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A pick-me-up for infants' exploratory skills: Early simulated experiences reaching for objects using 'sticky mittens' enhances young infants' object exploration skills

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Abstract

Infants' early object contact was enriched by giving a group of pre-reaching infants experience with prehension earlier than they would normally acquire it. These infants received 10–14 10-min play sessions wearing "sticky mittens": mittens with palms that stuck to the edges of toys and allowed the infants to pick up the toys. After these enrichment sessions, the experienced infants' object engagement and object exploration skills were compared to those of infants who were the same age as the experienced infants but had not received the play sessions. The results showed that the experienced infants showed more object engagement via a number of measures, and showed more sophisticated object exploration strategies compared to their inexperienced peers. The results suggest that the early simulated experience reaching for objects serves to jump-start the process of object engagement in young infants.

Keywords: Sticky mittens; Exploratory skills; Infant

1. Introduction

A question as old as the study of development itself is how the developing organism is affected by its environment. Traditionally, critical (or sensitive) periods have been proposed to account for the influence of experience on the developing organism. These periods have typically been conceived of as intervals of time during which the organism is especially sensitive

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to input from the environment. The influence here is largely unidirectional: as long as it comes at the right time, the environment has its effect on the organism. Other formulations of the effects of experience on development explicitly acknowledge the interdependence between the organism and its environment and the complex ways in which these interactions can influence development (Bertenthal & Campos, 1987; Gottlieb, 1991a, 1991b; Greenough, Black, & Wallace, 1987; Hofer, 1981). In the current research, we explore what effect the enrichment of infants' typical early experience as agents acting on objects would have on their object exploration behavior. Infants were given the opportunity to reach for and "grasp" objects earlier than they would normally do so. The effects of this experience on infants' object exploration behavior were assessed by comparing the exploratory skills of infants who had this early reaching and grasping experience with those who did not.

How are infants' actions influenced by their prior experiences? This question has been addressed by a number of different researchers (Adolph, 1997, 2000; Bertenthal, Campos, & Barrett, 1984; Bertenthal, Campos, & Kermoian, 1994; Clifton, Rochat, Litovsky, & Perris, 1991; Needham, 1999a; see Campos et al., 2000 for a recent review). In a set of influential studies, Campos, Bertenthal, and their colleagues (Bertenthal et al., 1984, 1994; Campos, Hiatt, Ramsay, Henderson, & Svejda, 1978) explored the relation between infants' self-produced locomotion and their reaction to the deep side of the visual cliff. The results of the studies showed that infants who had experience with self-produced locomotion (either their own naturally-acquired experience or artificially-acquired experience using an infant walker) showed evidence of wariness toward the deep side of the cliff. This wariness was shown by an increase in the infants' heart rate when placed on the deep side of the visual cliff, or simple avoidance of the deep side, as compared to infants who did not have locomotor experience. These findings suggest that infants' wariness of heights may develop at least in part as a result of experience with self-produced locomotion, a relation first suggested by Held and Hein's (1963) classic 'kitten carousel' study.

However, the situation is unlikely to be that simple. Adolph's (1997, 2000) elegant work has shown that infants do not acquire a general fear of heights through their early self-produced locomotor experiences (i.e., while crawling) that generalizes to walking postures. Presumably, if infants developed fear of heights via their crawling experiences (either their own visual or vestibular sensations or observing scary emotional responses from parents who find their infants in dangerous situations), these same fears would constrain their behaviors as they began to walk. But Adolph's results show an amazing specificity to infants' learning in this domain—infants must learn all over again what the consequences of dropoffs and steep slopes are for their walking, even though they have already learned what the consequences are for their crawling.

The studies described above indicate that we know relatively little about how infants' experiences in a domain affect their abilities within or outside that domain. The literature suggests that cross-domain influences do occur, although the changes may be less sweeping or far-reaching than originally thought. Despite the domain- or posture-specificity of some motor accomplishments, researchers have claimed that changes in infants' object exploration skills may be influenced by their early actions on objects. Gibson (1988), in her seminal review paper, proposed that the acquisition of new motor skills makes possible a whole new array of exploratory situations which in turn have important implications for cognitive

development (see also Bushnell & Boudreau, 1993). Following up on Gibsons's claims, some experimental work has linked developments in object exploratory skills with other non-motor developments such as (a) noting the correspondence in the visual and auditory components of an event involving objects (Eppler, 1995) and (b) determining a boundary between two adjacent objects (Needham, 2000). The current research investigates Gibson's claim about the potentially far-reaching affects of attaining new motor skills by studying the relation between early reaching experiences and the development of infants' object exploration skills. We now review what is known about the development of object exploration during the first few months of life.

