of the postsucrose phase was spent in sleep.

There was no consistent change in hand-at-mouth behavior due to sucrose. As will be demonstrated, however, this is misleading in that the lighter weight infants engaged in much less HAM behavior during the sucrose as opposed to presucrose phase, whereas the heavier infants engaged in considerably more HAM during the sucrose phase.

The two most striking changes during sucrose administration occurred in mouthing and hand-in-mouth behavior. Mouthing essentially doubled relative to the presucrose level and then returned almost immediately to this level upon sucrose termination. Hand-in-mouth activity doubled relative to its presucrose level and also fell off rapidly in the postsucrose phase. HIM was not obviously pacific, as crying had essentially stopped prior to its initiation and did not resume after the hand was removed. Moreover, there was no evidence that a baby was more likely to bring hand to mouth during crying. Of the eight babies who cried at all during any phase of the session, seven were more likely to bring the hand to the mouth during any given second of a calm and inactive state (average likelihood .06) than during crying (average likelihood .03; sign test, $p = .035$). For the five babies who did not cry at all, the average likelihood of HIM during calm and awake was .04.

The intimate relationship between mouthing and HIM during sucrose administration is shown in Figure 2, which presents the mean duration of mouthing episodes during the three phases of the experiment when bouts did or did not include HIM or HAM. The duration of mouthing episodes with hand-in-mouth contact tripled during sucrose administration. This was likely due to its being sustained by the presence of the hand at or in the mouth, as bouts that ended *without* a hand at or in the mouth were of a 7-s mean duration even during the sucrose phase. Thus, sucrose elicits mouthing; sucrose or mouthing recruits the hand to the mouth; and hand-in-mouth contact either protracts mouthing or is recruited by it during very long mouthing episodes. Each of these hypotheses represents a different form of coordinative structure that can be evaluated empirically.

Figure 3 presents the percentage occurrence of mouthing and hand activities (HAM and HIM combined) for each of the three phases of Experiment 1A. There is a marked shift in the incidence of mouth and hand activity during the sucrose phase. Elevated mouthing occurs within 5 s of sucrose introduction in each trial and returns slowly to "sucrose baseline" levels (the 5-s delay probably reflects the time necessary for peripheral → central → peripheral neural transmission in these infants). Hand–mouth contact consistently remains relatively elevated throughout the 2-min cycles of the sucrose phase, as opposed to being elevated at the point of sucrose administration and declining, as does mouthing, as the sucrose either becomes diluted with saliva or the infant habituates to the sweet taste during a given trial. This implies that the change in hand–mouth contact reflects a change in motivational state elicited by the general change in experimental condition. This idea is strengthened by the abrupt change in both hand and mouth activity during the postsucrose phase when hand–mouth contact ceases concomitant with changes in mouthing. Thus, Figure 3 suggests specific forms of linkage between intermittent sucrose administration, mouthing, and the coordination of the hand and mouth. Whereas mouthing is clearly under the immediate control of sucrose administration, hand–mouth contact seems to reflect state and situational dependencies.

In summary, analysis of group data demonstrates tight control over behavior exerted by sucrose administration. Sucrose quickly calmed newborn infants, and a significant proportion of them brought their hands into their mouths. The termination of sucrose delivery caused an equally abrupt change in behavior in all infants exhibiting HIM or HAM patterns of behavior. Mouthing returned to baseline levels and so did HIM activity. In the absence of sucrose delivery, mouthing behavior did not become elevated or protracted and did not recruit the hand to the mouth. This pattern occurred in those infants who remained awake during the second baseline period as well as those infants who slept. In the latter case, the shift in oral and manual behavior always occurred well before drowsiness ensued, which invariably was toward the end of the second baseline period.

Calming was a more enduring effect of sucrose delivery, however. Crying was essentially eliminated by sucrose and did not resume during the second baseline period. This observation is relevant in two regards. It points to a state change of short latency and long duration that was protracted well beyond the taste of sucrose (as judged by Figure 3). Moreover, mouthing and HIM behavior stopped at sucrose termination despite the maintenance of the calmed state.

Infant Categories: Qualitative Description and Categorization

To appreciate more readily the relationships among the various behaviors and between sucrose delivery and these behaviors, a representational system was devised to generate a portrait of each infant's behavior in relation to experimental treatment. One such portrait is presented in Figure 4. Time moves from left to right, and each individual row represents a single trial. The width of Figure 4 equals 2 min. Thus, there are five 1-min baseline trials, followed by seven 2-min sucrose trials and nine 1-min baseline trials.

The vertical band traversing Figure 4 represents sound presentation between Seconds 11–20 at the beginning of each trial; sucrose delivery (21–30 s) is adjacent to sound in the 2-min trials.

The central portion of each horizontal line designates either crying (thick line) or awake without crying (straight continuous line). When the space above this line is enclosed, mouthing occurred. Hand–mouth activity is indicated below the line. Unfilled space indicates no hand–mouth activity; HAM or HIM is represented by the completely filled space.

Thus, the infant depicted in Figure 4, a girl weighing 3,390 g, presented a virtually uninterrupted cry state during the initial baseline period. This state was punctuated by mouthing during the initial portion of the sucrose phase, with crying persisting intermittently. On the third sucrose trial, the hand contacted the mouth and remained there for most of the duration of the sucrose phase. When sucrose was terminated, the hand came out of the mouth but maintained contact for about 2 min, when contact ended completely.

Infants were classified in one of four ways based on the pattern, across experimental phases, of their coordinative hand–mouth behaviors: (a) HIM: children whose hand-in-mouth behavior during the sucrose phase totaled at least 15% of that phase, with this proportion representing a minimum increase of 100% over each baseline; (b) HAM: children who did not meet the criteria to be classified as HIM, but whose HAM behavior followed the pattern set forth for HIM; (c) phase-insensitive (P-I): infants who exhibited HAM or HIM behavior totaling at least 15% of any one phase, but not showing significant (i.e., doubling) change across phases; and (d) no hand–mouth (NOHM): infants who rarely or never brought hand and mouth in contact.

