When young infants are in an alert and quiet state, they display behaviors that are "exploratory" in nature because they appear to be primarily oriented toward bringing sense organs into various relations with objects in the environment. Newborns show elements of reaching with arms and hands toward an object moving close to them (Hofsten, 1982). Young infants track objects moving in their field of view with both eyes and head (Bullinger, 1984). From birth, they orient their heads in the direction of a sound source (Clifton, Morrongiello, Kulig, & Dowd, 1981; Muir & Field, 1979) and appear to selectively orient (root) their mouths in the direction of a familiar odor (Macfarlane, 1975). Contrary to the view that babies are passive spectators bombarded with stimulation, these observations indicate that from the earliest age infants are actors and, in particular, explorers of their environment. From a theoretical point of view, it is relevant to approach early behavior as involving action systems with specific adaptive functions like communication, locomotion, consumption, and exploration (Reed, 1982). Indeed, the active search for information is a basic motive—among others—guiding behavior from birth (E. J. Gibson & Spelke, 1983). Recent progress in the study of early action development shows that perceptual and motor aspects of behavior are closely intertwined, perception and action appearing as two inseparable phenomena (Thelen & Fogel, 1986). From the origin of development, action is under some perceptual or sensorimotor control (Rochat, 1987; Rochat, Blass, & Hoffmeyer, 1988), and the picking up of perceptual information is somehow inherent to any performed act (Thelen & Fogel).

The idea that infants actively contribute to their perceptual and motor development is not new. Piaget (1952, 1954) stressed that sensorimotor and cognitive development originate from the infant's busy transaction with objects in the environment (i.e., assimilation and accommodatin). Helmholtz (1962), observing that the youngest infants deliberately interact with objects they encounter, even suggested that knowledge about the causes of sensations (distal stimuli) originates from active experimentation with objects in the environment (Helmholtz, p. 31).

In general, perceiving and acting involve information that is picked up simultaneously by more than one perceptual system. Exploration and the search for information is indeed multimodal (Neisser, 1976). Manipulating, mouthing, listening, and looking at objects potentially contribute to the discovery of their properties and what they afford for action (E. J. Gibson, 1982; Rochat & Reed, 1987). Multimodal activity involved in exploration is considered as contributing both to the specification of the properties of objects and the perceivers themselves (J. J. Gibson, 1979). Properties of sensorimotor and perceptual systems are sometimes viewed as actively elaborated during infancy by means of exploration (Bullinger, 1984, 1987). By analogy, this elaboration is considered as proceeding in essentially the same way that blind individuals discover the properties of an ultrasonic guide. They discover these properties in using the device and in exploring the new sensorimotor loops provided by this prosthesis in relation to distal objects (Bower, 1977; Bullinger, 1987). Thus, the importance of exploratory behavior in development may equally involve the discovery of object and event properties and the discovery for the perceiver of the various sensorimotor loops that bind him or her to the environment.

Recent studies of early exploratory behavior document this
activity in infants of 5 to 6 months of age and older, but not
earlier. Analysis of free play in infants shows that, from 7
months of age, the amount of manipulative and joint manipula-
tive and visual exploration increases with age as oral inspection
decreases (McCall, 1974; McQuiston & Wachs, 1979). From 6
to 12 months of age, there is an increase of fine object manipu-
lative such as fingering, rotating, and banging behaviors, which
depend on the properties of the object explored (Ruff, 1984;
see also Palmer, 1989) and on its relative novelty (Harris, 1972;
Rubenstein, 1974; Ruff, in press).

From the beginning of the second semester of life, infants
possess a solid repertoire of exploratory activities. This reperto-
ire continues to be refined within the first year, with coordina-
tion of action between various perceptual systems such as vi-
sual, haptic, and oral. Objects are brought to the mouth for oral
inspection and are visually scanned while being rotated with
hands and fingers. Questions remain as to what characterizes
younger infants’ exploratory activities and how they emerge
prior to six months of age.

Despite the fact that exploration appears to be a central pro-
cess of perceptual and motor development from birth, the litera-
ture documenting these activities in the course of the first se-
semester of life remains sparse. Relative to this period, the obser-
vations of Gesell (1940) on early motor development, of Piaget
(1952) on sensorimotor development, and of White (1969) and
Bruner (1969) on early action development remain pertinent.
They show strengthening of eye–hand and hand–mouth coordi-
nation as well as the emergence of systematic handling and
grappling of objects. Their observations suggest that in order to
capture the origin of object manipulation and exploration, in-
fant action should be studied when basic coordinations between
perceptual systems (i.e., hands, mouth, and eyes) are first de-
veloping. Recent studies indicate that during the first semester,
infant s can already discriminate haptically among objects and
transfer information from one modality to another. One-
month-olds have been shown to visually recognize the shape,
texture, and substance of objects that they explore with the
mouth only (E. J. Gibson & Walker, 1984; Meltzoff & Borton,
1979), whereas 5-month-olds have been reported to habituate
dishabituate to objects that they explore with the hands
only (Streri & Pechex, 1986). These results indicate that, from
the earliest age, hands and mouth can be used to pick up infor-
mation about objects. In coordination with other perceptual
systems, the hands and mouth contribute to the specification of
interesting properties of objects in the environment.

The general aim of the present research is to document the
early development of object manipulation and exploration.
Three studies are reported that address questions pertaining to
the characterization and control of multimodal exploration of
objects during the first semester of life. The first study is primar-
ily descriptive, documenting changes in object manipulation
and exploration in infants from 2 to 5 months of age. The sec-
ond study compares 3- and 5-month-old infants when manipu-
lating an object either in the light or in the dark (i.e., with and
without the possibility of visual control over their exploration).
Finally, the third study compares multimodal exploration in 3-
and 4-month-olds when presented with two different objects
varying in size, shape, texture, and color.

Study 1

Two- to 5-month-old infants were videotaped while freely
manipulating and exploring a novel object. This first descriptive
study was guided by the three following empirical questions: (a)
What characterizes early development of object manipulation?
(b) When does multimodal exploration emerge, with infants
starting to explore objects by means of the active combination
of manual, oral, and visual inspections? (c) What is the relative
importance, or “status,” of manual, oral, and visual exploration
early in development?

Method

Subjects

Fifty-nine healthy infants, divided into four age groups, were tested.
The first group consisted of thirteen 2-month-old infants (9 boys and
4 girls), 65 to 87 days of age, with a mean age of 81 days. The second
group consisted of fifteen 3-month-old infants (7 boys and 8 girls),
90 to 115 days of age, with a mean age of 101 days. The third group con-
sisted of sixteen 4-month-old infants (9 boys and 7 girls), 121 to 145
days of age, with a mean age of 132 days. The fourth group consisted of
fifteen 5-month-old infants (8 boys and 7 girls), 150 to 194 days of age,
with a mean age of 166 days. Infants were tested in the infant laboratory
at the University of Pennsylvania and came from primarily White, mid-
class families living in the Philadelphia suburbs.

In addition to the total number of 59 infants who completed testing
and were used in the analysis, three 2-month-olds, two 3-month-olds,
two 4-month-olds, and one 5-month-old were tested but excluded from
the sample because of poor state or failure to grasp the object.

Object

The object presented to the infant is sold commercially as a teether.
It was made of a bright blue elastic rubber with various textures at each
extremity of six branches distributed around a ring shape (see Figure
1A). The object weighed 30 g. Its largest diameter was 9 cm between
the ends of opposite branches, and each of its textured branches was
1 cm in diameter. The object was chosen so as to be attractive for manual,
oral, and visual inspection. It was “lookable at” as well as “graspable,”
“manipulable,” and “mouthable” for the infant. Parents reported that
the object was novel for their infants.

