Journal of Experimental Child Psychology 164 (2017) 209–224

Contents lists available at ScienceDirect

Journal of Experimental Child Psychology

journal homepage: www.elsevier.com/locate/jecp

Characteristics of brief sticky mittens training that lead to increases in object exploration

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ARTICLE INFO

Article history:
Received 12 November 2016
Revised 24 March 2017
Available online 25 May 2017

Keywords:
Object exploration
Infancy
Pre-reaching experiences
Learning about objects
Sticky mittens
Auditory feedback

ABSTRACT

The onset of independent prehension marks the beginning of infants' direct interaction with the physical world. The success infants have in contacting objects with their hands and arms can have both visual and auditory consequences; objects may move and collide with other objects or fall onto table surfaces. Seeing and hearing these events could have important consequences for infants' learning about objects and their subsequent behavior toward objects. The current research assessed the effects of brief object manipulation experiences and how a specific characteristic of training, auditory feedback produced by hard plastic toys colliding with a tabletop surface, affects pre-reaching infants' subsequent object exploration. In Experiment 1, infants participated in either active "sticky" mittens training or passive "nonsticky" mittens training with a set of toys; before and after this experience, infants explored a teether. Results showed that infants participating in active training increased looking toward and sustained touching of the teether from pre- to post-training, whereas infants receiving passive training decreased their looking toward and touching of the teether following training. To investigate whether infants' exploration behaviors were related to the amount of auditory feedback produced by the objects during training, in Experiment 2 data were collected from infants who received active sticky mittens training that had either more or less auditory feedback potential. Results showed more robust increases in infants' exploratory activity from pre- to post-training in the *more* auditory

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http://dx.doi.org/10.1016/j.jecp.2017.04.009

feedback condition compared with infants' exploratory activity in the *less* auditory feedback condition. These findings support the idea that active control of objects, including experiencing contingent feedback through multiple sensory modalities, promotes the development of object exploration during early infancy.

Introduction

As infants begin to gain more control over the movement of their arms, they can swipe at and hit objects with their hands or arms, resulting in salient feedback from the visual and auditory modalities. This feedback may consist of the visual stimulus of objects moving through their visual fields or the auditory stimulus of objects colliding with other objects, table surfaces, or the floor. This feedback could also be reinforcing. How do these sources of feedback contribute to infants' learning? This is the question addressed by the research reported in this article.

Perceptual feedback from actions

Experiencing the contingency between actions and the consequences of those actions has far-reaching implications for learning and development. As Held and Hein (1963) famously observed in their "kitten carousel" experiments, the kittens who actively produced and observed the effects of their own movements around the carousel apparatus were subsequently able to navigate through space more effectively than the kittens who passively experienced these movements. It follows that moving one's body and experiencing the feedback produced by that movement are critical for developing perception and action systems. Researchers have demonstrated that this is true for human infants as well (Adolph, 2000; Gibson, 1988).

The feedback in the Held and Hein (1963) study just described was visual and proprioceptive in nature, but we know that infants are very sensitive to auditory information as well. Even prior to birth, fetuses hear, learn, and remember sounds that enter the uterine environment, and newborns prefer to listen to the sounds they recognize from the fetal period (DeCasper & Spence, 1986; Hepper, 1991; Kisilevsky, Hains, Jacquet, Granier-Deferre, & Lecanuet, 2004). Newborns show evidence of visual investigation of the sources of sounds by looking toward sound sources (Clarkson & Clifton, 1985; Clarkson, Morrongiello, & Clifton, 1982; Morrongiello, Clifton, & Kulig, 1982). This behavior likely supports learning about intermodal stimuli and helps infants to link up the visual and auditory components of events. Research has also shown that sounds reengage infants' attention to a visual stimulus and can even cause dishabituation to a previously habituated stimulus (Kaplan, Fox, Scheuneman, & Jenkins, 1991). This evidence suggests that infants regard auditory information as relatively straightforward to attend to, learn, and remember.

