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Effects of Contingent Reinforcement of Actions on Infants' Object-Directed Reaching

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The role of contingency learning was examined in 3-month-old infants' reaching movements. Infants in the experimental group experienced 9 min of active training during which they could move their arms in a reach-like fashion to pull and move a mobile. Infants in the control group experienced 9 min of passive training during which they watched a mobile move. Prior to (pre-training) and following the mobile experience (post-training), infants in both conditions were given an opportunity to interact with a rattle placed within and out of their reach. Compared with infants in the control condition, infants in the experimental condition produced reach-like movements more frequently during the mobile experience; they also showed a greater increase in reaching attempts from pre- to post-training assessments with the rattle. These findings show that reinforcement of arm extensions and retractions increases the frequency of infants' reaching behaviors. This result suggests that the reinforcement of components of infants' behaviors may

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contribute to the successful assembly of these behaviors. This process could help keep infants engaged during the lengthy transition from prereaching to independent reaching.

The contingencies we experience yield consistent and predictable relations between our actions and the consequences brought about by those actions. Learning and responding to these contingencies form the basis of our interactions with objects and people. Changing our behavior in response to a contingency allows us to maximize benefits and minimize costs encountered in the environment (Rovee-Collier, Morrongiello, Aron, & Kupersmidt, 1978).

Infants are keen learners of contingencies. Some of the earliest research on infant learning documented young infants learning that turning their heads in a particular direction produced a squirt of sugar water (Siqueland & Lipsitt, 1966) or the appearance of interesting pictures (Caron, 1967). Watson (1966) described his son learning an artificial contingency (eye gaze and fist opening), which eventually appeared to generalize to learning a natural contingency (using his legs to bounce in a bouncy chair). More recently, DeCasper and Spence (1986) found that newborns could learn to change their sucking behaviors to hear a recording of a familiar, preferred story over a novel story. Rovee-Collier and colleagues showed that in addition to figuring out that kicking their legs made an overhead mobile move and jingle (Rovee & Rovee, 1969), infants could learn to identify which of their legs caused the mobile to move, responding quickly when the leg controlling the mobile's movement changed to the other leg (Rovee-Collier et al., 1978). Thus, it is not surprising that various aspects of development have been hypothesized to depend upon contingency learning (Bigelow, 1998; Dunham & Dunham, 1990; von Hofsten, 2004; Murray & Trevarthen, 1986; Nadel, Carchon, Kervella, Marcelli, & Réserbat-Plantey, 1999; Thelen, 2005). Here, we focus on the possibility that contingency learning might facilitate motor development in young infants. In particular, we examine the role of contingency learning in the beginnings of reaching movements.

We focus on reaching because it is one of the earliest motor skills to develop, and its emergence ushers in a new learning landscape. The visual world provides fertile ground for active exploration and learning beginning immediately after birth, and it serves as a strong motivator for reaching (Thelen, 2005). We know that infants who are blind reach for sounding objects several months later than typically developing infants, consistent with the idea that visual stimuli serve as motivation for infants' reaching (Bigelow, 1986; Fraiberg & Fraiberg, 1977).

Similar to contingency learning, the development of the behaviors contributing to reaching (arm extensions, grasping) begins early in life.

Reaching movements begin prenatally, when fetuses produce arm movements that result in their hands hitting the uterine wall (Sparling, Van Tol, & Chescheir, 1999). Soon after birth, infants engage in more forward-directed arm/hand extensions that come closer to objects when they are fixating on the objects than when they are looking at other things (Ennouri & Bloch, 1996; von Hofsten, 1982). These actions must in some way be related to the object (because they are dependent on the presence of the object), although it is not clear whether newborns actually “reach for” these objects in the same purposeful way that older infants do.

In order for reaching to be considered goal-directed, infants must have a goal in mind when planning and guiding their actions. How infants turn intention into action was the focus of a groundbreaking paper by Thelen et al. (1993). This study revealed that each infant has a unique problem to solve when determining how to most effectively transport his or her hand to an object because individual infants begin this transition with different levels of ambient activity. Infants with high levels of baseline activity must dampen down the movements of their wildly flapping arms to move their hands to the exact position in space occupied by the object. In contrast, infants with low levels of baseline activity must energize their arms sufficiently to transport their hands all the way to the object's location. These findings make it clear that reaching cannot be considered a preprogrammed set of movements, because the specific movements required for reaching are different depending on each infant's baseline level of activity prior to beginning his or her progression toward a successful reach. These findings, along with others that have shown substantial cultural differences in the average age of attainment of different motor milestones (see Adolph, Karasik, & Tamis-Lemonda, 2010 for a review), indicate that infants' experiences are critically important for the progression of motor development.

In addition to the kinds of opportunities infants have for learning, research has shown that the context in which reaching takes place contributes in substantial ways to the production of independent reaching movements. This research has shown the effects of body position and postural support on infants' reaching movements (Kawai, Savelsbergh, & Wimmers, 1999; Rochat, 1992), making it clear that trunk support, gravity, and muscle strength exert important influences on the frequency and quality of reaching movements that infants produce.