Procedure

Infants were seated facing a video camera on a slightly inclined infant
seat (approximately 75° relative to the floor), which had low armrests
so as not to constrain arm movements. The experimenter stood behind
the seated infant and introduced the object into the right or left hand
of the infant for grasping. When the infant had a firm grasp of the bot-
tom branch of the object (see Figure 1A) and could hold it by himself
or herself, the experimenter removed his hands, uncovering the object
and leaving the infant to explore it freely with hands, mouth, and eyes.
After introducing the object, experimenter remained silent and out of
view throughout testing. At the beginning of the trial, while putting the
object in either one of the infant’s hands, the experimenter covered
the object with his own hands to prevent any visual inspection before
the actual trial started. The infant’s hand was lowered by the experimenter
on the side of the baby’s lap for grasping. The object was put in the
infant’s hand with the same orientation (i.e., the orientation represented
in Figure 1A), the bottom branch introduced at the junction of thumb
and index for palmar grasp, the rest of the object oriented upward, like
a bouquet of flowers. Once the object was firmly grasped by the infant, the experimenter removed his hands and the trial started. The trial ended after 90 s of free exploration or when the object was dropped. When the object was dropped prior to approximately 10-s trial duration, it was picked up by the experimenter and reintroduced in the same hand up to three times. Behavior was scored while the infant was in manual contact with the object. Periods during which the experimenter was reintroducing the object into the infant's hand and while manual contact was interrupted following a dropping of the object by the baby were omitted.

The object was presented to the infant once in the right and once in the left hand with approximately 15 s between trials. Left- and right-hand presentation was counterbalanced among subjects of each age group. The general procedure of this study (as for Studies 2 and 3) is the reverse of the one used in several studies on early reaching behavior (i.e., Hofsten, 1982; Hofsten & Lindhagen, 1979), where the infant is presented first visually with an object, eventually leading to a manual reach. Here, the infant starts with a manual grasp of the object that eventually leads to visual and oral capture.

Scoring and Analysis

Video recordings were analyzed in real time using a multichannel event recorder. Each of the following six behaviors was scored and entered on one channel of the event recorder:

1. **Looking.** The infant is looking at the object, after he or she has oriented his or her gaze toward the object or brought it into the field of view for visual inspection.

2. **Mouthing.** The infant is mouthing the object after he or she has brought it up toward the mouth for oral contact, touching the object with the lips or introducing it inside the oral cavity for contact with the tongue and gums.

3. **R-H grasp.** The infant is grasping the object with the right hand.

4. **L-H grasp.** The infant is grasping the object with the left hand.

5. **Bigrasp.** The infant is grasping the object with both hands. (This behavior was not entered on one particular channel of the event recorder but identified on the polygraphic transcript as the co-occurrence of R-H grasp and L-H grasp, that is, simultaneous entry of Behaviors 3 and 4.)

6. **Fingering.** The infant is touching and scanning the object's surface with the fingertips of either one of the hands while the other is holding (grasping) the object. Fingering is accompanied with a simultaneous entry of Behavior 3 or Behavior 4.

Two observers simultaneously scored the videotapes—one scoring looking and mouthing behaviors, and the other scoring right-hand grasping, left-hand grasping, and fingering. The same two observers scored all the tapes (including those in Studies 2 and 3). Each observer was highly trained and skilled in the scoring task with this particular apparatus. Comparison of the scoring and rescoring by the same observer of six randomly selected subjects indicated a within-observer agreement ratio above .89 for all the measures considered in the analysis. Interobserver reliability of the two independent observers who coded six randomly selected subjects (one 3-month-old, four 4-month-olds, and one 5-month-old) on the duration ratio (% of looking, mouthing, bimanual grasp, and fingering) was calculated. Using Pearson's product-moment correlation test, interobserver reliability was above .95 for the four measures.

Results

Duration and frequency of behaviors were analyzed. The relative duration (% duration) over the total trial length was computed considering (a) monograsping of the object (either by left or right hand), (b) bimanual grasping of the object, (c) fingering, (d) mouthing, and (e) looking at the object. Further analysis included paired co-occurrence among four scored behaviors: mouthing and either bigrasping (f) or fingering (g); looking and either bigrasping (h) or fingering (i). Monograsping was not included in the co-occurrence analysis because it is imposed by the procedure of object's presentation and thus potentially biased. Other analyses also included first transport either (j) to mouth or eyes and frequency of object's transport (within a second) from mouth to eyes or eyes to mouth (k). Finally, frequency of transfer of the object from hand to hand (l) was analyzed.

The duration of exploration averaged 37 s per trial-presentation for the group of 2-month-olds; 44 s for the 3-month-olds; 47 s for the 4-month-olds; and 54 s for the 5-month-olds. Despite the apparent increase with age of the average time that infants spontaneously interacted with the object, a 4 (ages) × 2 (left- or right-hand presentation) analysis of variance (ANOVA) shows that this trend is not significant and that there is no effect of right- versus left-hand presentation. At each age, there was important interindividual variability in the overall duration of exploration, some babies dropping the object after less than 15 s, and others exploring it for a period exceeding 90 s. In further analysis, to correct for this extreme variability, duration of be-

**Figure 1.** Objects presented to the infant for free manipulation and exploration. (Object 1A was used in Studies 1 and 2. Both Objects 1A and 1B were used in Study 3. Object 1A was made of a bright blue elastic rubber with various textures at each of its extremities. Object 1B was made of a bright red styrofoam sphere covered with a thin plastic wrapping and attached to a wooden rod for handling. Compared with Object 1A, Object 1B was too large to be introduced in the mouth.)
Table 1
Mean Percentage of Durations and Standard Deviations of Each Scored Behavior
According to Age and Left- (L) or Right- (R) Hand Presentation

<table>
<thead>
<tr>
<th>Age</th>
<th>Monograsping</th>
<th>Bigrasping</th>
<th>Fingering</th>
<th>Mouthing</th>
<th>Looking</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L R</td>
<td>L R</td>
<td>L R</td>
<td>L R</td>
<td>L R</td>
</tr>
<tr>
<td>2 months</td>
<td>90.5 90.7</td>
<td>9.5 6.9</td>
<td>0.0 2.4</td>
<td>15.8 15.6</td>
<td>8.6 1.7</td>
</tr>
<tr>
<td></td>
<td>17.6 20.0</td>
<td>13.2 10.0</td>
<td>0.0 9.4</td>
<td>18.5 21.0</td>
<td>22.1 6.7</td>
</tr>
<tr>
<td>3 months</td>
<td>75.8 81.8</td>
<td>17.3 10.4</td>
<td>6.8 7.8</td>
<td>24.0 9.6</td>
<td>19.3 14.8</td>
</tr>
<tr>
<td></td>
<td>27.2 30.1</td>
<td>25.5 19.9</td>
<td>12.3 25.7</td>
<td>29.6 14.2</td>
<td>26.6 23.8</td>
</tr>
<tr>
<td>4 months</td>
<td>52.4 69.7</td>
<td>21.5 16.6</td>
<td>25.9 13.5</td>
<td>48.7 29.5</td>
<td>28.8 37.1</td>
</tr>
<tr>
<td></td>
<td>27.2 26.1</td>
<td>22.6 19.3</td>
<td>18.7 13.6</td>
<td>31.4 32.1</td>
<td>28.6 26.1</td>
</tr>
<tr>
<td>5 months</td>
<td>55.9 55.7</td>
<td>14.6 13.6</td>
<td>27.6 30.0</td>
<td>41.8 47.1</td>
<td>34.9 33.6</td>
</tr>
<tr>
<td></td>
<td>30.4 31.8</td>
<td>13.4 17.7</td>
<td>22.7 22.6</td>
<td>26.7 26.1</td>
<td>23.9 21.0</td>
</tr>
</tbody>
</table>

Age effect: $F(3, 55) = 5.57$ 1.46 10.09 6.14 6.66

- $p < .002^a$  
- $ns$  
- $.0001^b$  
- $.001^c$  
- $.001^d$  

Post hoc Tukey tests revealed that both 2- and 3-month groups differed from the 4- and 5-month groups at the .05 level at least, but did not differ from each other. Post hoc Tukey tests revealed that both 2- and 3-month groups differed from the 5-month group at the .05 level at least, because only the 2-month group differed from the 4-month group. The 2- and 3-, 3- and 4-, 4- and 5-month groups did not differ from each other. Post hoc Tukey tests revealed that the 2-month group differed from the 4- and 5-month groups at the .01 level, the latter two groups not differing from each other. The 3-month group did not differ from any other groups.