Although infants do not systematically reach for objects until approximately 5 months of age, even newborns will sometimes bring objects placed in their hands up to the mouth for oral contact (Butterworth & Hopkins, 1988; Lew & Butterworth, 1997; Rochat, 1993; Rochat & Senders, 1991). Indeed, hand–mouth behavior broadly construed (e.g., thumb-sucking) has been observed even in fetuses (Nillsson & Hamberger, 1990). In one of the only studies to investigate very young infants' object exploration, Rochat (1989) observed many developmental changes in 2- to 5-month-old infants' oral and visual object exploration. One major change is that object exploration becomes more coordinated over different sensory modalities, so that by 4–5 months of age, visual, oral, and manual exploration often occur in concert. This change results in more effective and efficient collection of information over a given period of time (Gibson, 1988; Gibson & Pick, 2000). Infants also engage in significantly more oral and visual exploration over time, with increasing emphasis on visual exploration. One example of this trend is that although 2- and 3-month-old infants' initial exploration of an object tended to be *oral*, 4- and 5-month-old infants' initial exploration tended to be *visual*. By 5 months of age, the visual modality seems to lead and help coordinate the exploration taking place in other modalities (see also Ruff, Saltarelli, Capozzoli, & Dubiner, 1992, who provide evidence that mouthing immediately followed by looking is a clear indication of infants' gathering information about an object).

What abilities come together to produce this rapid increase in exploratory behavior between 2 and 5 months of age? One very basic notion is that in order for infants to engage in longer bouts of object exploration, their gross motor skills (e.g., arm strength, hand strength) must be sufficiently developed (Halverson, 1931, 1933; Jeannerod, 1981, 1984; von Hofsten, 1979). These gross motor skills would presumably allow infants to maintain a grasp of the object for longer periods of time, an important contributor to longer bouts of object exploration when infants must hold the object they explore (as in Rochat, 1989). Further, developments in infants' fine motor skills must also contribute. For example, the development of fingering behavior Rochat observed beginning around 4 months of age requires a certain amount of fine motor control (Bushnell & Boudreau, 1993; Gibson, 1988; Ruff, 1984).

Another factor related to the increase in object exploration could be improvements in hand–eye and hand–mouth coordination (Bruner, 1969; Gesell, 1934; Lockman & Ashmead, 1983; White, 1969). The coordination of these exploratory systems makes possible the increases in multi-modal exploration noted by Rochat (1989). It also seems likely that infants' motivation to explore objects could increase during the time between 2 and 5 months of age. Researchers have long noticed that infants' interest in objects increases dramatically once they develop the ability to reach for objects (Fogel, Dedo, & McEwen, 1992; Gibson, 1988; Gibson

& Pick, 2000; Kaye & Fogel, 1980). In one study investigating connections between postural position, reaching ability and visual gaze during mother–infant interactions, Fogel et al. (1992) found that infants who could reach for objects spent less time gazing at their mothers than infants who could not yet successfully reach for objects.

Like Bertenthal's walker studies that explored the role of self-produced locomotion on the development of infants' wariness of heights, we sought to learn more about the factors underlying the development of infants' object exploration skills by giving infants experiences that would simulate prehension earlier than they would normally engage in this behavior. The participants in this study were 3 months of age at the time of testing (i.e., 0.5–1.5 months prior to spontaneous effective reaching and grasping), and were in the midst of the transitions in object exploration skills discovered by Rochat (1989).

The enrichment experience consisted of 12–14 brief parent-led object play sessions held at the infant's home. During the play sessions, the infant sat on a parent's lap at a table and wore mittens with the soft side of Velcro covering the palms. On the table in front of the infant were small, lightweight objects with edges covered in the corresponding side of the Velcro. With a quick swipe of the hand, the infant could easily "pick up" an object as it stuck to the mitten. Our pilot observations of infants wearing these "sticky mittens" led us to believe that they quickly became visually engaged in the objects on the table, possibly as a result of the realization that they were in control of the objects' movements.

After the enrichment phase for the infants in the experimental condition, these infants as well as the infants in the control condition (who did not receive any prior experience) were brought to the lab for an assessment of their prehensile and object exploration skills. Based on the idea that the onset of self-produced locomotion facilitates changes in the infant's life due to the new experiences that accompany the change, we hypothesized that early production of prehensile actions may bring with it new experiences that would lead to changes in infants' object-directed activity. If this hypothesis is correct, experience interacting with toys while wearing the mittens would facilitate the development of infants' object-directed activity both while the mittens were being worn and after they were taken off.

2. Method

2.1. Participants

Participants were 32 healthy, full-term infants (15 girls, 17 boys) ranging in age from 3 months to 3 months, 19 days ($M = 3$ months, 9 days, SD $= 5.4$ days). Half of the infants were in the experimental condition ($M = 3$ months, 11 days) and half were in the control condition ($M = 3$ months, 7 days). Data from seven additional infants were collected and eliminated: three due to fussiness during the trials, two because their at-home experience did not exceed the minimum of 80 min, and one due to drowsiness during the session. Data from one infant were excluded because her scores on all measures exceeded two standard deviations from the average scores of the rest of the infants in that condition.

The infants' names for this experiment were obtained from the Durham County vital records office. Parents were contacted via letter and follow-up phone calls. They were

offered reimbursement for their travel expenses but were not compensated for their participation.