Because the transition into independent reaching is a prolonged process that varies across infants, a reasonable next question to ask is how infants' experiences during this period of time shape the transition itself. In particular, the protracted nature of the transition into reaching raises questions about how infants maintain the motivation to practice these actions sufficiently until they become successful independent reachers (von Hofsten,

2004; Thelen et al., 1993). One possible candidate is contingency learning: Infants begin noticing the consequences their actions have on nearby objects, and these observations are rewarding. As the principles of operant conditioning predict, behaviors that result in desirable outcomes increase in frequency, so object-directed actions would be produced in greater numbers. This possibility is supported by findings from previous research that suggest infants enjoy learning about contingent relationships. Infants who were able to control the onset of a slide show with their arm-pulls showed more expressions of excitement, enjoyment, and interest compared with infants whose actions were not related to the onset of a slide show (Lewis, Alessandri, & Sullivan, 1990; Sullivan & Lewis, 1989). In contrast, infants showed anger and frustration when a contingency was removed (DeCasper & Carstens, 1981; Shapiro, Fagen, Prigot, Carroll, & Shalan, 1998; Sullivan & Lewis, 2003).

There is reason to believe that contingency learning is sometimes specific to the perceptual context in which the contingency was learned (Borovsky & Rovee-Collier, 1990), and sometimes less so (Rovee-Collier & DuFault, 1991). What are the conditions under which contingency learning can be generalized? Although various models have been proposed to explain the principles behind contingency learning (De Houwer & Beckers, 2002), the models agree on the importance of factors such as understanding the statistical and causal relationship between events. Learning to reach for an object, for example, may start with the observation that more frequently producing arm movements directed toward an object results in more frequently contacting the object. As infants begin to experience successful contact with an object, they may also learn that it is not the case that the two events (arm movements and contacting the object) merely co-occur; it is the case that one event (arm movements) causes the other event (contacting the object) to take place. This understanding, in turn, may lead to the realization that the actions are useful in bringing about other consequences, leading to a generalization of reaching movements.

Researchers have also made this point through designing experiments that systematically vary infants' experiences to observe the consequences for the development of infants' motor skills (Libertus & Needham, 2010, 2011; Needham, Barrett, & Peterman, 2002; Zelazo, Zelazo, & Kolb, 1972). The logic of these studies rests on the fact that experience reaching for and grasping objects is provided just prior to the time infants would normally be able to engage in reaching for objects independently. Thus, we can look specifically at the effects of this experience.

In one study, 3-month-old infants were given early reaching experience using "sticky mittens" (Libertus & Needham, 2010). The palms of the sticky mittens were covered in Velcro and they were used in conjunction with light-

weight toys that had edges covered in the corresponding Velcro. Infants needed only to swipe at the toys to pick them up with the sticky mittens and move the toys through their visual fields. The infants in the experimental condition participated in daily play sessions featuring sticky mittens for about 2 weeks; the infants in the control condition received similar play sessions in which they wore plain mittens, and the lightweight toys were moved by an adult rather than through infants' own movements. After 2 weeks, the infants in the experimental condition showed significant increases in independent reaching, grasping, and exploration of toys compared with the infants in the control condition. This is further evidence that infants' experiences can substantially alter the kinds of motor behaviors they engage in as well as the timing of the emergence of such behaviors.

As the research discussed above makes clear, there are many reasons to believe that learning facilitates infants' transitions into independent reaching. However, we do not know how, specifically, learning helps different motor abilities develop. One possibility is that the advances, after sticky mittens training, in reaching, grasping, and object exploration were largely caused by experiencing contingency between the movements of their own hands and the movements of the toys attached to their mittens. However, the motor consequences of contingency learning have not been studied. Further, there is no evidence about whether the kind of learning that influences infants' motor skills is limited to the perceptual context in which they learned specific actions. In the current experiment, these gaps in the literature are addressed.

Three-month-old infants were tested because at this age infants are not yet reaching independently but they can benefit from training in reaching and they are able to quickly recognize contingent relationships between their actions and external consequences. All of the infants in this experiment received identical pre- and post-training trials in which their visual and manual exploration of a rattle were assessed. Between these two phases of the study, infants in the experimental condition received contingent reinforcement of their arm movements: a ribbon was attached to their right wrists and the ribbon was kept taut so that when they bent their elbows, a mobile, which hung from a microphone stand, moved and rattled. The infants in the control condition also had their wrists attached via a ribbon to a stand, but this stand was empty. The mobile hung from an adjacent stand and an experimenter moved the mobile surreptitiously. It was expected that infants in the experimental condition, who received contingent reinforcement for their arm movements during the mobile experience, would show bigger differences between pre-training and post-training measures of object-directed actions compared with the infants in the control condition, who did not receive contingent reinforcement.

METHOD

Participants

Thirty-eight full-term infants (19 females) participated in the current study. Nineteen 3-month-old infants ($M_{\text{age}} = 89.58$ days, range = 80–105 days) participated in the experimental condition. These infants' arm movements produced contingent movements in the mobile hanging in front of them. An additional nineteen 3-month-old infants ($M_{\text{age}} = 89.63$ days, range = 74–105 days) participated in the control condition. These infants passively viewed an experimenter produce movements in the mobile.