The occurrence of mouthing or looking with either one of the two categories of bimanual behavior (bigrasping and fingering) was further analyzed. Monograsping was not included in this analysis because neither mouthing nor looking could occur without at least one hand grasping the object. This necessity, together with the imposed monograsping of the object at the beginning of each trial, might have indeed potentially influenced the manifestation of this particular co-occurrence. The co-occurrence analysis involved a comparison of the observed duration of co-occurrence of either mouthing or looking and bigrasping or fingering ($P_{obs}$) with the expected duration of co-occurrence ($P_{exp}$) knowing only the separate overall durations of each behavior. Thus, for two behaviors, A and B, $P_{exp}$ ($AB) = % duration (A) \times % duration (B)$. These calculations were carried out for each infant for each of the two object's

havior was calculated as the percentage of the total length of each trial for each individual baby. These ratios were then averaged for each age group and for left- or right-hand presentation of the object.

Table 1 shows the mean percentage of duration and standard deviation of monomodal grasp, bimanual grasp, fingering, mouthing, and looking at the object during exploration (according to age and left- or right-hand presentation). For each of the five categories of behavior, an overall 4 (age) $\times$ 2 (hand presentation) mixed-design ANOVA was performed on the percentage of duration of these behaviors. Except for mouthing, no main effect of right- versus left-hand presentation was found, nor any interaction of this variable with age. On the other hand, the ANOVA shows a significant main effect of age for four of the five categories of behavior considered in the analysis.

As is apparent in Table 1, the mean percentage of duration of monograsping decreases significantly with age. At the youngest ages (2 and 3 months), infants tended simply to hold the object the way it has been introduced by the experimenter. With older infants (4 and 5 months), both hands are increasingly involved in exploring and manipulating the object.

There is no significant age effect for mean percentage of duration of bigrasping, where both hands are holding the object. However, there is a significant increase with age of fingering behavior, where one hand holds the object and the other scans it with the tips of its fingers. Post hoc analyses indicated that this main effect of age is due to significant contrasts between the two older groups of infants and the youngest (2 and 3 months compared with 5 months). By five months of age, there is a significant increase in duration of oral contact, with the infant bringing the object to the mouth for longer bouts of mouthing.

For looking, the ANOVA shows a significant age effect. With increasing age, infants bring the object into the field of view for significantly longer visual inspection. Post hoc analyses reveal significant contrasts between the two older age groups and the 2-month-olds. Again, 3-month-olds appear to be at a transitional stage in the development of object manipulation and exploration involving multiple modalities.

The co-occurrence of mouthing or looking with either one of the two categories of bimanual behavior (bigrasping and fingering) was further analyzed. Monograsping was not included in this analysis because neither mouthing nor looking could occur without at least one hand grasping the object. This necessity, together with the imposed monograsping of the object at the beginning of each trial, might have indeed potentially influenced the manifestation of this particular co-occurrence. The co-occurrence analysis involved a comparison of the observed duration of co-occurrence of either mouthing or looking and bigrasping or fingering ($P_{obs}$) with the expected duration of co-occurrence ($P_{exp}$) knowing only the separate overall durations of each behavior. Thus, for two behaviors, A and B, $P_{exp}$ ($AB) = % duration (A) \times % duration (B)$. These calculations were carried out for each infant for each of the two object's
Table 2

Means and Standard Deviations of the Percentage of Durations Observed (% obs) and the Percentage of Durations Expected (% exp) of Co-occurrence of Mouthing or Looking With Either Bigrasping or Fingering Behaviors According to Age

<table>
<thead>
<tr>
<th>Age</th>
<th>Mouthing × Bigrasping</th>
<th>Mouthing × Fingering</th>
<th>Looking × Bigrasping</th>
<th>Looking × Fingering</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%obs</td>
<td>%exp</td>
<td>%obs</td>
<td>%exp</td>
</tr>
<tr>
<td>2 months</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>6.84</td>
<td>2.50</td>
<td>0.07</td>
<td>0.07</td>
</tr>
<tr>
<td>SD</td>
<td>11.17</td>
<td>4.30</td>
<td>0.39</td>
<td>0.39</td>
</tr>
<tr>
<td>3 months</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>7.63</td>
<td>5.80</td>
<td>0.23</td>
<td>0.20</td>
</tr>
<tr>
<td>SD</td>
<td>18.98</td>
<td>17.21</td>
<td>1.27</td>
<td>1.09</td>
</tr>
<tr>
<td>4 months</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>13.21</td>
<td>12.28</td>
<td>9.03</td>
<td>8.31</td>
</tr>
<tr>
<td>SD</td>
<td>19.10</td>
<td>19.67</td>
<td>13.24</td>
<td>11.72</td>
</tr>
<tr>
<td>5 months</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>8.73</td>
<td>7.26</td>
<td>13.73</td>
<td>12.96</td>
</tr>
<tr>
<td>SD</td>
<td>12.79</td>
<td>11.39</td>
<td>16.03</td>
<td>14.48</td>
</tr>
</tbody>
</table>

Co-occurrence

\( F(1, 55) = 14.13, p < .0004 \)
\( \text{ns} \) \( ns \) \( < .0001 \)

Age × Co-occurrence

\( F(3, 55) = 1.75, p < .05 \)
\( ns \) \( ns \) \( ns \) \( < .05 \)

* Simple effects analysis reveal a significant co-occurrence effect only for the 4-month-olds, \( F(1, 55) = 11.91, p < .001 \), and the 5-month-olds, \( F(1, 55) = 4.50, p < .038 \).

presentations. Accordingly, if \( P_{\text{obs}}(AB) \) is larger than \( P_{\text{exp}}(AB) \), it would indicate that the observed co-occurrence of \( A \) and \( B \) is above chance level. On the other hand, if \( P_{\text{obs}}(AB) \) is equal to \( P_{\text{exp}}(AB) \), it would indicate that the observed co-occurrence of \( A \) and \( B \) happens in a proportion that would be expected by chance, thus pointing to a random overlap of these behaviors over exploration time (for a similar analysis, see Fogel, 1981).

On the basis of this analysis, an overall 4 (age) × 2 (presentation) × 2 (co-occurrence probability) mixed-design ANOVA was performed for each of the four paired categories: mouthing and bigrasping, mouthing and fingering, looking and bigrasping, and looking and fingering. Table 2 presents, according to age, the means and standard deviations of observed and expected percentage of duration for the four considered co-occurrences of behavior, as well as the results of the ANOVAs. No significant effect of left- versus right-hand presentation was found in any of the four ANOVAs.

Considering mouthing and bigrasping of the object, the ANOVA shows that their observed co-occurrence is significantly higher than would be expected by chance. Furthermore, no significant Age × Co-occurrence Probability interaction was found. Thus, for all ages, bigrasping of the object shows higher-than-chance expected association with oral exploration. Both hands appear to be significantly involved in supporting the object for oral contacts.