2.2. Apparatus

2.2.1. Home session

The enrichment sessions received by the infants in the experimental condition featured three different sets of toys. These toys were purchased at a store and altered in the ways described below for this experiment. Set 1 consisted of wooden blocks of various sizes (2 cm × 6 cm × 2 cm, 2 cm × 8 cm × 2 cm, 4 cm × 2 cm × 4 cm, 3 cm × 3 cm × 3 cm) and brightly colored (red, yellow, blue, or orange). Set 2 was made up of black plastic rings of four different shapes: square, oval, triangle, and diamond. Each measured 6.5 cm at its widest point. Set 3 was comprised of plastic cubes, also known as Duplos® blocks, measuring 4.5 cm on each side and with a 2.5 cm dome on the top. Each infant received a set of four blocks that were either blue, red, or yellow.

Tabs of Velcro (the 'hard' side) were placed on each object. The blocks in Set 1 were covered in an average of 11 pieces, each measuring 3.2 cm^2. The rings in Set 2 had six 1.3 cm width pieces wrapped around at evenly-spaced locations. The plastic cubes in Set 3 received seven pieces, each measuring 6.5 cm^2.

The mittens were made of soft fleece. Long strips of the Velcro's soft side were sewn horizontally along the palm of the mitten. The length of the strips varied from 7.5 to 10 cm depending on where on the palm it was found. The mitten was secured at the infants' wrist by an adjustable strap that could expand to as large as 9 cm across.

Parents were given a daily log to track the time spent on the enrichment sessions with their infant. The log was used to both quantify the minutes spent on the enrichment, and as a reminder for the parent to incorporate the toys into their daily play.

2.2.2. Laboratory session

The first two laboratory test trials utilized the same kind of plastic cubes and mittens that the experimental infants played with at home. The infants sat on their mothers' laps to explore the plastic cubes at a wooden table that was 74 cm in height. A pillow was placed under an infant if his or her arms could not rest above the table top. The table top was 81 cm from left to right sides and 64 cm from infant to the experimenter, who sat facing the baby. A half circle (23 cm radius) was cut out of the infant's side of the table, so the infant was surrounded by table. The table was covered in a brightly lined white contact paper.

For the object exploration trials, the infants sat in a semireclined "bouncy seat" to give postural support while they held a series of four novel objects (see Fig. 1). These four objects were designed to be either high or low in visual and oral information. One of the objects (the low-visual/high-oral object) was a commercially available red rubber teether with four mouthable segments that had different orally available textures on them (small bumps, small dimples, one large dimple, and raised straight edges). The high-visual/high-oral object was an identical teether that was decorated with black, blue, green, and yellow plastic tape. The low-oral objects were smooth wooden replicas of the high-oral objects; they were made to be roughly the same as these objects in size, shape, and weight, and were decorated in the same way as the high-oral objects.

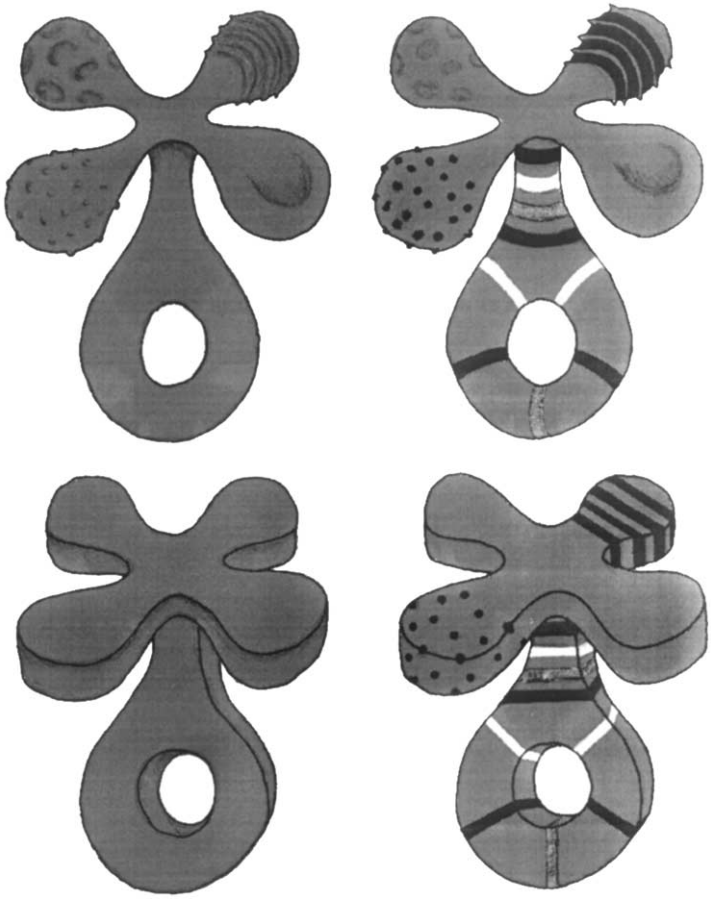

Fig. 1. Teethers given to the infants in the object exploration portion of the lab visit.