Birth records were obtained for infants born in the Nashville, TN area. Families were contacted via home telephones, and parents were informed of the opportunity to participate with their infants in a research study. Infants received a small gift (i.e., a rubber duck or a rattle) as a token of appreciation for their participation.

Data from an additional 16 infants were collected but excluded from analyses. Data from ten of these infants were not included in analyses due to fussiness, sleepiness, or disinterest in the training procedure. Data from four infants were excluded due to equipment failure (three because the ribbon was not taut enough, one due to a camera angle that prevented coding). Lastly, the experiment was disrupted and led to the data from two infants being excluded from analyses. This attrition rate is not out of the ordinary for studies involving a procedure this long and demanding with infants this young (Angulo-Kinzler & Horn, 2001; Gerson & Woodward, 2014).

Apparatus

Throughout the study procedure, infants were seated on a parent's lap in front of a kidney bean shaped table. The table measured 180 centimeter at its widest part, 74 centimeter across, and the diameter of the cutout (where the parent and infant were seated) was roughly 64 centimeter. During the mobile training experience, the parent's chair was pushed back from the table to provide more space (Figure 1). Two standard microphone stands stood on the opposite side of the table. A brightly colored wooden mobile (Beetles and Bees Wooden Ceiling Mobile by Handelshaus G. Gollnest & F. R. Kiesel KG) hung from one of the microphone stands. Weights were placed on the bases of the microphone stands to stabilize them. In the experimental condition, one end of a ribbon was connected to the infant's wrist via a custom-made wristlet, and the other end of the ribbon was tied to the mobile. In the control condition, one end of the

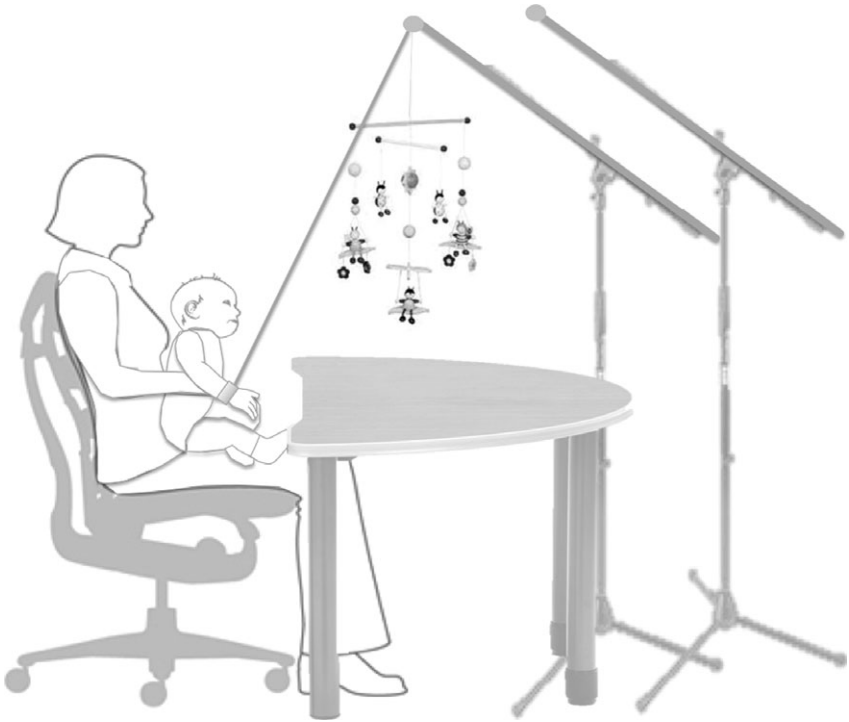


Figure 1 Infants were seated on their parents' laps facing the mobile and microphone stands. A ribbon connected infants' right wrist to the microphone stand from which the mobile hung (experimental condition) or the empty microphone stand (control condition).

ribbon was connected to the infant's wrist, and the other end of the ribbon was tied to the empty microphone stand. When the infant was seated and the mobile was in place, the infant's face was about 69 centimeter from the mobile (Figure 1).

For the pre- and post-training assessments of object interest, the parent's chair was scooted forward so that the infant's arms rested on the surface of the table. A brightly colored plastic rattle (Sassy Flip and Grip Rattle, Figure 2) was used for the object exploration portions of the session. The rattle was approximately 10×7 centimeter and composed of an easily graspable handle and a clear sphere. A disk featuring an image of a zebra's face on one side and a mirror on the reverse side spun inside the sphere when the rattle was moved. Additionally, four small plastic balls inside the rattle made noise when it was moved.



Figure 2 Rattle used to assess infants' object exploration behaviors before and after the mobile training experience.