Relative to mouthing and fingering of the object, the ANOVA shows that the observed probability of the co-occurrence of these behaviors is not significantly higher than would be expected by chance. Furthermore, there is no interaction of co-occurrence probability with age. In the light of the results above, bigrasping and not fingering is shown to be the bimanual action significantly associated with oral exploration of the object. The next analysis indicates that the reverse is true when considering the co-occurrence of looking with either one of these bimanual behaviors.

The ANOVA reveals that the co-occurrence of looking and bigrasping does not occur above chance level and that there is no interaction between age and probability of co-occurrence. Co-occurrence of looking and fingering appears to be significantly above chance level. Furthermore, the ANOVA shows a significant interaction of age with probability of co-occurrence. Post hoc analysis of simple effects reveal that \( P_{\text{obs}} \) are significantly higher than \( P_{\text{exp}} \) for the 4- and 5-month-olds. The group of 2- and 3-month-olds display no more co-occurrence between fingering and looking than would be expected by chance. This absence of significant difference in the youngest groups probably reflects a floor effect. Indeed, the percentages of duration of looking and fingering at these ages are small whenever these behaviors are manifest, limiting the probability of their co-occurrence (see Tables 1 and 2). Nevertheless, these results provide further information about the significant increase in the proportion of fingering at 4 months of age that has been seen in previous analyses. They suggest that the development of fingering is linked to vision. These data indicate that vision might play a role in the control of fine manual exploration early in
development. This observation was further assessed in Study 2 (reported below).

Three further analyses were conducted for Study 1, examining the relative importance of oral and visual modality, the frequency of transition between oral and visual contacts, and the frequency of object transfer from one hand to the other during manipulation.

To discuss the status or relative importance of oral and visual modality, the first contact the infant made either orally or visually was considered. Thus, only infants who brought the object either to mouth or into visual regard at least once were included in this frequency analysis. In total, ten 2-month-olds, thirteen 3-month-olds, sixteen 4-month-olds, and fifteen 5-month-olds were considered. Only the first trial presentation (either left- or right-hand presentation) was analyzed to control for contamination by previous exploration of the same object. Figure 2 shows the percentage of infants for each age group that either brought the object first to the mouth for oral contact and exploration or first to the field of view for visual inspection.

Figure 2. Percentage of infants for each age group that either brought the object first to the mouth for oral contact and exploration or first to the field of view for visual inspection.

Conversely, at 4 and 5 months, the majority of infants start with the object first to the mouth for oral contact. By 5 months, vision appears to predominate for initial exploration. By 4 and 5 months, vision appears to progressively take over this initial role. Indeed, at 5 months, over 90% of the subjects resort to vision first.

Table 3 shows the mean frequencies and standard deviations of the transition from looking to mouthing, the transition from mouthing to looking (these transitions occurring within 1 s), and object transfer from hand to hand (with corresponding F and p values for age effect).

The frequency of transition during exploration from visual contact to oral contact (and vice versa) increases significantly with age. Again, no significant effect of left- versus right-hand presentation was found. Post hoc analyses indicate that the age effect results from significantly more contrasts at 5 months than at 2 or 3 months. Between 3 and 5 months of age, infants appear to refer their exploration increasingly to multiple successive oral and visual contacts with the object, thus significantly increasing their multimodal activity.

Analysis of the frequency of object transfer from one hand to another during manipulation and exploration shows a significant age effect and no hand-presentation effect. Post hoc tests indicate that the age effect is based on the significantly more frequent transfer in the 5-month-olds than in the three younger groups. On average, 5-month-olds transfer the object from hand to hand over three times per trial, whereas 2-, 3-, and 4-month-olds show such transfer less than once a trial. This result, combined with those pertaining to the emergence of fingering behavior, suggests that, by 5 months of age, bimanual action becomes reorganized. At this age, infants manifest functional differentiation between grasping and exploring by hand (i.e., fingering) and increase the amount of intermanual transfer of the object. From a perceptual point of view, the emergence of these manual behaviors is a developmental milestone, because they provide the young infant with novel means of action for potential discoveries of objects' properties and their affordances.

Study 2 further investigates an important feature of the observations collected in Study 1, namely the role of vision as a potential organizer of multimodal exploration and object manipulation early in development.

Table 3

Mean Frequencies and Standard Deviations of Transition From Looking to Mouthing, Transition From Mouthing to Looking, and Object Transfer From Hand to Hand

<table>
<thead>
<tr>
<th>Age</th>
<th>Looking to mouthing</th>
<th>Mouthing to looking</th>
<th>Object transfer from hand to hand</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 months</td>
<td>M = 0.07</td>
<td>M = 0.00</td>
<td>M = 0.11</td>
</tr>
<tr>
<td></td>
<td>SD = 0.39</td>
<td>SD = 0.00</td>
<td>SD = 0.32</td>
</tr>
<tr>
<td>3 months</td>
<td>M = 0.46</td>
<td>M = 0.36</td>
<td>M = 0.10</td>
</tr>
<tr>
<td></td>
<td>SD = 1.85</td>
<td>SD = 1.82</td>
<td>SD = 0.30</td>
</tr>
<tr>
<td>4 months</td>
<td>M = 1.31</td>
<td>M = 0.90</td>
<td>M = 0.68</td>
</tr>
<tr>
<td></td>
<td>SD = 1.37</td>
<td>SD = 1.14</td>
<td>SD = 1.17</td>
</tr>
<tr>
<td>5 months</td>
<td>M = 2.53</td>
<td>M = 2.13</td>
<td>M = 2.70</td>
</tr>
<tr>
<td></td>
<td>SD = 2.28</td>
<td>SD = 2.06</td>
<td>SD = 4.09</td>
</tr>
</tbody>
</table>

Age effect $F(3, 55) = 9.79$ and $p < .0001^*$ for the comparison of age groups.

*Post hoc Tukey tests revealed that both 2- and 3-month groups differed from the 5-month group at the .01 level. 

*Post hoc Tukey tests revealed that 2-, 3-, and 4-month groups differed from the 5-month group at the .01 level.
itself in coordination with vision. This important association suggests that the development of fine manipulatory behavior could depend on the distal control of visual guidance. Fine object manipulation is more likely to occur when infants look simultaneously at the object, thus seeing the consequences of what they do with their hands. When vision is involved, it appears that hands start to be used not only as grasping instruments but also as perceptual tools for fine haptic exploration. Developmental studies of visually handicapped infants provide further support for the role of vision as an organizing factor of object manipulation and exploration early in development. Fraiberg (1977) found that congenitally blind infants exhibit drastic delays in the use of hands as exploratory tools. Even though congenitally blind toddlers are found to develop manual haptic strategies such as object rotation (Landau, 1988) spontaneously, the absence of vision seems to affect the pace and possibly the course of this development. For the visually handicapped child, haptic exploration remains predominantly oral up to 3 to 4 years of age—in sharp contrast with the sighted child.

In comparison with vision, oral perception is not a likely coordinator of fine object manipulation and exploration. Study 1 showed that oral contact with the object is not associated with fingering, although mouthing duration does increase significantly at the time that fingering begins to be systematically manifested by the young infant (4 months). Results show that mouthing co-occurs significantly with bimanual grasping of the object where hands are used as instruments of capture, transport, and support for oral exploration.