2.3. Procedure

2.3.1. Home session

Only the infants in the experimental condition participated in this portion of the study. An experimenter went to the homes of the infants in the experimental condition, bringing with her a set of mittens and toys and a copy of the daily log. The experimenter demonstrated the procedure to the parent and then watched while the parent completed the first 10 min session.

Parents were asked to put the mittens on their baby's hands and play with the toys as instructed, 10 min a day for 2 weeks. This involved setting one of the three sets of toys on a table in front of the infant while the infant was wearing the mittens. Parents were asked to cycle through the three sets of toys in turn, but the timing of presentation of each set was left to the discretion of the parent. The rings and blocks were to be arranged in a pile in front of the infant; whereas, the cubes were arranged in a square. Parents were told that if their infant did not spontaneously swat at the objects, they could tap near the objects and/or place the infant's

mittened hand on the objects. If the infant made contact with an object, the parent would then remove the toy(s) from the mitten(s) and place them back in front of the infant to allow them to try again. The parents recorded the time their infant spent engaged with the mittens and toys on the daily log.

2.3.2. Laboratory session

The infants in both the experimental and control conditions participated in this portion of the study. The laboratory session consisted of two kinds of trials: the prehension trials and the object exploration trials. The prehension trials featured objects that had been used in the enrichment sessions. Infants wore the sticky mittens for one of these trials, but not the other. For these trials, we were interested in infants' visual contact with the objects on the table and swiping at these objects. The object exploration trials were designed to assess infants' object exploration skills, and featured novel objects. The infants did not wear the sticky mittens during any of these trials. For these trials, we were interested in infants' visual and oral exploration of the objects. The upright-seated posture and the reclined postures of these two kinds of trials were chosen to facilitate infants' accomplishment of the tasks in each portion of the study. The infants' behaviors in these trials were recorded on videotape and coded using a videocassette recorder and color video monitor.

For the prehension trials, the infant sat on a parent's lap in front of the wooden table. The experimenter sat opposite the infant and introduced objects that had been used in the enrichment sessions. For both trials, the experimenter placed the four plastic cubes of Set 3 together to make a square in front of the infant (these cubes may have been a different color than the infants had experience with in the home enrichment sessions). The infant was allotted approximately 2 min to interact with these objects, and this behavior was recorded. If the infant became inattentive to the objects or experimenter, the experimenter tapped lightly on the table or moved the objects slightly to reorient the infant. The second trial was identical to the first, with one exception: the mittens were placed on the infants' hands prior to the beginning of the trial.

Following the prehension trials, the mittens were removed from the infants' hands in preparation for the object exploration trials. In these trials, the infants sat in a semireclined "bouncy seat" while they held a series of four novel teethers that they could visually, orally, and manually explore. Infants were presented with each red teether (see Fig. 1) in a random order. Each object was brought into the infant's field of view and placed into the infant's hand. The teethers were presented in a vertical orientation, as if they were bouquets of flowers. The length of time the infant held the object was monitored by the experimenter, who used the following decision rules to determine the ends of the trials:

(1) If the infant dropped the object prior to accumulating 30 s of holding, the experimenter put the object back into the infant's hand and continued the trial.
(2) If the infant dropped the object after holding it for 30 s, the experimenter went on to the next trial.
(3) If the infant had held the object for 60 s without dropping it, the object was removed from the infant's hand and the next trial was begun.

Objects were placed alternately in the infants' right and left hands.

Four infants failed to complete the full set of test trials in the lab, due to fussiness: three infants were missing one of the object exploration trials and one infant was missing one of the prehension trials. The remainder of each of these infants' data sets was included in the analyses.

2.4. Coding

Duration measures (e.g., Looking time, Holding time, Mouthing time) were determined by trained coders who pressed the trigger of a joystick in a continuous fashion whenever the infant engaged in each behavior. For example, when coding for Looking time, the coder would press the trigger as soon as the infant looked at the object and would keep pressing until the infant looked away. The input from each joystick fed into a program that tabulated duration.

2.4.1. Prehension trials

To determine the effect of the enrichment experience on object exploration, both the amount of time infants spent looking at the plastic cubes and the number of times the infant tried to "pick up" the cubes were measured. Looking time was defined by the amount of time spent looking at the plastic cubes. Looking percentage scores were calculated as Looking time divided by total time of the trial. Total time was the amount of time between the beginning and end of a trial. The beginning of each trial started when the infant was presented with the plastic cubes and the experimenter's hands were taken away. The trial ended when the experimenter retrieved the blocks from the infant. If the mittens fell off or needed to be adjusted, that time was subtracted from the measure of total time.