Four mounted video cameras recorded infants' behaviors: one camera was mounted on the ceiling and captured a top view of the table surface, one camera was directly across the table from participants and captured infants' faces and hands during the study, one camera captured a table-level side view, and one camera captured a side view from approximately an adult's eye-level. The two cameras located on the left and the right sides of the table were 1/3 inch Sony Super HAD CCD High Resolution Hood Color IR Day/Night cameras. The two cameras located above and in front of the table were Lorex Color Pro-Style surveillance cameras (model CVC 8001). Video feeds from these four cameras were mixed into a single image and recorded as a video file on a MacBook laptop computer. Coders were able to use all four perspectives when assessing infants' object exploration (during pre- and post-training measures) and pulls on the mobile (during the training experience). The front and above camera views tended to be most informative in coding behaviors during the pre- and post-training assessments. In contrast, the front and right camera views were most informative when coding pulls on the mobile because the infant was facing the front camera and the ribbon was attached to the infant's right arm.

Procedure

Object exploration assessments were completed directly before (*pre-training*) and after (*post-training*) the mobile experience. Each infant was seated on his or her parent's lap throughout the study. During assessments of object exploration, the chair in which the parent sat was scooted forward so that the infant could rest his or her arms comfortably on the table. The experimenter asked parents to hold their infants' midsections firmly to support

their torsos, which allowed infants to remain in an upright, seated position during the pre- and post-training assessments.

Infants' visual, manual, and oral exploration of a rattle was assessed at three different locations for 30 sec each (adapted from Libertus & Needham, 2010). First, the experimenter set the rattle on the table outside of the infant's reach (approximately 20 centimeter from the infant's hands). The experimenter drew the infant's attention to the rattle by pointing to it and saying, "Look! What is this? Do you want this? Can you get it?" Next, the rattle was placed near the infant, but far enough away that the infant had to reach to touch it (approximately 5 centimeter from the infant's hands). As before, the experimenter called attention to the rattle by gesturing toward it and verbally encouraging the infant to explore it. Lastly, the experimenter placed the rattle in the infant's hand, arranging his or her fingers and thumb to ensure the rattle was securely grasped. If the infant dropped the rattle, the experimenter picked it up and placed it in the infant's hand again, ensuring that the infant held the rattle for a total of 30 sec.

The chair in which the parent sat was rolled back from the table during the mobile training phase of the study to allow more space for this portion of the study, and the mobile was hung up on the microphone stand. The experimenter secured the ribbon around the infant's right wrist with a Velcro cuff. In the experimental condition, the other end of the ribbon was tied around the top loop of the mobile so that the ribbon was taut. The experimenter moved the infant's hand four times to demonstrate that arm movements caused contingent movements in the mobile.¹ After this demonstration, the mobile experience lasted 9 min during which infants could independently control the movement of the mobile. In the control condition, the other end of the ribbon was tied to the empty microphone stand. The experimenter sat in a chair behind the infant and parent and manipulated the mobile, producing approximately the same amount of mobile movement as infants in the experimental condition during the 9-min experience. To determine precisely when the experimenter should move the mobile in the control condition, we recorded the pulls of the first eight participants in the experimental condition, and then we averaged their number of pulls for each of the 9 min of training. A random number generator was used to determine precisely when, within each minute, the experimenter would produce each pull. At the end of the mobile training

¹These demonstrations were not done for the infants in the control condition because there was no contingency between their movements and the movement of the mobile for them to learn. Although it is possible that this difference could be responsible for the increased amount of pulling observed over the 9 min of training, it seems unlikely that this could be the case.

phase, the experimenter removed the mobile from the microphone stand and placed it on the floor, out of the infant's view.

Measures

The pre-training and post-training assessments were video recorded and stored as digital files for off-line coding. From these files, infants' visual, manual, and oral exploration of the rattle were coded frame by frame using Stop Frame Coding (Libertus, 2008). These measures consisted of the total duration that infants spent in *visual contact* (looking at the rattle), *manual contact* (any touching of the rattle with hand or fingers), *oral contact* (any contact between the rattle and the infant's mouth, including brief contact with lips), *bimanual exploration* (contacting the rattle with both hands simultaneously), and *looking toward the experimenter* (making visual contact with the experimenter's body or face). Additionally, durations of infants' reaching behaviors were coded for the portion of the trials in which the rattle was placed outside of and within the infant's reach. *Reaching* was defined as movement of the hand and arm in the direction of the rattle. Contact with the rattle was not required for movements to be coded as a reaching.

The mobile experience was also video recorded. The frequency of infants' reach-like arm movements (or pulls), which produced movements in the mobile for infants in the experimental condition, was coded for all infants throughout the 9-min training experience. A *pull* was defined as a movement of the arm away from the mobile that returned at least partly to its starting position.