Infants learn about the limits of their body movements as they add new postures to their motor repertoires (e.g., reaching, sitting, crawling, walking; Adolph, 1997, 2000). Infants are also highly sensitive to contingencies between their own actions and the perceptible consequences of these actions (e.g., Bahrick & Watson, 1985; DeCasper & Carstens, 1981; Rovee-Collier & Gekoski, 1979). These experimental results and others (e.g., Adolph & Avolio, 2000; Rochat & Striano, 1999) indicate that infants can learn quickly about the match between their physical abilities and opportunities in the environment.

Infants' propensities for exploration lead them to learn about the kinds of action opportunities that are available within a given level of ability. This may be what leads infants to engage in actions such as pulling up to a standing position once they can crawl up to a stable coffee table (Thelen, 2005, pp. 264–265). Knowing that infants are capable of taking advantage of novel possibilities for action in their environments, we asked what information infants respond to when altering their actions to exploit new opportunities for action in a reaching context.

Sticky mittens experience

We investigated this question using "sticky mittens," infant mittens with palms covered in Velcro loop. These mittens enable infants to pick up lightweight toys covered in the corresponding Velcro hook (Needham, Barrett, & Peterman, 2002) (see Fig. 1). Wearing these mittens, infants as young as 2.5 months readily learn to swipe at and move objects through their visual fields. Past research investigating the effects of mittens training on infants' exploratory behaviors has used an extensive training paradigm. Infants who participated in 10–14 daily 10-min sessions practicing with the sticky mittens and a set of toys at home showed heightened engagement in an object exploration task involving an object quite different from the objects involved in training (see Fig. 2). In a study comparing the effects of two weeks of active (sticky) versus passive (nonsticky) mittens training, infants who participated in the active experience showed more exploration of objects and began reaching for objects earlier in development than infants who received the passive experience (Libertus & Needham, 2010). This enhanced exploration of objects has been shown to last for at least 12 months after training (Libertus, Joh, & Needham, 2016).

Together, previous studies show that 2 weeks of parent-guided active mittens training positively influences infants' reaching and grasping behaviors (Libertus & Landa, 2014; Libertus & Needham, 2010), their object exploration (Needham et al., 2002), and even their social orienting behaviors (Libertus & Needham, 2011). Further research has determined that the different components of the sticky mittens experience—being encouraged to reach for the toy, planning to bring their hand toward the toy, obtaining the toy, and controlling the toy once obtained—all are important components of the active mittens experience (Libertus & Needham, 2014). Specifically, when infants only controlled a toy that was strapped to their hand or only received encouragement to obtain the toy but did not have the scaffold of sticky mittens, they did not show increased object exploration behaviors afterward.

Responses to changes in action capacity

Previous studies have used a brief version of the sticky mittens paradigm to provide both training and testing within a single laboratory session (Gerson & Woodward, 2013; Rakison & Krogh, 2012; Skerry, Carey, & Spelke, 2013; Sommerville, Woodward, & Needham, 2005). These studies examined how very short experiences with sticky mittens training leads to immediate differences in infants' cognitive skills. Infants in these studies participated in just 3–5 min of active mittens training, proving sufficient to promote infants' action understanding and causal understanding, among other cognitive skills. These studies show that short durations of sticky mittens training can influence infants' *cognitive* skills, but would such brief experiences be sufficient to affect infants' *motor* skills?

One study relevant to this question investigated whether 14-month-old infants would respond to trial-to-trial changes in their body weight (introduced by inserting lead- or feather-filled packs into a vest worn by the infants) when walking down a sloped walkway (Adolph & Avolio, 2000). Infants' abilities to descend the slopes were impaired when wearing the lead-filled vest but not when wearing the feather-filled vest. Infants adjusted their actions on the slopes to accommodate the weight of the vest, choosing to avoid steeper slopes when wearing the heavy vest. This finding shows that infants respond in real time to changes in their capacity for action.