Study 2 was undertaken to assess further the role of vision in early object manipulation and multimodal exploration. Three- and 4- to 5-month-olds were observed while exploring and manipulating an object presented either in light or in total darkness. These two conditions manipulate the possibility of visual access to the object and visual control over manipulation and exploration of it. Two empirical questions guided this second study. These questions pertain to the role of vision as organizer of both object manipulation and multimodal exploration including mouthing: (a) How should object manipulation and exploration in the dark be characterized in comparison with an illuminated condition, where vision appears to be linked with haptic (manual) exploration? (b) When exploring in the dark, do oral contacts with the object significantly increase so as to compensate for the absence of visual access to the object and lack of visually controlled fingering of the object?

Subjects

Thirty healthy infants were tested, equally divided into two age groups. The first group consisted of fifteen 3-month-old infants (7 boys and 8 girls), from 96 to 118 days of age, with a mean age of 109 days. The second group consisted of fifteen 4- to 5-month-olds (4 boys and 11 girls), from 120 to 172 days of age, with a mean age of 144 days. As in the first study, infants were tested in the infant laboratory at the University of Pennsylvania. In addition to the total of 30 infants who completed testing and were used in the analysis, four 3-month-olds and three 4- to 5-month-olds were tested but excluded from the final sample because of poor state or failure to complete the experiment. These babies usually fussed when lights were turned off for dark trials.

Procedure

The object presented to the infant for exploration was identical to the one used in Study 1 (see Figure 1A). The same procedure was used, except that infants were seated on a parent’s laps. This variation was introduced to provide the child with physical closeness in order to reduce possible fear of darkness. Aside from the few babies discarded from final analysis, the infants showed no sign of distress in the dark. The parent holding the infant was instructed to hold the child with both hands on his or her hips and not to interfere with the baby’s manipulation and exploration of the object. The object was again presented from behind the infant, in the same way as described in Study 1. Infants were facing a video camera sensitive both to normal and infrared light originating from an infrared lamp placed above baby and parent. This apparatus allowed recording of a clear image while the infant was exploring in either in normal lighting or when the room was dark.

Each infant was successively tested in both conditions of normal illumination (light condition) and in the dark (dark condition). To prevent sudden transition from light to total darkness in the dark condition, the lights were slowly turned off and slowly turned on at the end of the test trial by means of a rheostat. In each condition, the object was introduced twice, once in the infant’s right hand and once in his or her left hand. Order of conditions and hand presentations within each condition were approximately counterbalanced among subjects of each age group.

Scoring and Analysis

Video recordings were scored using the same technique described in Study 1. Mouthing, right-hand grasp, left-hand grasp, and fingering were scored in real time by two observers (in the same way as in Study 1) using a four-channel event recorder. Comparison of the scoring and rescoring by the same observer of four randomly selected subjects indicate a within-observer agreement ratio above .90 for all the measures considered in the analysis. Interobserver reliability of two independent observers, who coded four randomly selected subjects exploring in the dark condition (two 3-month-olds and two 5-month-olds) on the duration ratio (%) of mouthing, looking, monomodal grasp, bimanual grasp, and fingering, was calculated. Using Pearson’s product–moment correlation test, interobserver reliability was above .96 for the five measures. Interobserver reliability was only performed relative to the dark condition because it was novel compared with Study 1.

Results

Average duration of object manipulation and exploration did not vary significantly with age, averaging 31 s for the 3-month-olds and 34 s for the 4- to 5-month-olds. In general, test trials lasted longer in the light compared with the dark condition (an average of 7 s longer for the 3-month-olds and 6 s for the 4- to 5-month-olds). Nevertheless, this difference was not quite significant, because of great variability among babies. A 2 (age) × 2 (condition) × 2 (hand presentation) mixed-design ANOVA shows no significant effect of age, a marginally significant effect of condition F(1, 28) = 3.227, p < .08, and no Age × Condition interaction. No significant right- versus left-hand presentation was found.

The relative durations (% duration) over the total trial length of monograsping, bigrasping, fingering, looking, and mouthing of the object were calculated and compared in a 2 (age) × 2 (condition) × 2 (hand presentation) mixed-design ANOVA. Table 4 shows the means and standard deviations for each scored behavior (with F and p values for age and condition effects).
Table 4
Mean Percentage of Durations and Standard Deviations or Frequency (f) of Each Scored Behavior According to Age and Light or Dark Condition

<table>
<thead>
<tr>
<th>Behavior</th>
<th>3 months</th>
<th>5 months</th>
<th>Age effect</th>
<th>Condition effect</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Light</td>
<td>Dark</td>
<td>Light</td>
<td>Dark</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Monograsping</td>
<td>76.93</td>
<td>27.33</td>
<td>63.63</td>
<td>25.13</td>
</tr>
<tr>
<td>Bigrasping</td>
<td>15.70</td>
<td>26.44</td>
<td>22.00</td>
<td>19.60</td>
</tr>
<tr>
<td>Fingering</td>
<td>4.40</td>
<td>8.74</td>
<td>11.16</td>
<td>11.47</td>
</tr>
<tr>
<td>Looking</td>
<td>16.85</td>
<td>12.09</td>
<td>11.26</td>
<td>12.09</td>
</tr>
<tr>
<td>Mouthing</td>
<td>29.43</td>
<td>30.70</td>
<td>50.20</td>
<td>49.70</td>
</tr>
<tr>
<td>Transfer (f)</td>
<td>0.03</td>
<td>0.01</td>
<td>1.73</td>
<td>2.91</td>
</tr>
<tr>
<td>To mouth (f)</td>
<td>1.56</td>
<td>1.59</td>
<td>3.00</td>
<td>1.11</td>
</tr>
</tbody>
</table>

No significant hand-presentation effect was found for any of the scored behaviors.

Regarding monograsping of the object, at both ages and in both conditions, infants appear to hold the object monomanually for comparable proportions of trial duration.

Considering bigrasping of the object, infants regardless of age or condition appear equally involved in grasping the object with both hands. Again, the ANOVA shows no significant age or condition effect.

Together with looking, fingering of the object appears to be the sole behavior that occurs in significantly greater proportions in light than in the dark. Although the ANOVA reveals only a marginally significant age effect, $F(1, 28) = 3.34, p < .07$, fingering of the object tended to increase in proportion between 3 and 4 to 5 months of age, this trend confirming the developmental observations of Study 1. The present research also confirms what was inferred from the observations of the first study, that is, that early fingering of the object is linked to vision and depends on this modality. Fingering behavior decreased drastically in the dark compared with the light condition. There is a significant overall condition effect, $F(1, 28) = 9.44, p < .004$.

The percentage of duration of looking was considered in order to analyze its co-occurrence with fingering, in an attempt to replicate the results that led to the present study (see Results section of Study 1 for the rationale of this analysis). At both ages, infants look rarely in the direction of the object in the dark and significantly less than in the light. Although the ANOVA reveals only a marginally significant age effect, $F(1, 28) = 3.34, p < .07$, fingering of the object decreased drastically in the dark compared with the light condition. There is a significant overall condition effect, $F(1, 28) = 9.44, p < .004$.

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Means of the percentage observed and expected durations of co-occurrence were, respectively, 3.03 and 2.18 in the light, and 0.99 and 0.01 in the dark. Simple effects analysis reveals that only in the light condition is the observed probability of the co-occurrence of looking and fingering significantly higher than what would be expected by chance, $F(1, 28) = 5.53, p < .026$. The absence of such an effect in the dark is most probably due to a floor effect. Indeed, the minimal percentage of durations of looking and fingering in the dark reduces the possibility for the observed and expected co-occurrence to differ significantly. Relative to the light condition, this result confirms again that there is an early functional link between vision and the fine haptic exploration of fingering.