In addition, because the behavioral pattern that determined classification was, for every infant in Experiment 1A, established in the presucrose and sucrose phases of the experiment, infants from Experiment 1B were classified along these same lines based solely on their behavior during these two phases. Thus, although it is important both phenomenologically and conceptually that HIM and HAM infants from Experiment 1A altered hand–mouth activity in the postsucrose phase, whereas P-I and NOHM infants did not, the postsucrose phase has proved unnecessary for present classificatory purposes.

Hand in mouth (n = 12). A clear example of an infant who engaged in hand-in-mouth activity is presented in Figure 4. This infant cried extensively during the presucrose phase, as did 8 of the 12 HIM infants. There was occasional mouthing during this phase and, on several occasions, the hand contacted and even entered the mouth. Careful inspection of Figure 4 reveals, however, that hand contact of the mouth preceded (elicited?) mouthing. The mouth would occasionally strain toward the contacted hand in a classic rooting reflex. When hand–mouth contact was established, the mouth then started to move but the hand did not stop and often jerked away. HIM bouts during the baseline period were short, lasting fewer than 10 s.

Sucrose onset caused marked and sustained changes in behavior as well as in affective expression. As expected, sucrose elicited considerable protracted mouthing behavior, often expressed as sustained sucking movements in advance of HIM. Sucrose also exerted a profound soothing effect on the infants. Without exception, all crying infants in Experiments 1A and 1B stopped crying within two sucrose administrations. This is impressive considering that only 0.4 ml of sucrose were needed to achieve this effect.

Concomitant with crying reduction were two other state changes that occurred regularly during the early portions of the sucrose phase. One was a relaxation of the hands and a change in the direction in which they moved—they oriented toward mouth and face. The other was a softening of the facial features and an arching of the back, often accompanied by arm extension and a slowing of side-to-side head movements. The softening is difficult to define operationally or capture empirically, but it is especially clear on a high-quality color monitor, and, of course, in person. These may represent critical aspects of the changes caused by sucrose administration that allow HIM to be engaged and sustained.

Mouthing was always sustained and generally lasted well beyond the proximal stimulation of sucrose. Mouthing that incorporated HIM almost always preceded HIM during the sucrose phase (see also Figure 2). This is not trivial because mouthing was not continuous. Bouts of mouthing would often occur spontaneously following long pauses. Occasionally a hand then came *directly* to the mouth and did so with the mouth in different positions during head turning. Thus, the hand accurately tracked the position of the mouth and contacted it smoothly. This tracking is of considerable interest and begs formal study that lies beyond the capacity of this laboratory. It may serve as a predecessor for infants accurately tracking the trajectory of moving objects in space (Hofsten, 1979).

The most dominant pattern during the sucrose phase, however, was that the hand moved more in the general vicinity of the face, articulating shorter movements than in the other phases. When perioral contact was established, the hand slowed further, thus maintaining contact with the face. It moved toward the mouth, and the mouth often opened before actual hand contact. Alternatively, the hand remained still and the head turned, allowing the mouth to seize the hand. Both of these patterns were common; indeed, they occurred within an individual infant.

Generally 1–2 min after sucrose termination, behavior patterns started to disintegrate. Hand movement seemed more tentative and mouthing no longer preceded hand movement. The HIM phenomenon can thus be described as the infant shifting, concomitant with sucrose delivery, from a state of moderate or extreme arousal or distress (as marked by crying) to a calmer state characterized by mouthing (sucking) movements. After sucrose termination, the hand eventually returned to the head area, but the head had already turned so that the hand either landed on the mattress near the head or contacted the side of the head. Hand movement continued at a slow pace, mouthing was generally considerably reduced, and it was only very occasionally and fleetingly that the hand maintained mouth contact. This abrupt change in mouthing and HIM is noteworthy be-