The procedure in the study just described involved infants engaging in an action (walking) that was already well practiced. Could infants respond in a similar way to opportunities for *novel* actions? This could be possible if infants had some skills that, together with some scaffolding provided by the experimental situation, would allow them to engage in these novel actions. In the current research, we provided pre-reaching infants with opportunities to successfully reach out and "grasp" toys using sticky mittens. As discussed above, infants who have 2 weeks of daily experience with sticky mittens show increased object exploration compared with infants who do not have sticky mittens experience. In this study, we asked whether even very brief experience with sticky mittens leads to increases in object exploration. Object exploration is important because it provides infants with opportunities for learn-

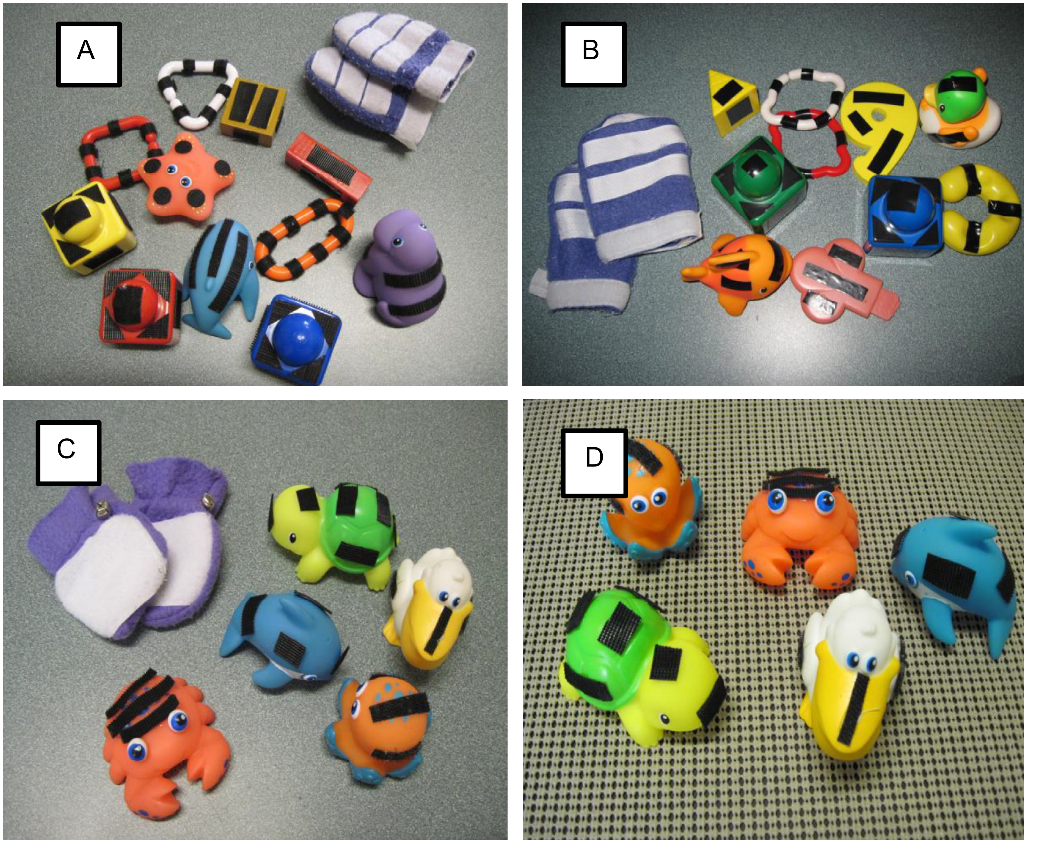

Fig. 1. These are the toys and mittens used in Experiments 1 and 2. (A) Infants in the active condition of Experiment 1 wore sticky mittens with Velcro on the palms and interacted with toys covered in strips of Velcro. (B) Infants in the passive condition of Experiment 1 wore nonsticky mittens with ribbon sewn on the palms and interacted with toys covered in strips of black tape. (C) In the *more* auditory feedback condition, bells were attached to the mittens, and bells were also inserted into the five small toys with which infants interacted. (D) In the *less* auditory feedback condition, the surface of the table was padded to make the procedure quieter. No bells were sewn onto the mittens or inserted into the toys in this condition.