To assess inter-rater reliability, two experimenters coded a subset of ten randomly-selected participants. The experimenters agreed on 94.28% of measures during the pre- and post-training assessments and 84.13% of instances of pulling movements during the mobile experience.²

RESULTS

Mobile experience

First, to examine the effects of contingency learning on reach-like movements, we compared the number of pulls produced by infants during the 9-min mobile experience. A between-groups *t*-test revealed that infants in

²A small subset of the sample was re-coded by research assistants blind to the conditions infants were participating in. The blind coders and previous coders agreed on 95.50% of reaching during pre- and post-training assessments and 91.10% of pulling movements.

the control condition ($M_{con} = 123.79$, $SD_{con} = 27.44$) produced fewer pulls throughout the training experience than those in the experimental condition ($M_{exp} = 165.84$, $SD_{exp} = 39.24$), $t(32.21) = -3.83$, $p < .001$, 95% CI, $[-64.42, -19.68]$. This condition-related difference suggests that infants in the experimental condition recognized and responded to the contingency between their arm movements and movement of the mobile (Figure 3).

Object exploration assessments

Next, to examine the effects of contingency learning on exploratory behaviors, we used a repeated measures MANOVA to assess potential differences in infants' pre- and post-training object exploration behaviors in each condition. Phase (pre- or post-training) was entered as a within-subjects factor, and condition (experimental or control) was entered as a between-subjects factor. Six dependent variables, all of which measured durations, were tested: looking toward the rattle, manually contacting the rattle, engaging in bimanual exploration of the rattle, looking toward the experimenter, engaging in oral exploration of the rattle, and reaching toward the rattle.

As shown in Table 1, in general, the MANOVA revealed no differences between the two training phases or between the two conditions. For visual

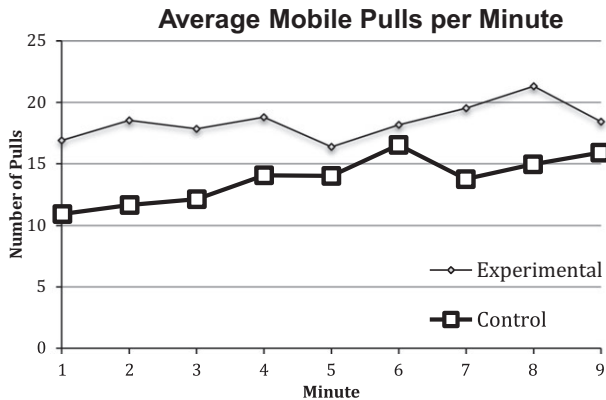


Figure 3 Average number of pulling movements produced by infants in the experimental and control conditions throughout the mobile training experience. Although the infants in the experimental condition pulled the mobile more across the 9 min of training than the infants in the control condition, the experimental ($M_{diff} = 1.78$, $SD_{diff} = 6.26$) and control groups ($M_{diff} = 3.32$, $SD_{diff} = 5.01$) did not differ in how they increased their pulls across the 9 min of mobile experience, $t(36) = -.83$, $p = .409$, 95% CI $[-5.26, 2.19]$.

TABLE 1
 Durations of Object Exploration Behaviors

	<i>Experimental condition</i>			<i>Control condition</i>		
	<i>Pre-training</i>	<i>Post-training</i>	<i>Difference score</i>	<i>Pre-training</i>	<i>Post-training</i>	<i>Difference score</i>
Looking at rattle	31.21 (16.54)	33.45 (20.45)	2.24 (19.23)	33.05 (20.89)	32.22 (18.44)	-0.84 (16.08)
Manual contact with rattle	31.97 (6.65)	31.56 (7.06)	-0.42 (10.49)	34.13 (7.60)	32.87 (7.30)	-1.25 (9.48)
Bimanual exploration of rattle	2.80 (5.76)	2.31 (6.59)	-0.49 (8.95)	3.06 (5.53)	1.66 (2.93)	-1.40 (6.60)
Looking at experimenter	22.52 (14.64)	21.02 (17.56)	-1.49 (19.56)	13.34 (9.07)	11.21 (8.04)	-2.13 (8.16)
Oral exploration of rattle	1.10 (2.11)	1.01 (3.20)	-0.09 (4.06)	1.24 (2.31)	0.66 (1.12)	-0.58 (2.37)
Reaching toward rattle	6.59 (4.79)	10.69 (5.33)	4.10 (3.55)	4.94 (3.99)	6.14 (4.88)	1.20 (4.08)

Note. The parenthetical values denote standard deviations. Difference scores are post-training measures minus pre-training measures.