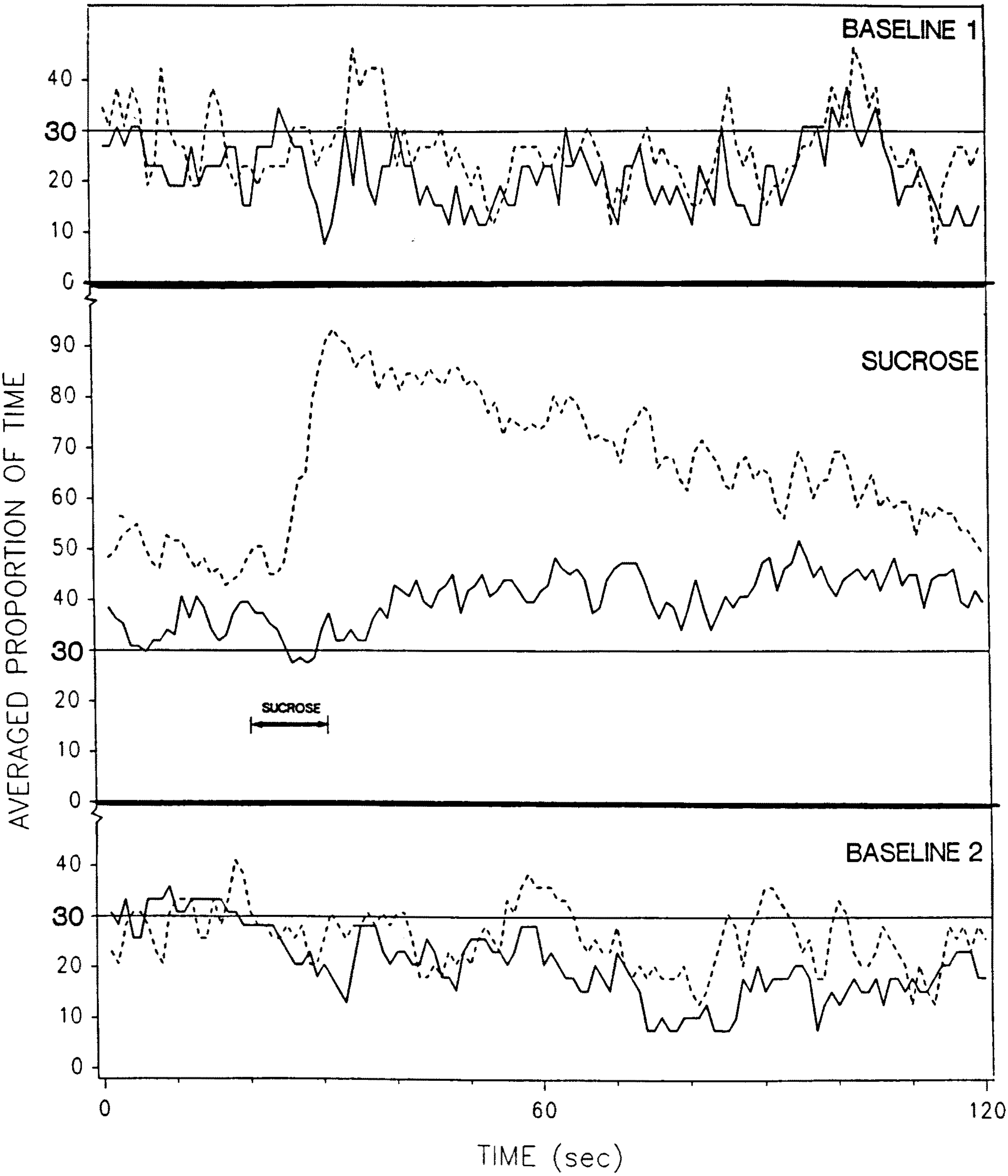

Figure 3. Average proportion of time spent in mouthing (broken lines) and hand–mouth contact behavior (HIM and HAM combined solid line) for all infants in each phase of Experiment 1A (n = 13). (All 2-min periods within each phase have been collapsed so as to obtain the averaged second-by-second response. HIM = hand in mouth; HAM = hand at mouth.)

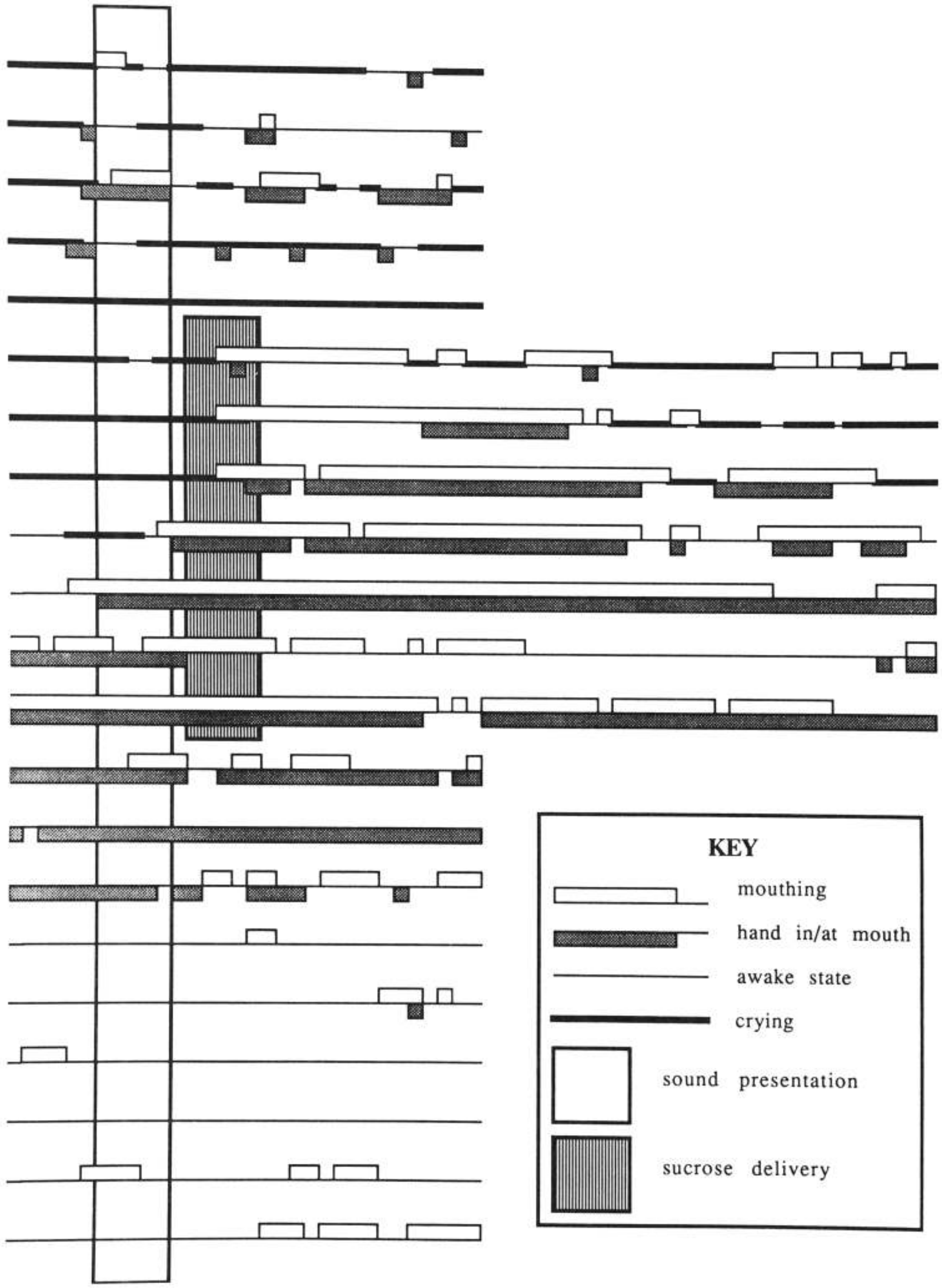

Figure 4. Time-line representation of Infant 5, a typical hand-in-mouth baby. (The entire width of the figure represents 2 min. Each horizontal line follows its predecessor in time. Symbols are explained in the key.)

cause it preceded any apparent change in state when such change occurred. It speaks to sucrose engaging the coordinative aspects of a suckling–feeding system.