Fig. 2. This is the teether that was used in both Experiment 1 and Experiment 2 to assess infants' object exploration behaviors pre- and post-training.

ing about objects and has the potential to set off a developmental cascade resulting in higher IQ and academic achievement even years later (Bornstein, Hahn, & Suwalsky, 2013).

The current research

In these experiments, we asked whether brief active sticky mittens training affects infants' object exporation skills (Experiment 1) and, if so, whether the auditory feedback infants receive during training affects their object exploration from pre- to post-training (Experiment 2). Specifically, Experiment 1 compared active training (using sticky mittens) and passive training (using nonsticky mittens) experiences to determine whether one brief training session is sufficient to encourage object exploration in young infants. To examine the possible role of auditory feedback during training, Experiment 2 systematically manipulated the sound potential of the toys infants interacted with during active training. In both experiments, we measured changes in object exploration behaviors using identical pre- and post-training assessments of infants' *barehanded* exploration of a multitextured plastic teether *that was not involved in training*. In Experiment 1, we predicted that experience with active training would produce larger increases in subsequent object exploration compared with the experience of passive training. In Experiment 2, we predicted that both groups of infants would increase their exploration behaviors after active training but that infants whose training featured toys with higher sound potential would show more robust increases in subsequent object exploration compared with infants whose training featured toys with lower sound potential.

Experiment 1

Method

Participants

Participants were 38 healthy full-term infants. Random assignment placed 19 of the infants (8 girls) in the active training condition (M_{age} = 4 months, SD = 14.69 days) and 19 (12 girls) in the passive training condition (M_{age} = 4 months 2 days, SD = 30.45 days). Data from 7 additional infants who participated in this study were excluded from analyses for the following reasons: incomplete video recordings of the study ($n = 3$), excessive fussiness ($n = 3$), and successful independent reaching in the pretraining session ($n = 1$).

Apparatus

The infant sat on a parent's lap at a wooden table (74 cm in height $\times$ 81 cm in width $\times$ 64 cm in length) covered in white contact paper. The experimenter was seated across the table from the infant. A half circle (21 cm radius) was cut out of the infant's side of the table, surrounding the front and side of the infant with table. Care was taken to ensure that the infant's arms were above the table and that the parent provided the infant with enough trunk support to allow for free arm movements above the table. A selection of small pillows placed on the parent's lap made this positioning possible.

Stimuli

The experimenter presented toys one at a time at infants' midlines and within their reach. In both training conditions, infants interacted with small lightweight toys, such as plastic blocks and foam letters, weighing approximately 25 g each. These toys were selected because they were manageable for infants to move through space using the sticky mittens. In the active training group, a Velcro hook covered the edges of the toys (see Fig. 1). Infants wore sticky mittens with the palms covered in strips of Velcro loop. In the passive group, colored tape (chosen to match the Velcro in color, size, and shape) covered the edges of the toys. Infants in the passive group wore nonsticky mittens with white ribbon sewn onto the palms to mirror the appearance of the Velcro strips on the palms of the sticky mittens (see Fig. 1).

A textured, plastic, red teether toy (Super Yummy Teether, Discovery Toys) was used in the pre- and post-training trials. This teether weighed about 70 g and measured 10.8 cm long and 8.3 cm across. It was 25.4 cm in circumference at its widest point and 6.4 cm in circumference at its most narrow point (see Fig. 2).