The number of times an infant tried to "pick up" the cubes was measured by the swats made toward the toy. A swat was defined as a movement of the arm(s) that resulted in manual contact with the blocks. A swat was not counted if the experimenter accidentally pushed the blocks into the infant's hands when presenting them. During the prehension trials, only one swat was counted until the experimenter took the blocks off of the mittens and placed them back in front of the infant.

To assess the intentionality of swatting behavior, swats were further divided into two groups: (1) with visual contact toward the objects immediately prior to the swat or (2) without visual contact toward the objects immediately prior to the swat. We thought that this difference might reflect a difference in the intention behind the action (with prior visual contact suggesting intentional contact with the object and no prior visual contact suggesting unintentional contact). To give an indication of the amount of the infant's general activity with the arm regardless of intention to act upon the objects, both groups of swats were summed to yield the total number of swats for both trials.

2.4.2. Object exploration trials

Three behaviors (Holding time, Looking time, and Mouthing time) were coded from the videotapes, and additional measures (percentage scores for each of the three main measures, an overall exploration percentage, and a measure of switching between looking and mouthing) were derived from these three main behaviors.

Holding time, Looking time, and Mouthing time were measured in real time as described above. Holding time was the amount of time the infant held each object. Looking time and Mouthing time were coded simultaneously for each baby by two different coders (this was done so switching between looking and mouthing could be determined and so simultaneous looking and mouthing could be measured). Looking time was the amount of time the infant spent visually exploring each teether. Looking percentage scores were determined by finding the proportion of time that the infant looked at each teether over the total time that the infant held it. Mouthing time was the amount of time the infant spent orally exploring each teether (including brushes of the teether against the lips). Mouthing percentage scores were determined by finding the proportion of time that the infant mouthed the teether over the total time that the infant held it.

For each infant and each object, an Exploration percentage was calculated by adding the looking and Mouthing times together and subtracting the time that the infant was engaged in both activities. This score was then divided by the total Holding time to make an Exploration percentage score. This score reflected the percent of the trial time that the infant spent exploring the object (either visually or orally).

To measure the level of coordination between visual and oral exploration, we counted the number of times that each infant switched between exploration in the two modalitites. Switches were determined from the paper printouts of the Looking and Mouthing time coding (which resulted in a continuous record of the infants' looking and mouthing behavior at the tenth-of-second level). A switch was defined as (1) a change from exploration in one modality (looking or mouthing) to exploration in the other modality that took place within 1 s and with less than 1 s of overlap of the two modalities, or (2) the onset and offset of exploration in one modality during a longer bout of exploration in the other modality.

To assess reliability for the Holding time, Looking time, and Mouthing time measures, one-third of all subjects ($N = 10$) was recoded by a trained observer who was aware of the condition of each infant but not aware of the goals or hypotheses of the study. Percent agreement was calculated for each of the following measures: Swatting and Looking time for the prehension trials and Looking time, Mouthing time, and Holding time for the object exploration trials. The range of percent agreement was 87–99% with an average of 93%.

Because the experimenters running the sessions could not be kept unaware of the condition each infant was in (parents who participated in the experimental condition brought the toys and mittens back to the laboratory; parents would also sometimes make comments about the home sessions at various points during the lab visit), we coded a sample of the sessions for the experimenter's and parent's behavior during the test sessions. Although the experimenters tried to keep quiet during the sessions and instructed the parent to do the same, it was not always possible to keep the session perfectly quiet. We were concerned that potential interruptions during the sessions (i.e., the experimenter or parent talking or laughing) could have happened more frequently for either the control or the experimental groups.

To address this possibility, we coded a randomly selected sample of 10 sessions (5 from the experimental condition and 5 from the control condition) for the experimenter's and parent's behavior during the lab session. We counted the number of vocalizations produced by the parent or experimenter during the session, regardless of whether they were directed to the experimenter, parent, or baby. All vocalizations were counted, even if they were so quiet that

the infant was unlikely to have heard them. This coding effort determined that the experimental ($M = 22$, SD $= 11$) and control ($M = 18.6$, SD $= 9.3$) groups had approximately equal number of vocalizations, $F(1, 8) = .278$, $p = .61$. We also counted the number of times that a vocalization during the trial resulted in the baby disengaging in the task (even briefly), and this number was also not different between the experimental ($M = 3$, SD $= 2.6$) and control ($M = 1$, SD $= 1$) groups, $F(1, 8) = 2.67$, $p = .14$. Thus, any differences in the behaviors of the infants in the experimental and control conditions could not be a result of the experimenters' and parents' behaviors during the sessions.

3. Results

3.1. Prehension trials

The results for the prehension trials are shown in Fig. 2. The looking percentage scores and swatting measures were analyzed by means of analysis of variance (ANOVA) to assess differences in looking and swatting between the infants in the experimental and control conditions.

First, a two-factor ANOVA was run to assess differences in infants' visual exploratory behavior depending on whether the infant was in the experimental or control condition (between-subjects factor) and whether they were wearing the mittens or not (within-subjects factor). This analysis revealed that the infants in the experimental condition ($M = 68.3$, SD $= 25.1$) looked at the objects for a greater portion of the trial than infants in the control condition ($M = 33.0$, SD $= 30.4$) whether the infants were wearing the mittens or not, $F(1, 29) = 13.82$, $p < .001$.