Hand at mouth (n = 6). The following features characterize the HAM children: (a) Crying was minimal if it occurred at all (only 2 HAM infants cried); (b) the hands never or only rarely entered the mouth; (c) the hands did, however, contact the lips; (d) infants were responsive to sugar as shown in changes in mouthing behavior; (e) HAM contact was not nearly as sustained as HIM contact; and (f) mean weight of HAM infants was 3,768 g; and mean weight of HIM infants was 3,289 g.

In short, HAM infants differ from those categorized as HIM by being heavier and less able or willing to place their hands into their mouths. Also, 2 of 6 HAM infants cried during their baseline period, as opposed to 8 of 12 HIM infants during the first baseline. As in the case of HIM infants, behaviors shifted during sucrose presentation and normalized during the second baseline. There was a shift in mouthing and, of course, in the incidence of HAM. These infants tended to sleep toward the session's end more than HIM infants, possibly because of their increased weight and the efforts involved in protracted limb movement.

Phase-insensitive (n = 8). Phase-insensitive infants showed a sustained high rate of hand–mouth activity. The lack of change in hand–mouth behavior with either onset or offset of sucrose delivery suggests that this behavior did not come under stimulus control. Unlike infants in the HIM and HAM groups, who showed a behavioral redistribution during sucrose presentation and withdrawal, P-I infants showed little or no changes in behavior in any category. In addition, only one of the eight P-I infants cried during the presucrose phase. Infants tended to be light, with only one weighing more than 3,600 g (M = 3,236).

No hand–mouth (n = 5). For all five NOHM infants, the hands rarely, and then only briefly, contacted or entered the mouth. As a group, NOHM infants were remarkable in two respects. First, they tended to be heavy, all weighing over 3,500 g (M = 4,030). In fact, of all 31 infants from both experiments, only 6 weighed more than 4,000 gm, and 3 of those were NOHM infants. Second, 3 of the 5 NOHM infants showed only a very slight increase or no increase in mouthing during the sucrose phase.

Discussion

Experiment 1 has identified a phenomenon in newborn infants of extraordinary coordination between hand and mouth that has been brought under experimental control. Sucrose affected behavior in at least three ways in the present setting. First, sucrose calmed the infant, an effect seemingly independent of its coordinating hand–mouth activity. The infant stopped crying during the sucrose phase and remained calm even after sucrose termination, after the hand had left the mouth, and after mouthing returned to baseline levels. Second, mouthing behavior was tightly linked to sucrose presentation. Mouthing peaked within seconds of sucrose administration and slowly receded after sucrose termination, only to resume again with the next intraoral delivery. Mouthing termination at the end of the 14-min sucrose cycle, therefore, probably reflects the absence of new proximal stimulation. Third, hand-in-mouth behavior was different yet. Like mouthing, it was exaggerated only during the sucrose phase of the experiment. Yet it was not linked to sucrose delivery, as HIM remained at a steady level, considerably elevated relative to baseline, throughout the experimental period.

Within the confines of the present experiment, HIM appears in supine infants when their state with its attendant activity is reduced from excited to calm. Sucrose achieves this. The transition to calm is necessary and its sufficiency will be evaluated in Experiment 2. A calm state per se is generally not sufficient for the expression of either HIM or HAM with or without sucrose stimulation. This is hardly surprising in the absence of sucrose (i.e., the suckling system is not engaged). It probably is not seen in 1–3-day-old infants because of the immaturity of the suckling system. In order for the coordinated pattern to appear, the infant must already be active, either in response to orogastric signals indicating a suckling need or in response to currently nonspecifiable stimuli. An important transition in this system will be the appearance of the coordinated behavior in infants who had not previously been in an excited state.

The data support the idea of engaging a suckling system. By suckling system we refer to different sensory–perceptual and motor systems that orient the infant to the milk source and facilitate milk withdrawal. The system can be spontaneously exhibited, as when infants make sucking movements in their sleep. Its threshold is lowered by suckling privation and by the taste of various solutions (e.g., milk). The components of the system, in turn, have different thresholds and can be activated independently by specific stimulation. Thus, the orient response is specifically elicited by a touch to the cheek, thereby turning the head into contact with the nipple. Hand-to-mouth activity and hand-in-mouth activity are also envisaged as part of the system because the hand routinely comes to the mouth during nursing and is the agent of ingestive behavior when free feeding.

Our current position is that the calm state acts permissively to allow the suckling–feeding system to be engaged. The transition away from mouthing and HIM behavior during the second baseline period demonstrates that the calm state is not sufficient to either elicit or sustain HIM. We have not evaluated, however, whether the transition from agitated to calm is necessary and sufficient to elicit mouthing *and* HIM behaviors. Experiment 2 evaluates this possibility.

Experiment 2

Our interpretation of the findings of Experiment 1 focused on hand–mouth coordination as an expression of an integrated suckling–feeding system engaged by the taste of sucrose. This next study examines two alternative interpretations. The first is that it was the introduction and subsequent termination of a fluid to the mouth, not specifically the taste of sucrose, that caused the delimited period of hand–mouth coordination. The second is that because sucrose calmed the infant, it allowed the high-probability behavior of HIM to be expressed. This interpretation, if true, would direct analysis along very different experimental and theoretical pathways.

Experiment 2 evaluates the specific hypotheses that calming per se and plain water delivered to the mouth were sufficient for the appearance of hand–mouth coordination. If the transition from excited to calm elicits mouthing and HIM behavior, then any means that cause this transition should elicit these coordinated activities. In contrast, if calming is permissive and allows the suckling–feeding system to be engaged by internal or external determinants, sucrose in the present instance, then calmed infants should not mouth extensively or bring their hands to their mouths. Infants were calmed by gentle stroking, quieting sounds, and rocking. All of these treatments, including water delivery, calmed the infants, as judged by crying cessation and slowing of arm movements. Yet none of these manipulations brought the hand to the mouth. Sucrose, however, elicited HIM, and this behavior stopped with sucrose withdrawal.