contact with the rattle, we found no evidence of main effects for phase, $F(1, 36) = .06$, $p = .808$, $\eta_p^2 = .002$, or condition, $F(1, 36) = .003$, $p = .957$, $\eta_p^2 = .000$, or an interaction between the two factors, $F(1, 36) = .29$, $p = .596$, $\eta_p^2 = .008$. For manual contact with the rattle, we found no main effects for phase, $F(1, 36) = .27$, $p = .610$, $\eta_p^2 = .007$, or condition, $F(1, 36) = 1.09$, $p = .304$, $\eta_p^2 = .029$, or an interaction between the two factors, $F(1, 36) = .07$, $p = .798$, $\eta_p^2 = .002$. For bimanual exploration, we found no main effects for phase, $F(1, 36) = .55$, $p = .464$, $\eta_p^2 = .015$, or condition, $F(1, 36) = .03$, $p = .869$, $\eta_p^2 = .001$, or an interaction between the two factors, $F(1, 36) = .13$, $p = .723$, $\eta_p^2 = .004$. For the amount of time infants spent looking toward the experimenter, we found no main effect for phase, $F(1, 36) = .56$, $p = .461$, $\eta_p^2 = .015$, or a phase by condition interaction, $F(1, 36) = .02$, $p = .897$, $\eta_p^2 = .000$. There was a main effect of condition, $F(1, 36) = 7.7$, $p = .009$, $\eta_p^2 = .176$, which was due to the infants in the experimental condition spending more time looking toward the experimenter compared with the infants in the control condition. There was no interaction associated with this effect, and it seems to reflect random individual variations more than effects of the experimental manipulation (see means and standard deviations in Table 1). For example, one participant in the experimental condition looked at the experimenter for a total of 105 sec, whereas none of the participants in the control condition looked at the experimenter longer than a total of 44 sec. Lastly, for oral exploration of the rattle, we found no main effects for phase, $F(1, 36) = .40$, $p = .533$, $\eta_p^2 = .011$, or condition, $F(1, 36) = .04$, $p = .845$, $\eta_p^2 = .001$, or an interaction between the two factors, $F(1, 36) = .21$, $p = .652$, $\eta_p^2 = .006$.

However, the mobile training experience did influence one critical aspect of infants' object-directed behavior: reaching toward the rattle, a behavior that is motorically similar to what was reinforced during the mobile training experience. The MANOVA yielded main effects for both phase, $F(1, 36) = 18.21$, $p < .001$, $\eta_p^2 = .336$, and condition, $F(1, 36) = 4.78$, $p = .035$, $\eta_p^2 = .117$, as well as an interaction between the two factors, $F(1, 36) = 5.45$, $p = .025$, $\eta_p^2 = .131$. This interaction was due to a significant increase in reaching movements between the pre- and post-training phases for the infants in the experimental condition, $t(18) = 5.03$, $p < .001$, 95% CI [2.38, 5.81]. No such increase was found for the infants in the control condition, $t(18) = 1.28$, $p = .217$, 95% CI [-.77, 3.18]. On average, the duration of infants' reaching (collapsed across the rattle locations) from pre- to post-training assessments increased about 4 sec. In contrast, infants in the control group produced about one additional second of reaching during the post-training assessment compared to the pre-training assessment.

To further explore the effects of contingency learning, we created two linear models to best predict the number of reaches that infants in the experimental and control conditions should make throughout the post-training assessment based on their pre-training assessment reaching durations (Figure 4).³ These linear models enable us to estimate the duration of an infant's reaching during the post-training assessment based on (1) condition assignment (experimental or control) during training, and (2) the infant's reaching behavior prior to the mobile experience, during the pre-training assessment. For each model, the intercept represents the average increase in duration of reaching from pre-training to post-training assessments, and the slope shows the relation between the amount of reaching in pre-training and the amount of reaching in post-training.

The linear models for the control and experimental conditions have different intercepts, but the fit of the linear models did not improve when different slopes were introduced in addition to the different intercepts, $F(1, 33) = .787, p = .381$. For both conditions, the slope of the line is .759. The intercept for the control condition is 1.65, and the intercept for the experimental condition is 5.69. The intercepts are significantly different, $t(34) = 4.00, p < .001$, meaning that the duration of infants' reaches increased differentially from pre-training to post-training assessments between the two groups. This finding replicates the results of the MANOVA analysis above. In other words, the mobile experience prompted the infants in the experimental condition to produce more reach-like movements than the infants in the control condition, controlling for how much infants reached during the pre-training phase.

DISCUSSION

The results of this experiment reveal that 3-month-old-infants' reaching movements can be increased by experience with contingent reinforcement of reaching movements. In our study, the reach-like behaviors of the infants in the experimental condition were reinforced by the movements of a mobile that was attached to their wrist via a ribbon. In contrast, the infants in the control condition saw the same amount of mobile movement as the infants in the experimental condition, but they were not in control of this movement. Before and after the mobile training regimen, all infants

³One participant's data was excluded from analysis because the data point was 4.57 standard deviations away from the linear model created to predict post-training reaching based on pre-training reaching in the control condition. The explanation above does not include this participant's data point. (The same results were obtained when this data point was included, but the p -value is reduced when this point is excluded.)