Concerning the percentage of duration of mouthing, older infants mouthed the object significantly more, regardless of conditions. These results indicate an overall developmental trend consistent with the findings of the first study. This trend is not affected by conditions, because infants of both ages mouthed the object for equal durations in the light or in the dark. Relative to the second empirical question guiding the present research, the absence of visual access to the object does not play any significant role relative to the duration of oral contact with the object. Infants do not appear to compensate for the absence of visual experience in the dark condition by increasing the duration of their oral exploration. This result suggests the relative functional independence of mouthing and looking, each of these actions eventually serving different functions or being oriented toward different affordances of the object.

In further analysis, frequency of object transfer from one hand to another during manipulation and exploration was con-
considered. Again, a 2 (age) × 2 (condition) × 2 (hand presentation) mixed design ANOVA was performed. Manual transfer of the object increased significantly with age, confirming the developmental trend exhibited in Study 1. Infants of both ages appear to switch the object from hand to hand with equal frequency in light and dark conditions, regardless of the two hand presentations. These results indicate that, early in development, object transfer from hand to hand does not depend on vision to occur.

In contrast to fingering behavior, this manipulatory behavior and its emergence early in development does not appear to be linked or eventually controlled by vision.

In a final analysis, frequency of object transport to the mouth, which ended with oral contact, was considered. At both ages, the object was brought an average of 2 to 3 times to the mouth. The ANOVA showed no significant age effect, no significant hand presentation effect, nor any significant condition effect.

Considering mouthing, bigrasping, manual transfer, and transport of the object to the mouth, infants' level of manipulatory and exploratory activity is comparable in the two conditions, ruling out eventual inhibition of action caused by a sudden (unusual) absence of light. Aside from the occurrence of fingering and looking, there is no evidence for a significant difference in the occurrence of other haptic behaviors across conditions. In general, Study 2 confirms that vision seems to differ in the occurrence of other haptic behaviors across conditions. It has been suggested that from birth infants are oriented toward discovering what objects afford for action. This is a major orientation of infant perception and action (J. J. Gibson, 1979; Rochat & Reed, 1987). An important question addressed in this third study is the extent to which this modulation of manipulatory and exploratory activities is manifest in infants before 6 months. It has been suggested that from birth infants are oriented toward discovering what objects afford for action (J. J. Gibson, 1979; Rochat & Reed, 1987). Neonates, for example, show differential oral and manual responding to objects varying in substance and texture, suggesting early detection of object's affordances for either hands or mouth (i.e., graspability and suckability of the object; Rochat, 1983, 1987). In this context, Study 3 was concerned with whether the emerging exploratory behaviors described in the first two studies are, from the start, object dependent. Infants of 3 and 4 months of age were observed while manipulating and exploring two different objects that differed in shape, size, color, texture and, theoretically, in what they afford for multimodal action. One object was identical to that used in Studies 1 and 2 (see Figure 1A); the other was spherical and too large to be introduced in the mouth (see Figure 1B). Two empirical questions guided the study: (a) Will young infants manifest different patterns of exploratory behaviors when manipulating and exploring two different objects? (b) Will one object be mouthed more than another object because only the first object affords oral exploration and sucking?

**Method**

**Subjects**

Twenty infants were tested, equally divided into two age groups. The first group consisted of ten 3-month-old infants (4 boys and 6 girls), from 80 to 100 days of age, with a mean age of 91 days. The second group consisted of ten 4-month-olds (6 boys and 4 girls), from 115 days to 148 days of age, with a mean age of 135 days. In addition to the total number of 20 infants who completed testing and were used in the analysis, one 3-month-old and two 4-month-olds were tested but excluded from the analysis because of poor state and because they did not complete the experiment. As for the preceding studies, these two groups of infants were tested in the infant laboratory at the University of Pennsylvania and came from a comparable population.

**Objects**

Two objects (see Figure 1A and B; henceforth referred to as Object A and Object B) were presented successively to the infant. As mentioned above, Object A was identical to the one used in Studies 1 and 2 and is described in the Method section of Study 1. Figure 1 represents Object A beside Object B (on the same scale). Object B consisted of a bright red sphere, 10 cm in diameter, attached to a 5 × 1.2-cm round wooden rod, which served as the object's handle for the infant (see Procedure section below). The spherical part of the object was covered with a thin, transparent, removable plastic wrapping for protection and sanitation. Object B looked like a large, wrapped candied apple and weighed approximately the same as Object A (30 g). Under the plastic wrapping, the object's surface was of a fine sandy texture that was haptically perceivable with combined pressure and motion of fingertips over the plastic protection. Object B differed from Object A in size (bigger), texture (homogeneous), color (red), shape (spherical), and by its limited affordance for mouthing (oversized). On the basis of interviews with each infant's caretaker, Objects A and B were novel to the babies.

**Procedure**

The same procedure as the one established for Study 1 was used. In the present study, the 2 objects were successively presented to each infant for two trials. Each object was introduced once in the right hand and once in the left hand for grasping. The order of object and hand presentation was counterbalanced among infants of each age group. Object B was introduced with the wooden rod (handle) at the junction of thumb and index for palmar grasp, the spherical part of the object oriented upward (like an ice cream cone). Infants were videotaped while freely manipulating and exploring each object. On the right side of the
infant seat, a mirror was facing the camera with a 60° tilt, in order to reflect a right-side view of the infant. The mirror was not visible to the seated infant. This mirror’s reflection was included in the field of the camera and helped disambiguate later scoring of oral contact whenever the big object was brought close to the mouth and occluded the oral region to the frontal view of the camera. The small object did not cause such an occlusion problem.

Scoring

The scoring technique was the same as the one used in the preceding studies. Six behaviors were scored on the basis of real time viewing of the videotapes by two observers using seven channels of a polygraphic event recorder. In addition to looking, mouthing, left-hand grasping, right-hand grasping, and fingering, scratching and banging were added to the list of behaviors scored in the preceding studies. The additional scoring of these behaviors was based on pilot observations suggesting their occurrence when infants explored Object B. Scratching and banging were added to allow finer discrimination of behaviors in relation to the two objects presented for exploration. These additional behaviors are defined as follows (see Study 1 for definitions of the other five behaviors):

- **Scratching.** The infant is holding (grasping) the object with one hand while the extremities of the fingers of the other hand flex back and forth in a rubbing motion over one portion of the object’s surface.
- **Banging.** The infant is holding (grasping) the object with one or two hands while shaking it in a repetitive motion, either banging it against another surface (seat, laps, or knees) or waving it.

Within-observer agreement and interobserver reliability were assessed relative to the scoring of scratching and banging behaviors because they were novel compared with the previous studies. Comparison of the scoring and rescoring of these two behaviors by the same observer of the randomly selected subjects indicates a within-observer agreement ratio above .90. Interobserver reliability of two independent observers who coded 6 subjects (two 3-months and four 4-months) on the duration of scratching and banging behavior was calculated. Using Pearson’s product–moment correlation test, interobserver reliability was above .93 for these measures.

**Results**

Overall duration of trials averaged 37.1 s for the group of 3-month-olds and 46.6 s for the group of 4-month-olds. A 2 (age) × 2 (object) × 2 (hand presentation) mixed-design ANOVA of duration times showed no significant age effect nor any significant object or hand presentation effects.

The same 2 (age) × 2 (object) × 2 (hand presentation) ANOVA was performed on the relative duration (% of monograsping, bigrasping, fingering, scratching, banging, looking, and mouthing. Further analysis also included frequency of object transfer from hand to hand, frequency of object transport to the field of view or to the mouth, and frequency of transition from mouthing to immediate visual contact with the object (mouth to eyes, within 1 s), and vice versa (eyes to mouth, within 1 s). Note that object transport to the field of view or to the mouth includes all object transports that did not qualify for the categories measuring frequency of transition from mouthing to immediate visual contact with the object. In the case of the categories of object transport to the field of view or to the mouth, these behaviors occurred following more than 1 s of visual or oral contact with the object.