Method

Subjects

Nine infants from Sinai Hospital were studied. Infants were selected to maximize the likelihood of HIM behavior. Thus, all infants weighed between 2,650 and 3,520 g and cried during the initial baseline. The infants were selected from a larger pool of 14 babies who weighed between 2,600 and 3,600 g. The selection criterion of crying during the first 5 min of the experiment was enforced to maximize conditions for the appearance of hand–mouth coordination. Thus, infants who did not cry during Baseline 1 were excluded from the experiment (n = 5).

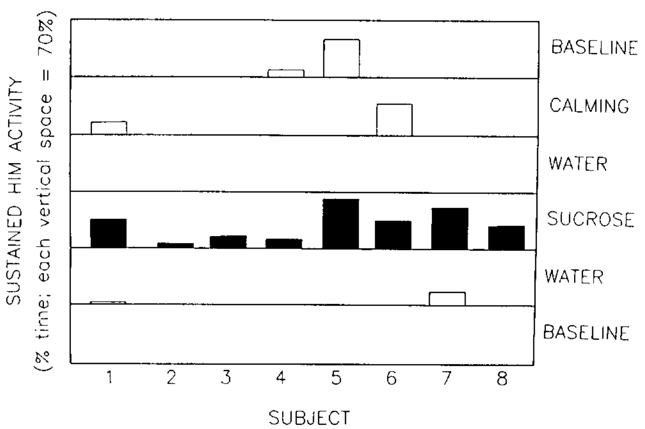

Figure 5. The percentage of time devoted to sustained (≥ 10 s) bouts of HIM behavior in each phase of Experiment 2. (Presented here are the eight of nine infants (all female) who exhibited such behavior. Sustained HIM was generally confined to the sucrose phase, despite infants being calmed in Phase 2, and despite delivery of water to the mouth during Phases 3 and 5. Phases 1 and 6 were baselines. The one infant who did not show sustained HIM was the male twin of Infant 7.)

Procedure

General test conditions were the same as described for Experiment 1. Different means of calming the infants were attempted sequentially for each infant. The experiment was divided into six phases.

The first phase, *Baseline 1,* lasted between 2 and 5 min and was terminated if the infant was crying excessively in the experimenter's view. No experimental manipulation was undertaken during this period. The *soothing* phase was attempted for 5–6 min by making the "shh" sound, quietly calling the baby's name, gently placing a hand on the chest, lightly stroking the baby's forehead, and vestibular rocking in either a lateral or vertical direction by moving the bassinet that accommodated the infant. In the third phase, *water,* 5–6 deliveries of 0.1-cc sterile water were administered at a rate of 1/min via sterile syringe. Each delivery was of a 10-s duration. In the fourth phase, *sucrose* (12%) was delivered in the exact manner as water. The fifth and sixth phases, *second water* and *Baseline 2,* were identical to the third and first phase, respectively.

The entire session was videotaped and analyzed. Hand-in-mouth behavior was scored when the hand was in the mouth for a minimum of 10 s. An infant was considered to have been calmed if it spent a minimum of 33 consecutive seconds without crying. (This was the mean latency to initiate HIM during the sucrose phase of the experiment, measured from the start of sucrose delivery, or, if the baby was crying, the termination of crying.)

Results and Discussion

The results were coherent and demonstrate that neither calming per se nor water in the mouth were sufficient to elicit hand-in-mouth behavior. Sucrose was sufficient, however, as eight of the nine infants placed their hands into their mouths during the sucrose phase of the experiment, confirming our previous findings. These findings are presented graphically for each infant in Figure 5, which demonstrates that neither soothing stimulation nor delivery of water into the mouth elicited hand-in-mouth behavior in any reliable manner. Sucrose, however, was effective.

Although six of the nine infants were calmed during the second (soothing) phase, only two initiated HIM behavior at this time. Similarly, whereas seven of the nine were calm during Phase 3 (water), none initiated HIM. In the sucrose phase, however, all were calm, and eight of the nine initiated HIM behavior, for a total of 28 sustained bouts totaling 781 s. We find it interesting that with the replacement of sucrose by water in Phase 5, only two infants exhibited HIM, for very brief periods, even though eight of the infants continued to be calm. None of the infants initiated a sustained HIM bout during the final baseline.

The behavior of infants during water administration is noteworthy for three additional reasons. First, the failure of infants to maintain HIM behavior during the second water period indicates that the termination of HIM behavior at the end of sucrose administration was not due to the cessation of fluid delivery. Rather, like the onset of HIM activity, its offset was controlled by change in sucrose status. Second, as was to be expected with water delivery, infants exhibited considerable mouthing during water epochs. However, mouthing duration did not reach levels seen with sucrose. Third, there was no obvious change in state when hand-in-mouth behavior terminated.

One possible mechanism for engaging hand–mouth coordination, therefore, is that there is a threshold for mouthing, expressed in frequency, intensity, or duration, that must be achieved before the hands are brought to the mouth. Stated differently, the hand may be recruited to the mouth through activation of the oral motor system and not directly by the sensory qualities of the stimulus that activated this system, an alternative raised above (Figure 2). This is consistent with the failure of infants to keep their hands in their mouths during the second water period, where mouthing declined.

To the point of Experiment 2, neither arresting crying nor delivering water into the mouth caused HIM behavior in infants in the supine position. Reduction from an agitated to a calm state accompanied by high levels of mouthing may be predisposing conditions for HIM expression but are not sufficient either singly or in combination to elicit HIM in the absence of sucrose.