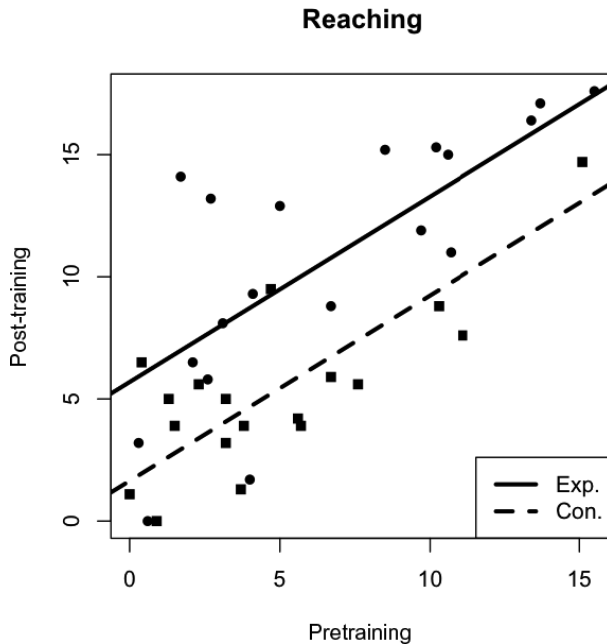


Figure 4 The x-axis indicates the duration of reaching behavior during the pre-training assessment of object exploration, while the y-axis indicates the duration of reaching after the training experience, during the post-training assessment. Therefore, each point plotted on this scatterplot indicates an infant's pre- and post-training reaching behaviors. Circles show values for the individual infants in the experimental condition and squares show values for the individual infants in the control condition. The linear model for the experimental group (solid line) can be used to predict how much reaching an infant in the experimental condition would engage in based on his/her pre-training reaching behavior. Likewise, the dashed line can be used to estimate an infant's reaching behavior after participating in the control condition.

received a rattle to explore freely. The increase in reach-like movements after the mobile training experience was greater for the infants in the experimental condition compared with the infants in the control condition.

These results allow us to rule out two alternative explanations for the findings: that the changes in infants' behaviors were only due to arousal from seeing the mobile move, and that infants had learned contingencies without learning something about causal relationships. First, it is unlikely that the findings reflect a generally elevated level of arousal from watching the mobile move. If infants were simply aroused by the mobile, then we

should expect infants in both conditions to show similar levels of activity during the mobile training experience. Infants in both conditions observed the same interesting outcome of seeing the mobile move, at the same rate of movement. They were also able to produce the same actions without any restriction. However, infants' activity level did not appear to result from arousal: The infants in the experimental condition showed more activity than the infants in the control condition. Additionally, if infants were simply aroused by the mobile experience, then we should expect infants to show increases in most, if not all, measures of behavior. Again, this was not what was found. Infants showed increases in reach-like movements only (the same behaviors that were reinforced during the mobile experience), and the infants in the experimental group (those who had an opportunity to learn about the causal relationship between their own actions and external events) showed a greater increase in reach-like behaviors than the infants in the control group.

Second, it is not likely that the findings suggest that infants had learned to simply move their arms more without learning about causal relationships to some degree. The reinforcer (mobile moving in a contingent fashion) was present only during the mobile training experience; it was removed immediately afterward and was absent during the post-training phase. Still, even without the reinforcer, infants in the experimental condition continued to move their arms in a reach-like manner in the presence of a new goal object, the rattle. If infants had simply learned to move their arms more without learning the causal relationship between their arm movements and a goal, then infants should show a decrease in arm movements when the reinforcer disappeared. However, infants in the experimental condition continued to show higher rates of reach-like movements, suggesting that they had learned something about the relationship between actions and goals. The results from the current study showed that when infants experienced rewarding consequences from their actions, those actions increased in frequency and continued being produced at a higher frequency even after the contingent reinforcement was no longer in effect (i.e., the mobile was not visible during the post-training assessment). This outcome persisted even when the infants were faced with a stimulus not involved in training.

These results may provide insight into the challenging question of why infants continue to try to engage in a motor behavior that they are not yet capable of performing successfully. Infants' attempts at prehensile acts (e.g., moving their arms in the direction of objects) sometimes result in interesting outcomes, even if they are not the original goal of their actions. Opportunities for such experiences could happen when an infant swats near dangling toys while in an infant gym or car seat. The discrete

components of prehensile acts (e.g., just the reach toward the object) might increase in frequency as a result of experiencing these interesting contingent movements of objects and ultimately lead to a fully successful prehensile action being assembled over time.

Factors other than outcomes contingent upon infants' own actions are likely to contribute to infants' motivation to continue to attempt reaching behaviors. This motivation could be provided in part by the object itself—objects are enticing, and curious infants want to explore them (Gibson, 1988). Long ago, Gesell (1934) reported that prereaching infants sometimes engaged in lengthy bouts of gazing at a dangling, red ring before they were capable of contacting it themselves. Infants may also be prompted by their observations of the actions of others in their environment, imitating goal-directed reaching (Hamlin, Hallinan, & Woodward, 2008).

The results of the current study also clarify that experience with contingent reinforcement is not, in itself, sufficient to boost infants' object exploration. In prior research, infants in this same age range were trained with a different kind of contingent reinforcement with a substantially different outcome. In these studies, infants received experience using “sticky mittens,” which delivered a different form of contingent reinforcement than that received by infants in the current study (Needham et al., 2002). In the sticky mittens paradigm, infants are shown once or twice how to use the mittens to swipe at lightweight toys that stick to the mittens. Thus, infants receive visual-proprioceptive feedback as they move their hands to the locations of the toys, “pick up” the toys, and move them through space. Infants can simultaneously hear and see the movement of the toys and see and feel the movement of their hands and arms. This contingency between actions and goals is presumably stimulation that infants' perceptual-motor systems “expect” to receive early in development, although not quite as early as they are receiving it here (Greenough, Black, & Wallace, 1987).