A second ANOVA was conducted on the numbers of swats that the infants produced during the prehension trials, again depending upon whether the infant was in the experimental or control condition (between-subjects factor) and whether they were wearing the mittens or not (within-subjects factor). Overall, there was a trend for the infants in the experimental condition ($M = 6.9$, SD $= 4.2$) to exhibit more swatting behavior toward the test objects than the infants in the control condition ($M = 4.8$, SD $= 5.0$), $F(1, 29) = 2.18$, $p = .15$. However, one might reasonably claim that only those swats that were immediately preceded by visual contact with the objects were actually intended to result in contact with the objects. Swats that did not have visual contact leading up to them may actually have been accidental contacts with the objects. When one considers only those swats that were immediately preceded by visual contact, it becomes clear that the infants in the experimental condition ($M = 5.7$, SD $= 4.4$) produced significantly more of these "intentional" swats than the infants in the control condition ($M = 2.5$, SD $= 4.3$), $F(1, 29) = 4.7$, $p < .05$.

3.2. Object exploration trials

The results for the object exploration trials are shown in Fig. 3. Because the object exploration trials yielded similar values across the four red teethers, each measure was averaged across the teethers for each infant. Simple one-factor ANOVAs were conducted on each measure to determine if the enrichment sessions affected infants' exploration of these novel objects.

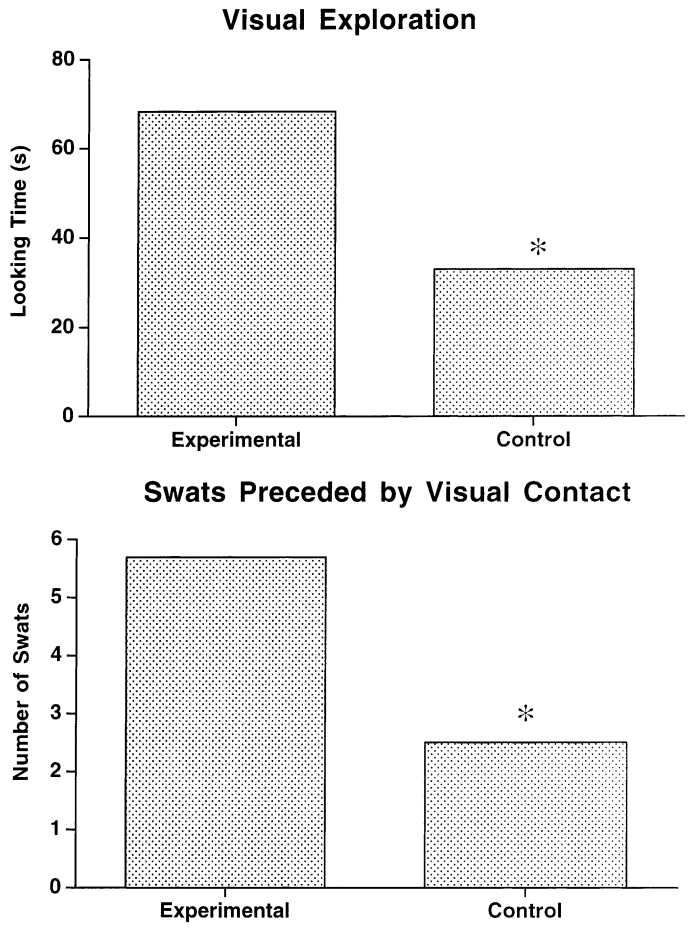

Fig. 2. Results of the prehension trials portion of the lab visit. The graphs show that the experienced infants looked at the objects more and produced more visually-coordinated swats than the inexperienced infants. An asterisk indicates significance at the $p < .05$ level.

These analyses showed that the infants in the experimental condition had higher Exploration percentages than the infants in the control condition, $F(1, 33) = 7.38$, $p < .05$, indicating that the experimental infants ($M = 47.6$, SD $= 28$) explored the objects orally and visually for a significantly greater portion of the trial than the control infants did ($M = 21.6$, SD $= 21.2$). The infants in the experimental condition also had greater Mouthing percentage scores than the infants in the control condition, $F(1, 33) = 6.80$, $p < .05$, indicating that the infants in the experimental condition ($M = 23.2$, SD $= 19.9$) spent a significantly greater portion of the trials engaging in oral exploration of the objects than the infants in the control condition did ($M = 8.1$, SD $= 12.8$). Although not quite significant, there was a trend for the infants in the experimental condition to have greater Looking percentage scores ($M = 30.0$, SD $= 25.8$) than the infants in the control condition ($M = 14.5$, SD $= 17$), $F(1, 33) = 2.97$, $p = .09$. Finally, there was significantly more switching between visual and oral exploration of the