The results of Experiment 2 are consistent with the idea that the taste of sucrose engaged the suckling–feeding mechanism, of which HIM is an integral part. This may have been done directly through sensory stimulation or indirectly by motor recruitment. Another indirect path may be through activation of opioid mechanisms known to affect ingestive behavior of sweets and fats preferentially in rats and humans (Blass, 1987; Blass, Fitzgerald, & Kehoe, 1987; Marks-Kaufman, 1982; Marks-Kaufman & Kanarek, 1980; Morley & Levine, 1980).

Experiment 3

We have identified circumstances under which HIM will occur and have eliminated both calming and oral reception of fluid per se as determinants of this act. We now focus on cessation of hand and head movements once HIM is established. Two logical alternatives can account for this cessation. One is that activating the suckling system engages a motor pattern that has as its trajectory hand-in-mouth contact. On this view, movement stops because the *hand* has entered the mouth. The other equally plausible and mutually exclusive hypothesis is that hand activity stops because *something* has entered the mouth. That is, sucrose causes an imbalance in the suckling system that can only be normalized when an object of proper affordance is in the mouth. This can be a nipple, breast, or hand (i.e. something with the affordance of sucking). Support is provided for the latter view in this experiment because inserting a pacifier into the mouth following a period of sucrose stimulation caused a cessation of both head and hand movement, with the hands some distance from the mouth.

Method

Subjects

The subjects were 8 female infants who weighed between 3,080 and 3,515 g (M = 3,252 g).

Procedure

The experiment consisted of a 5-min baseline period followed by 2–5 deliveries of 0.1 ml of 12% sucrose over 10 s. Each delivery was separated by 1 min. Variability in frequency of sucrose delivery reflected the experimenter's subjective sense of when HIM was likely to occur. One minute after the last sucrose delivery, a shielded pacifier was placed in the infant's mouth.

Scoring

A new scoring system was devised to capture changes in hand and head activity across the three phases of this experiment. A translucent paper was attached to the television monitor, and hand and mouth movements were traced in lateral and vertical planes with the base of separation of the middle digits as one referent and the center of the mouth as another. These tracings were obtained for the last 2 min of the baseline and sucrose phases and the first 2 min of the pacifier phase after the pacifier was accepted.

Results

Inserting a pacifier into the mouths of 2-day-old infants essentially arrested head and hand activity. This is seen clearly in the composite presented in Figure 6, which demonstrates the sequence of head and hand movements of the typical infant as she went from baseline to sucrose to pacifier. As was true in all eight cases, reduced movement in the sucrose phase terminated abruptly with pacifier insertion. Moreover, as was true in all but one case (Figure 7), both hands came to rest at a distance from the mouth. This allows us to reject the hypothesis that bringing the hands to the mouth in the previous experiments represents the necessary completion of a pattern initiated by activating the suckling system. It gives credence to the idea that the head and hands continue to move in a coordinated fashion until the activated suckling system is brought to balance by the presence of a firm yet soft object in the mouth, regardless of whether this presence is accompanied by oral stimulation of the hand. It is possible, of course, that other substances of a harder texture, for example, would also stop hand movement.

General Discussion

These studies have provided evidence for sucrose as a remarkable calming agent and for a coordinative behavioral system that integrates hand–mouth activity in supine human infants younger than 72 hr of age. The system can be activated by a fraction of a milliliter of sucrose and can be disengaged by withholding sucrose. The coordinative structure has relatively rapid onset and offset, as it was generally engaged and disengaged within 2 min of sucrose administration and termination, respectively. The rapidity of the transition states and the small volume of fluid needed to activate the system speak to control at the level of the oropharynx as opposed to a more distal portion of the digestive system.

To place this phenomenon in various related developmental contexts, this discussion focuses on the general themes of motivation and sensorimotor development and their potential interactions through hand–mouth coordination.

Motivational Factors

This study highlights a number of issues concerning the psychobiology of motivation in newborn humans. These issues center around interactions among state parameters and the engagement of specific motivational systems during development. This study has demonstrated that HIM behavior will occur under a set of restrictive state parameters. In particular, for HIM to be expressed, the sufficient and possibly necessary conditions are that (a) the 1–3-day-old infant must shift from an excited to a calm state, and (b) a suckling system must be engaged. Experiment 1 demonstrated that the former was necessary because sucrose stimulation in already calm infants generally did not cause HIM. Experiments 1 and 2 demonstrated the necessity of engaging the specific system. Sucrose termination in Experiment 1 and the transition to water in Experiment 2 both led to cessation of HIM. Moreover, calming infants in the absence of sucrose did not lead to HIM.

The pacific effect of sucrose was immediate and endured well beyond sucrose termination. We propose an opioid-mediated mechanism that allows sugars and possibly fats to both pacify and alleviate pain. These agents, when delivered intraorally, are remarkably effective in reducing ultrasonic vocalizations in isolated 10-day-old rats and cause a 50% increase in pain threshold (Blass et al., 1987; Shide & Blass, in press). Both of these effects are fully reversible by the opioid antagonist naltrexone and thereby precisely mirror findings obtained with morphine treatment (Kehoe & Blass, 1986; for reviews see Blass & Kehoe, 1987; Kehoe, 1988).

In parallel studies with human newborns we have found that sucrose markedly diminishes crying in response to painful standard hospital procedures such as circumcision or blood collection via heel prick (Blass & Hoffmeyer, 1988). It is of interest that the analgesic effects of sucrose endured well beyond sucrose administration. We suggest, therefore, that the quieting observed in this study may also be understood as a manifestation of an opioid mechanism. Studying the behavior of infants born to opioid-addicted, and hence tolerant, mothers would be of considerable interest in this regard because the tolerant infants should not present the behavioral patterns expressed by the normal population to sucrose.

Finally, Experiment 3 indicated a characteristic of the suckling system that is implied from the persistence of hand–mouth behavior. Activation of the system through either deprivational (suckling abstinence for a period of time; Kessen, Williams, & Williams, 1961) or gustatory factors involves mouthing and rooting behaviors that persist until objects with certain characteristics enter the mouth. The infant can satisfy this circumstance under relatively mild conditions by placing its hand in its mouth. Under conditions of either more extreme privation or noningestive-related trauma, the more substantial affordance of breast or milk-yielding nipple may be necessary for completion.