After receiving sticky mittens experience, infants showed a number of differences when compared with infants who received no prior experience (Needham et al., 2002) or prior experience in which infants had their attention drawn to objects that the experimenter moved for while the infants passively watched (Libertus & Needham, 2010, 2011). Regardless of which comparison group is used (the group that received no prior experience or the group that received passive experience looking at objects and wearing nonsticky mittens), the infants who had sticky mittens experience engaged in more visual and tactile exploration of objects (even those unrelated to their training experience), began independently reaching for objects earlier, and showed an enhanced preference for photos of human

faces over photos of toys. Many of these effects involve enhanced attention to objects that could result in increased opportunities for learning about objects after sticky mittens training. However, in the current research, this increase in focus on objects was not observed. What are the critical differences in these two kinds of contingent reinforcement?

The differential changes in infants' behaviors resulting from these two types of experiences (using sticky mittens to interact with objects and moving their arms to pull on a mobile) indicate that the main explanation for these effects cannot be simple exposure to stimulation contingent upon their own movements. Prior to the current study, one possible explanation for why the sticky mittens experience positively affected infants' object exploration was that it resulted from exposure to object movement contingent with their own body movements. Previous studies have shown that infants seek out more information from visual displays after experiencing contingent social interactions than after experiencing noncontingent social interactions (Dunham & Dunham, 1990; Dunham, Dunham, Hurshman, & Alexander, 1989). However, the fact that exposure to contingent movements of objects linked to their own body movements in this study did not result in major changes in infants' object exploration indicates that exposure to contingency could not have been solely responsible for the previous effects of sticky mittens experience.

One possible explanation for the difference in these two sets of findings is that it might be easier for infants to understand the causal relationship between their own actions and the movements of toys when they produce movements using sticky mittens than when they produce movements by moving their arms to pull the ribbon that is attached to a distant mobile. There may be a gradual progression in infants' understanding of the relationship between objects and actions, and the sticky mittens experience might highlight this relationship more saliently than the mobile experience due to the physical proximity between infants' hands/arms and objects (Cohen & Amsel, 1998). Or, it may be that the sticky mittens experience is more similar to everyday action experience than the mobile training experience, and thus sticky mittens training may be more likely to help infants learn about causal relationships (Rakison & Krogh, 2012). These possibilities are supported by previous work on infants' perception of causality in launching events, with the latter study conducted using sticky mittens to investigate infants' enhanced perception of causal events (Rakison & Krogh, 2012).

An explanation for these findings that focuses more on motor development is that experience using the sticky mittens to contact objects provides infants with valuable practice controlling the movement of their arms and hands as they approach the toy (Thelen et al., 1993). As Thelen, von

Hofsten, and their colleagues discovered, infants' transitions into reaching are gradual processes, and it is often necessary for infants to engage in real-time correction as they approach objects with their hands with the goal of grasping them (von Hofsten, 1991; Thelen et al., 1993). Thus, perhaps using the sticky mittens to obtain objects facilitates the development of infants' abilities to control the movements of their hands toward toys. In contrast, although infants in this study increased the durations of their full-arm reaching movements, they did not have a reason to monitor their hand movements closely and therefore would not have received practice with this kind of careful monitoring of their hand and arm movements.

Another possibility is that experience with sticky mittens is useful for encouraging reaching attempts that lead to the development of successful grasping because prehension requires attention to multiple aspects of a task simultaneously: An independent reacher must approach the object in the correct object location and the correct distance from his or her body while simultaneously opening and closing his or her hand at the appropriate time to actually capture the object. Sticky mittens practice allows babies to focus on the placement of their hand(s) in space and the movement of the hand(s) toward the object. Having the opportunity to practice focusing on this part of the action may facilitate subsequent successful contact with objects that requires all of the components of the action to be performed in concert.

What do the current findings, along with others in the literature, mean for the development of reaching for and manipulating objects? As we mentioned before, the transition into independent reaching, like most motor transitions, takes place over a protracted period of time. These results and others in the literature suggest that when infants' actions are reinforced by consequences (e.g., object motion), this helps encourage infants' continued attempts to act upon the world. Having noticeable effects on the physical world (and perhaps the social world, as parents respond with positive social reinforcement) could provide motivation for infants to continue their attempts to reach out and actively explore their surroundings.

Evidence for contingency learning early in infancy has existed for some time, but studies such as the current one show that this kind of learning is valuable for infants, not just for experimenters. Many earlier studies used contingency learning as a way to delve into the infant mind (a worthy goal, to be sure!), but the current research shows that the contingencies infants experience help to alter their behavior both while they are experiencing the reinforcement as well as after the reinforcement has ended and the testing materials have changed. Infants are motivated to engage in actions of consequence and to understand the world around them. These

drives are the fundamental engines of development and contribute to the important task of learning to reach.

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