There was no significant main effect of hand presentation in any of the ANOVAs. Infants of both ages behave similarly with either hand starting to grasp the objects. Table 5 summarizes the results showing the overall means and corresponding standard deviations of percentage of duration or frequency for each scored behavior according to age and the object explored (small vs. big). Three- and 4-month-olds are differentiated only in the overall mean frequency of two scored behaviors, both increasing with age. ANOVAs reveal a significant main effect of age for the frequency of object transfer from hand to hand. Regarding this behavior only, the ANOVA reveals a significant Age × Object interaction, $F(1, 18) = 5.492, p < .03$. Four-month-olds show significantly more “switching” than the 3-month-olds, and this effect is greater with the small object than with the big one. Thus, the object’s characteristics appear to influence the occurrence of transfer from hand-to-hand for the 4-month-olds. The only other significant age effect revealed by the ANOVA occurs in the frequency of object transport to the field of view. There is a significant increase in the frequency of this behavior by the 4-month-olds.

Three of the 12 scored behaviors manifest in significantly different proportions for the two different objects. Scratching behavior was not displayed by either age group when exploring the small object. When interacting with the big object, 3-month-olds spent an average of 5.35% and 4-month-olds an average of 7.75% of exploration time scratching the object. An ANOVA reveals a significant object main effect for scratching behavior.

Frequency analysis of object’s transport from the mouth to the field of view, or from the field of view to the mouth, also revealed a significant object main effect. The big object was looked at significantly more after oral contact than was the small object and it was mouthed significantly more following a visual inspection than the small object. Contrary to the pilot observations, none of the infants showed banging behavior for either object.

In general, the results of Study 3 suggest that, from 3 months of age, infants demonstrate signs of adapted behavioral patterns when exploring and manipulating different objects. They show significant increase in the frequency of certain behavior and instances of novel action (i.e., “scratching” behavior) when exploring and manipulating an object with widely different physical characteristics.

**General Discussion**

On the basis of the evidence outlined above, a number of important characteristics of the early development of object manipulation and exploration can be identified. In general, it appears that from 2 to 5 months of age, significant changes occur relative to spontaneous multimodal exploration of a novel object. The object is increasingly brought into the field of view for visual inspection and to the mouth for oral contact. Parallel to the growing hand–eye and hand–mouth coordinations manifest during the first half-year of life, early object exploration becomes increasingly multimodal. Infants tend to use more than one modality in their exploration. Data from the first study suggest that, at 2 and 3 months, spontaneous interaction with a
novel object starts off with an oral contact, later, by 4 months, interaction opens with a visual inspection (see Figure 2). This observation is consistent with Piaget’s (1952) observation showing the precedence of hand–mouth coordination over hand–eye coordination early in development. By 4 months, even though vision emerges as the initial modality of exploration, infants continue to bring the object frequently to the mouth. At this age, infants’ spontaneous behavior suggests increasing multimodal organization of exploration, with vision playing a growing role. From 4 months on, infants show frequent rapid transitions from visual to oral contact with the object (and vice versa). The hands are serving both supporting and transporting functions, bringing the object alternately into the oral zone and in the field of view for exploration. This behavioral pattern could be a basis for active cross-modal comparisons, infants actively relating what they experience of the object in the oral and visual modalities.

In conjunction with the early development of multimodal exploration, the characteristics of object manipulation fundamentally change between 2 and 5 months of age. At 2 and 3 months, the infant’s manual involvement in haptically exploring the object consists mainly of grasping movements, potentially informing the infant about the object’s substance (i.e., Rochat, 1987). Beside the potential perceptual function of grasping, hands appear to essentially serve the functions of supporting and transporting the object to the mouth for oral contact.

A particularly interesting feature in the early development of object manipulation is the emergence of a new bimanual action at around 4 months of age, in particular the emergence of fingering behavior. Before this age, when both hands are involved in contacting the object, it is for transporting the object to the mouth. Analysis of the co-occurrence of mouthing and bigrassing indicates that from 2 months of age on, both hands are significantly involved in supporting the object for oral contact. Currently, it is not clear whether this bimanual involvement precedes or follows the episode of oral contact with the object once it is stabilized at the mouth. We are currently studying this

<table>
<thead>
<tr>
<th>Behavior</th>
<th>3 months</th>
<th>4 months</th>
<th>Age effect</th>
<th>Object effect</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Small</td>
<td>Big</td>
<td>Small</td>
<td>Big</td>
</tr>
<tr>
<td>Monograsping</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>65.95</td>
<td>64.05</td>
<td>71.90</td>
<td>58.15</td>
</tr>
<tr>
<td>SD</td>
<td>34.21</td>
<td>32.34</td>
<td>24.13</td>
<td>29.57</td>
</tr>
<tr>
<td>Bigrasping</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>26.45</td>
<td>19.65</td>
<td>12.80</td>
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<tr>
<td>SD</td>
<td>33.98</td>
<td>27.16</td>
<td>16.64</td>
<td>20.48</td>
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<td>Fingering</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>6.95</td>
<td>7.95</td>
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<td>18.70</td>
</tr>
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</tr>
<tr>
<td>M</td>
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<td>5.35</td>
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</tr>
<tr>
<td>SD</td>
<td>0.00</td>
<td>10.98</td>
<td>0.00</td>
<td>12.66</td>
</tr>
<tr>
<td>Banging</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
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<tr>
<td>SD</td>
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question and have already collected evidence that in 2- to 4-
month-olds both hands are involved in transporting the object
to the mouth. Young infants show a bimanual action organized
in a mirror synergy prior to contact with the mouth (Rochat &
Senders, in press). This observation points to the importance of
the mouth in the early manifestation of bimanual action and
coordination within the context of object manipulation. It ap-
ppears that bimanual coordination is initially linked to the oral
system and is later reorganized in relation to vision when behav-
iors such as fingering emerge. It is interesting to note that at
the time bimanual action appears to be reorganized with the
emergence of fingering behavior (4 months), infants are often
being introduced to solid food (at least in most western cul-
tures) and begin to teethe. New patterns of oral activities emerge
in connection with chewing (Sheppard & Mysak, 1984), the
processing of solid food, and teething. The haptic capacity of
the mouth might progressively become more focused within the
context of nutrition—specialized in supervising solid-food pro-
cessing and in selecting what is ingestible. Furthermore, the tak-
ning over by the hands of object exploration starts to leave the
mouth free to become an instrument of communication by
means of active structuring of vocalization (babbling), which
also emerges around this age (Kaplan & Kaplan, 1971). Indeed,
observations on later development indicate that, in the course
of the second semester, infants tend to bring fewer objects to the
mouth for oral contact (McCall, 1974). With the emergence of
fingering, the hands become powerful instruments of haptic
perception, eventually taking over from the mouth.