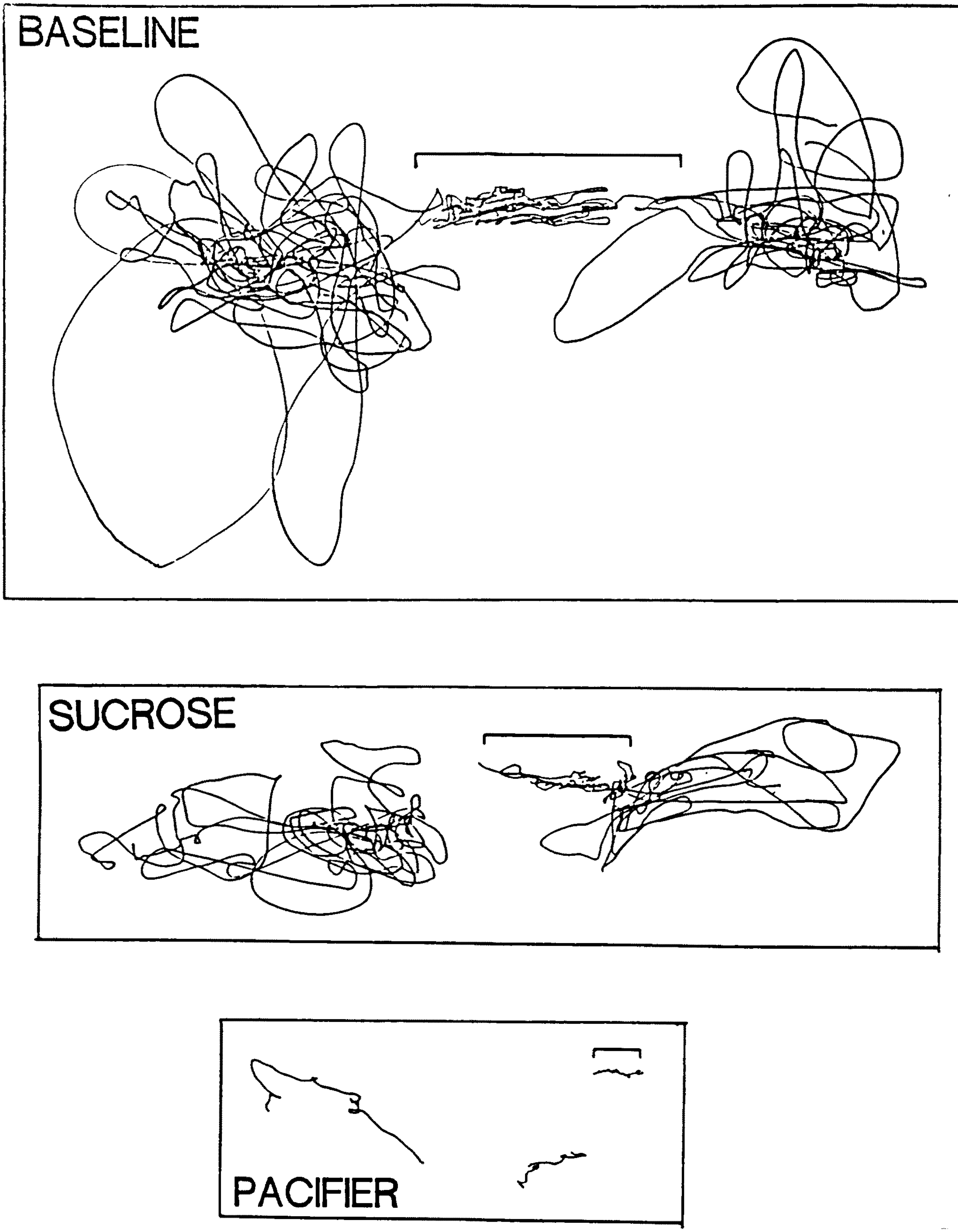

Figure 6. Tracings taken from the video image of the mouth (bracketed) and each hand of a typical infant from Experiment 3. (The tracings were made during [from top to bottom] the last 2 min of baseline, the last 2 min of the sucrose phase, and the first 2 min following placement of the pacifier.)