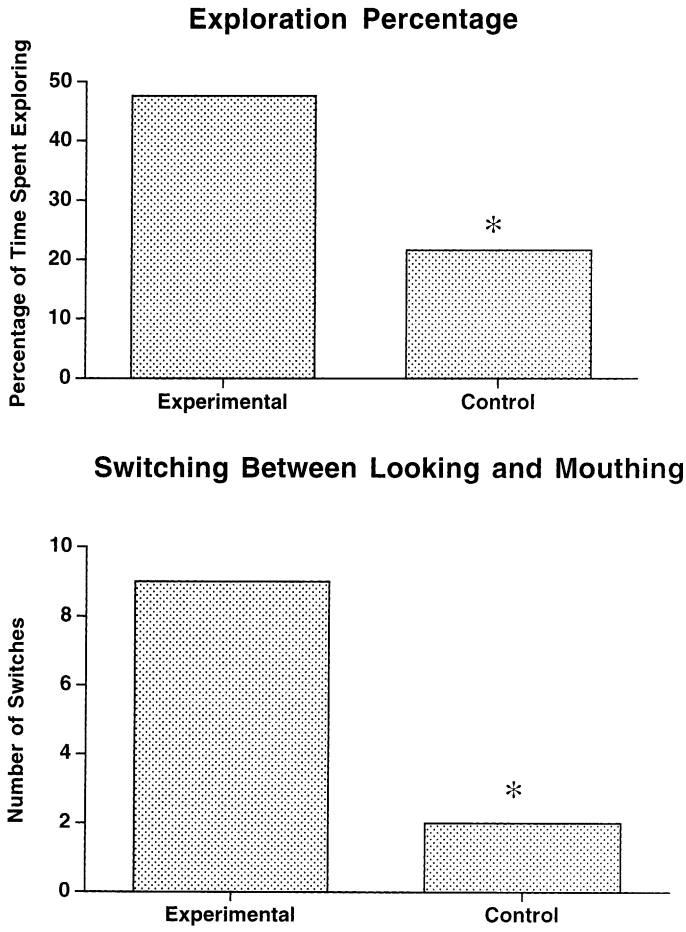

Fig. 3. Results of the object exploration portion of the lab visit. The graphs show that the experienced infants explored the teethers (both visually and orally) for a greater percentage of time and switched between visual and oral exploration more than the inexperienced infants. An asterisk indicates significance at the $p < .05$ level.

objects by the infants in the experimental condition ($M = 9.0$, SD $= 11.0$) compared to the infants in the control condition ($M = 2.0$, SD $= 3.0$), $F(1, 33) = 6.75$, $p < .05$.

4. Discussion

On almost every measure of object exploration and object-directed action obtained, infants who had the 2-week enrichment experience with the sticky mittens significantly outperformed their counterparts who did not have this experience. When seated at the table for the prehension tasks, the experienced infants looked at the objects significantly longer than the control infants both with and without the mittens. The experienced infants also swatted at the objects more during visual contact compared to the control infants whether or not they were wearing the

mittens. The fact that this finding held whether or not the infants were wearing the mittens suggests that the experienced infants were not just "trained up" on how to use the mittens to move the objects on the table. Rather, the enrichment experience may have increased their engagement in objects in general, and may have served as a motivator for initiating contact with objects in many situations.

When in the bouncy seat for the object exploration tasks, the experienced infants spent significantly more time exploring (visually and orally) the novel red teether objects than the control infants. The experienced infants spent significantly more time mouthing the objects and their levels of visual exploration during these trials were approaching significance. The experienced infants also switched between visual and oral exploration significantly more than the control infants, indicating that the experienced infants did not just explore more, but were employing exploration strategies that involved more coordination between oral and visual modalities.

Although the results show substantial differences between the infants who received the enrichment experience and those who did not, we do not yet know exactly what about the enrichment experience served to facilitate infants' object exploration skills. One possibility is that noticing the contingency between their own movements and the consequences of those movements for moving and transporting objects was the key reason for the behavior changes we observed. If this is true, then other manipulations that would give infants this same opportunity (e.g., simply connecting the objects to their hands using strings) should produce the same behavior changes. Alternately, the critical component of the experience we created could have been the additional practice bringing objects to the face for visual exploration or to the mouth for oral exploration. If this is true, then experiences in which the parent places objects in the infant's hands for transport to the eyes or mouth should also be effective. The experiences may also have functioned in this way because parents brought infants' attention to the objects in a more systematic fashion than they typically would have. If this is true, then infants tested in the same way as the experimental group in this study, except without the mittens, would show the same effects as we reported here. Finally, it may have been experience with the mittens on their hands that drew infants' attention to their hands and led to the changes in behavior we observed here (see, for example, White, 1971). If this last hypothesis is true, then the stickiness of our mittens was not actually essential, and infants wearing mittens without Velcro should experience the same facilitation as was observed in our current study. Our future research efforts will address these questions and we hope will reveal the exact nature of the effects of these experiences.