The emergence of fingering behavior in development is of par-
ticular interest because it demonstrates differentiation and inte-
gration of two basic functions of the hands: a grasping (support-
ing) function and an exploratory (perceptual) function (Hat-
well, 1987). In the present research, fingering was considered to
occur when one hand grasped and supported the object while
the other hand scanned it with the fingertips where the density
of tactile receptors is highest. Thus, fingering was considered as
a particular case of bimanual action, even though it can possibly
involve one hand only. Relative to this definition, fingering con-
stitutes of a coordinated action of the hands enabling fine haptic
scanning of an object. In this action, the most sensitive part of
one hand actively contact the object while the other hand sup-
ports it. It is the expression of haptic exploration par excellence
and its emergence is a milestone with regard to both motor and
perceptual development. By 4 months of age, infants start to
manifest this behavior systematically, demonstrating (per se) a
haptic use of the hands. From a functional point of view, it re-
veals a change in the status of the hands from being mainly ori-
ented towards prehension to involvement with perception and
fine exploration. Research with older infants suggest that this
development continues in the latter half to the first year (Ruff,
1984). Further research is needed to specify the details of this
development, whether, for example, it is characterized by con-
tinuous differentiation and progressive independence of hands
or on the contrary, marked by successive reorganizations of
manual action. Further support for functional differentiation of
hands and re-organization of bimanual action at around 4 to 5
months, comes from the observation of increased frequency of
object transfer from hand to hand. Hands become interchange-
able in their grasping, supporting and transporting functions.
With the emergence of object transfer from hand to hand and
fingering behavior, it is as if 4 to 5-month-olds infants start to
exploit this newly discovered property of their body (i.e., sym-
metry). It is possible that it is only when this differentiation oc-
curs that lateralization and hand preference can begin to be
manifest (Michel, 1983; Ramsay, Campos, & Fenson, 1979).

Two sets of observations reveal that fingering behavior is
linked to vision. The observed probability of co-occurrence be-
tween fingering and looking at the object is significantly higher
than would be expected by chance. This was true for 4- and 5-
month-olds but not for the few co-occurrences of such behaviors
shown by 2- and 3-month-olds. Co-occurrence analysis of
looking and fingering in the second study replicates this finding.
Further support is provided by the observation collected in
Study 2 showing that by 4 months the occurrence of fingering
behavior decreases significantly in the dark condition, where
there is no visual access to the object and no visual feedback
about object manipulation. This decrease does not appear to be
caused by a general inhibition of action in the dark condition,
because ANOVAS reveal no condition main effect for any of the
other scored behaviors. By 4 months, coordinated action of the
hands depends on vision and appears to be organized by visual
experience. Fingering, like reaching, appears as another by-
product of the eye–hand coordination developing from birth
(Hofsten, 1982) and during the first months of life (Hofsten &
Lindhagen, 1979). The second study also indicates that infants
do not compensate for lack of visual access to the object with
increased duration of oral contact with the object. This fact sug-
gests the relative functional independence of mouthing and
looking. It also suggests that, in general, infants might focus
on different characteristics or affordances of the object when
looking and mouthing. In fact, the findings do not provide any
answer as to what type of information the various exploratory
systems are sensitive to—whether they function together or se-
parately. They emphasize the important link existing from 4
months on between vision and fine manual action.

Finally, the third study provides some indication that the de-
velopment described above is not independent of the physical
properties of the object explored. From 3 months of age, the
characteristics of manipulation and exploration reflect some re-
lation to the physical properties and affordances of the object.
Compared with a small object, a large and overall different ob-
ject is associated with new (spontaneous) manual actions. Scrat-
ing behavior emerges for the large object only. Together with
the increased frequency of transport from mouth to the field of
view and vice versa, this supports the idea that, quite early, in-
fants possess a rich and flexible repertoire of manipulatory and
exploratory action. Within seconds of interaction with a novel
object, young infants display manual actions that are appropri-
ate to potentially maximize the affordances of the object. For
instance, the scratching of the large object afforded an interest-
ing noise that the small object did not (because of differences
in texture and material). It is not clear whether "scratching" of
the object corresponds to the secondary circular reactions
described by Piaget (1952), that is, infants starting to repeat a
particular action on object(s) in an attempt to make an interest-
ing event to last. In general, bouts of scratching behavior were
relatively short (averaging 2.6 s at 3 months and 3.8 s at 4 months) leaving little room for much repetition. Furthermore, it is not evident that the noisy and potentially interesting outcome of scratching on the big object was accidentally discovered and then reproduced by way of repeating the action that caused it. Twelve of the 20 infants tested in the third study were observed scratching the big object, and none of them showed this behavior with the small object. Thus, this behavior was not merely accidental. Scratching was unmistakable for the observer, both by the form of its movement and the noisy effect that it produced. It complemented fingering as a novel action and was not the mere expression of a constrained form of fingering. Indeed, along with the manifestation of scratching behavior, the proportion of fingering remained stable across objects in Study 3, a finding that replicates the results of Study 1 at the same ages (see Tables 1 and 5 for comparison of the percentage of duration of fingering for the 3- and 4-month groups). Scratching behavior appeared to stem from a deliberate investigation of the big object’s texture and eventuated in the discovery of its affordance for noise. Further studies should assess this interpretation, using more than two objects to vary the discovery of its affordance on the big object was accidentally discovered and then reproduced by way of repeating the action that caused it. Twelve of the 20 infants tested in the third study were observed scratching the big object, and none of them showed this behavior with the small object. Thus, this behavior was not merely accidental. Scratching was unmistakable for the observer, both by the form of its movement and the noisy effect that it produced. It complemented fingering as a novel action and was not the mere expression of a constrained form of fingering. Indeed, along with the manifestation of scratching behavior, the proportion of fingering remained stable across objects in Study 3, a finding that replicates the results of Study 1 at the same ages (see Tables 1 and 5 for comparison of the percentage of duration of fingering for the 3- and 4-month groups). Scratching behavior appeared to stem from a deliberate investigation of the big object’s texture and eventuated in the discovery of its affordance for noise. Further studies should assess this interpretation, using more than two objects to vary their physical characteristics systematically.

Overall, this research shows that major features of object manipulation and exploration develop during the first semester of life. These findings argue for the necessity of investigating what infants do within the first 6 months in order to understand the origin of action leading to increasing knowledge about objects and their affordances.

References


Call for Nominations

The Publications and Communications Board has opened nominations for the editorships of Psychology and Aging, the Journal of Experimental Psychology: Animal Behavior Processes, Contemporary Psychology, the Personality Processes and Individual Differences section of the Journal of Personality and Social Psychology, and Psychological Assessment: A Journal of Consulting and Clinical Psychology for the years 1992-1997. M. Powell Lawton, Michael Domjan, Ellen Berscheid, Irwin Sarason, and Alan Kazdin, respectively, are the incumbent editors. Candidates must be members of APA and should be available to start receiving manuscripts in early 1991 to prepare for issues published in 1992. Please note that the P&C Board encourages more participation by members of underrepresented groups in the publication process and would particularly welcome such nominees. To nominate candidates, prepare a statement of one page or less in support of each candidate.

- For Psychology and Aging, submit nominations to Martha Storandt, Department of Psychology, Washington University, St. Louis, Missouri 63130. Other members of the search committee are David Arenberg and Ilene C. Siegler.

- For JEP: Animal, submit nominations to Bruce Overmier, Department of Psychology-Elliott Hall, University of Minnesota, 75 East River Road, Minneapolis, Minnesota 55455. Other members of the search committee are Donald A. Riley, Sara J. Shettleworth, Allan R. Wagner, and John L. Williams.

- For Contemporary Psychology, submit nominations to Don Foss, Department of Psychology, University of Texas, Austin, Texas 78712. Other members of the search committee are Edward E. Jones, Gardner Lindzey, Anne Pick, and Hans Strupp.

- For JPSP: Personality, submit nominations to Arthur Bodin, Mental Research Institute, 555 Middlefield Road, Palo Alto, California 94301. Other members of the search committee are Charles S. Carver, Ravenna S. Helson, Walter Mischel, Lawrence A. Pervin, and Jerry S. Wiggins.

- For Psychological Assessment, submit nominations to Richard Mayer, Department of Psychology, University of California-Santa Barbara, Santa Barbara, California 93106. Other members of the search committee are David H. Barlow and Ruth G. Matarazzo.

First review of nominations will begin January 15, 1990.