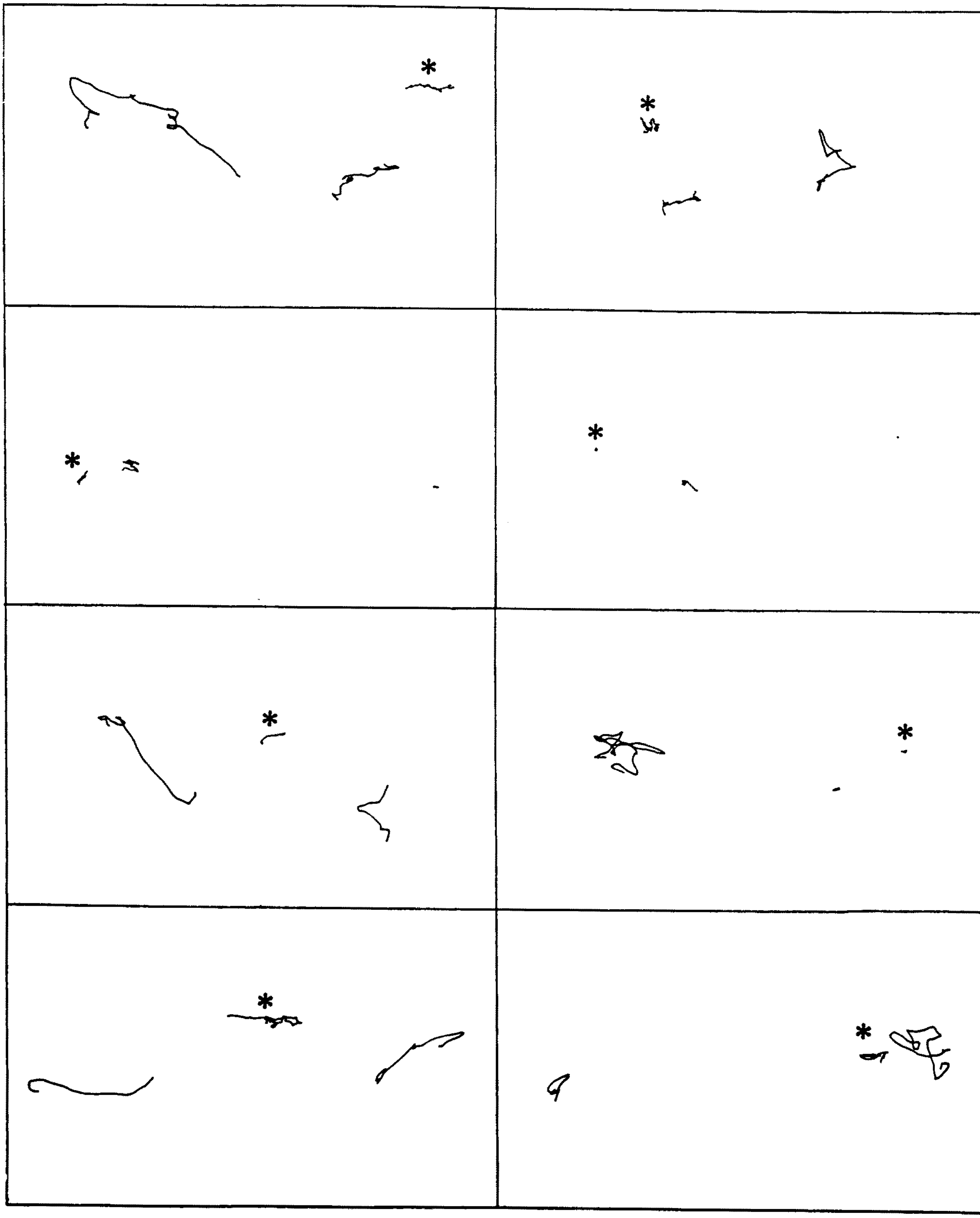

Figure 7. Movement of mouth (with asterisks) and hands for each infant in Experiment 3 during the first 2 min following placement of the pacifier.

It is currently not possible to specify whether hand-in-mouth behavior as observed in the present studies should be conceptualized as integral to a suckling or to a prefunctional feeding system. Presumably, this can be determined at the time that infants start to free-feed. The distinction is important conceptually. In rats, at least, the systems prior to weaning onset are independent (Blass & Cramer, 1982; Hall & Williams, 1983). Suckling duration and milk intake do not appear to be under the control of the physiological signals that govern adult feeding (Cramer & Blass, 1983). Even during the weaning period when infant rats eat freely from the environment, suckling initiation is determined by suckling abstinence and not by the nutritional consequences of the abstinence (Cramer & Blass, 1986). This is a transitional period because volume intake is determined by physiological signals (Cramer & Blass, 1983).

Following this distinction developmentally, the possible transition from a suckling to a functional feeding system is of interest because it may shed light on mechanisms involved in reaching for objects and bringing them to the mouth. In particular, analysis of hand–mouth coordination may reveal the perceptual processes that underlie discriminating food from nonfood substances. In this regard, hand-in-mouth behavior embodies a classic motoric and motivational developmental progression of not being available at first for grasping objects, then shifting globally in that all things grasped are brought to the mouth in the awake infant. The final and enduring stage is more restrictive both as to substances brought to the mouth and to the circumstances under which the action is performed.

Sensorimotor Analysis

A dynamic systems approach, as advocated by Thelen and her colleagues (Fogel & Thelen, 1987; Thelen, 1987), focuses attention on the events that give rise to HIM and those that prevent its expression. The most salient feature of HIM from a systems approach is that it appeared in infants who were active at the start of their experimental session and were calmed by sucrose administration. The breadth and vigor of hand movement decreased, and the hands oriented more toward the mouth. The converse also held. Alert and behaviorally competent infants who were not in a relatively high state of arousal at the beginning of the experiment generally did not bring their hands into their mouths even though the suckling system appeared engaged insofar as mouthing and head-orienting behaviors appeared to increase. This focuses again on the idea of a differential threshold reflecting suckling activation and infant state.

The current data stand in apparent conflict with earlier reports that viewed HIM as a reaction to perioral stimulation by the hand (Korner & Beason, 1972; Korner et al., 1968) and with those presented by Fogel (1985), who reported first substantial spontaneous and integrated HIM activity during interactions with parents starting at approximately 4 months of age. Fogel captured the spontaneous expression of the mature version of HIM behavior in need-free infants who were not suckling. Fogel may have been observing the start of a transitional period when hand-to-mouth behavior comes to the service of exploratory and communication systems and is influenced by external stimuli and objects as well as by internal state and gustatory stimulation. The present experiments make clear the early availability of this coordinated system, within a different motivational scheme, to at least one ingesta—sucrose—but not another—water.

A series of changes in the predatory behavior of laboratory cats presented with mice provides interesting parallels with and insights into the present finding. In their famous experiments, MacDonnell and Flynn (1964, 1966) demonstrated fully coordinated predatory behavior in laboratory cats when both of the following conditions obtained: (a) The brain was stimulated electrically at the level of the hypothalamus, and (b) a live mouse was presented to the cat. Neither of these conditions alone elicited the integrated attack pattern. The present study presents interesting parallels in that infants who exhibited HIM behavior tended to have achieved a certain level of activation prior to sucrose delivery and, of course, sucrose had to be presented. Stated differently, elevated nonspecific activities were channeled into the specific coordinated pattern through sucrose stimulation.

In short, the present studies have established experimental control over an integrated sensorimotor pattern during the days immediately following birth. The pattern, its proximal determinants, and developmental changes hold promise for revealing basic information concerning motor development in human infants.

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Received April 5, 1988
Revision received April 10, 1989
Accepted April 11, 1989 ■