These findings lead to a number of conclusions about the development of infants' object exploration skills. First, they suggest that experience acting on objects may be a critical factor in increasing infants' engagement in objects and their object exploration skills. Not only do infants explore objects more after this experience, they employ more sophisticated object exploration strategies that involve more coordination between visual and oral exploration. It seems unlikely that the sticky mittens experience could have had much of a direct effect on infants' fine motor skills, as the mittens themselves would have prevented much fingering activity. It is possible, though, that the mittens experience had an indirect effect on fine motor skills: the mittens experience could have piqued the infants' interest in objects in general and they could have begun more detailed exploration of objects over the 2-week period of the experience sessions that would have facilitated the development of their fine-motor skills.

The fact that there were no significant differences in the infants' actions whether they were wearing the mittens or not suggests that the infants did not just become conditioned to wave their hands around more while wearing the mittens. Rather, the evidence supports the conclusion that the infants generalized what they learned while wearing the mittens to other situations in which they were not wearing the mittens.

One might wonder whether the experienced infants' increase in visual exploration in the prehension trials as compared to the control infants could be a result of those objects being familiar to the experienced infants. However, studies have typically found that increasing an infant's prior experience with an object *decreases* his or her attention to the object at a later time (Cornell, 1979; Fagan, 1970, 1971, 1973, 1974, 1977; Lasky, 1980; Martin, 1975; Rose, 1981; Rose & Slater, 1983). Furthermore, an increase in visual attention to objects for the experienced infants compared to the control infants was also found in the object exploration phase of the study, which involved completely novel objects. Thus, we conclude that the sticky mittens experience led to an increase in infants' engagement in familiar and unfamiliar objects.

One explanation consistent with the current results is that noting the contingency between their own movements and the consequences for object movement facilitate their engagement in objects in a variety of ways. How could this effect be conceptualized? First, one may think of it as a kind of decalage, because infants have already learned how their social actions (facial expressions, gestures, crying) bring about a whole variety of different "observable effects", or responses from the people around them (Adolph, Eppler, & Gibson, 1993; Gibson, 1988; Gibson & Pick, 2000). Of course, the specific ways in which they have an effect in the physical world are so different from the ways in which they have an effect in the social world that they are unlikely to have much 'savings' from one to the other (recall Adolph's (1997, 2000) findings on learning specificity).

Another experimental paradigm that has allowed infants to produce observable actions on objects before they would typically do so on their own is Rovee-Collier's conjugate reinforcement paradigm (see Rovee-Collier & Hayne, 2000). In this paradigm, a ribbon is tied to an infant's ankle and the other end is tied to a mobile stand. What happens in this situation is that infants' rate of leg kicks increases sharply. This is additional evidence that producing actions on objects with observable effects is highly reinforcing for young infants. It remains an open question whether this experience with leg-kicking and mobile-moving would generalize to producing actions with the hands on objects on a table (or objects placed in their hands). If experience moving mobiles did lead infants to become more engaged in objects earlier than they typically would, a strong case could be made for the role of producing actions with observable effects on objects on increases in infants' object attention. It seems possible to us, however, that these two situations would seem so different to these young infants that they would not make the connection between the two.

What are the functions or consequences of infants' increased object exploration? There could be many consequences, of course, but one hypothesis we are investigating is that as infants explore objects more actively, they learn the relation between object features and object boundaries. That is, as they explore objects more actively, they may come to realize that object boundaries exist where there are abrupt changes in an object's shape, color, and pattern. Our lab has already produced evidence that infants who employ more active exploration strategies (exploring more, switching more between oral and visual modalities of exploration) are better

able to segregate a visual display into its component parts, as compared to infants who employ less active exploration strategies (Needham, 2000). If it is the case that the active exploration strategies are a key factor in the development of these segregation abilities (presumably as a result of their learning about object properties), then we would predict that infants who have the sticky mittens experience should have advanced exploration skills and, as a result, advanced object segregation skills.

In this framework, we believe that multimodal exploration could serve the special function of amplifying some information, making it easier for infants to attend to it. For example, object shape is available visually, orally, and haptically, whereas color and pattern are only available visually. Because research from our lab has shown that young infants use shape to segregate objects prior to the time that they use color and pattern (Needham, 1999b), our future research will explore the idea that one reason for this difference is that shape is available multimodally whereas color and pattern are not.

These findings give us a glimpse into the processes underlying the development of infants' exploratory skills: specifically, they show that experience acting on objects is an important contributor to the increase in object attention and object exploration that is typically observed by 6 months of age. Although infants typically receive this experience around 4.5–5 months of age, when they do receive it earlier, their object attention and object exploration skills are enhanced. These findings highlight the interrelations between developments in different areas and add to the growing body of research that shows important linkages between infants' perceptual, cognitive, and action-based abilities (e.g., Adolph, 1997, 2000; Gibson & Pick, 2000; McCarty, Clifton, & Collard, 1999, 2001). Future work will provide a better understanding of the complex interdependencies between these abilities as they develop during the first year of life.

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