Pre- and post-training assessments

Each infant participated in identical assessments of object exploration before and after training. During these trials, the infant's attention was drawn toward the teether by tapping it on the table and moving it into the infant's line of sight. The teether was then held at the infant's midline, close to the infant's hands, for approximately 1 min (M_{pre} = 53.03 s, SD = 19.76, M_{post} = 56.05 s, SD = 28.82). The experimenter would let go of the teether if the infant touched or grasped it but otherwise would hold the teether in the same position. The experimenter looked down (at a stopwatch) and engaged in little verbal communication unless the infant seemed distracted, at which time the experimenter would briefly point to the teether, tap it, or verbally encourage the infant (e.g., by saying "What's this?"). This was done in an attempt to keep the infant engaged in what was a very long testing session. These attempts to keep the infant engaged (and the infant's responses to these behaviors) were coded and analyzed as described below.

Mittens training

After the completion of the pre-training assessment of object exploration using the teether, the experimenter placed mittens on infants' hands. In the active group infants wore sticky mittens, and in the passive group infants wore nonsticky mittens (see Fig. 1). The experimenter then began presenting toys to infants, one at a time, for approximately 1 min each. The average duration of the training experience was 9 min 7 s (SD = 2 min 51 s) for infants in the active condition, and the average duration of training was 7 min 49 s (SD = 2 min 29 s). for infants in the passive condition.[1]

Importantly, details of the training procedure differed between the conditions. In the active group, the experimenter first demonstrated up to three times (M = 1.58, SD = 0.84) that toys could stick to the mittens. The rationale behind this demonstration is that infants would not discover the affordances of the mittens on their own. We showed each infant in the active condition how to use the mittens by guiding the infant's mittened hand to a toy, touching the mitten to the toy, and raising the infant's arm until the toy came up off the table. The experimenter tried to make sure that each infant saw this demonstration before moving on. The average duration of each introductory trial was 16.62 s (SD = 9.24). During the first three trials, the experimenter first presented each toy to infants at midline and briefly paused. If infants successfully contacted the toy on their own during this brief presentation, the experimenter did not demonstrate the utility of the mittens during that trial. After these initial trials, the experimenter presented a toy to infants and provided verbal encouragement to contact the toy. Infants in the passive condition observed as the experimenter moved the non-Velcro toys through their visual fields in an effort to replicate the object movements that infants in the active condition produced spontaneously. The experimenter also touched each toy to the palms of infants' mittened hands to provide a tactile experience for infants in the passive condition. The average number of toys presented to infants in the active condition was 16.16 (SD = 8.58), and the average number of toys presented to infants in the passive condition was 11.21 (SD = 3.79).

Pre- and post-training measures

The beginning of each assessment of object exploration was operationalized as when the experimenter presented the teether to the infant, and the end was operationalized as when the experimenter either removed the teether from the infant's grasp or moved it away from the infant. Two research assistants coded the duration of the pre- and post-training assessments, and reliability between coders was high (intraclass correlation coefficient $[ICC]_{pre}$ = 1.00, ICC_{post} = .94).

Assessments of object exploration with the teether were coded by trained observers from video-recordings using custom software with 0.1-s precision. Looking time was defined as time spent in

[1] The experimenter attempted to maintain each infant's interest in the training for approximately 10 min. However, the full 10 min of training (in addition to the pre- and post-training exploration trials) pushed the limits of infants' abilities. The experimenter could move on to the post-training trial before the 10 min of training was over if she or he believed that this was necessary to complete the procedure for that infant (e.g., if the infant was showing signs of fatigue).

visual contact with the teether, and touching time was defined as time spent with any part of the hands or mouth in contact with the teether. Trained observers pressed one button to indicate looking and pressed another button to indicate touching. A second observer coded 20% of the videos, and agreement was high between observers for looking and touching for pre-training assessments (ICC_{look} = .98, ICC_{touch} = .98) and post-training assessments (ICC_{look} = .96, ICC_{touch} = .99).

To keep infants engaged in the task, experimenters made attempts to draw infants' attention toward the teether. To investigate whether these attempts could have influenced our results, experimenters' attempts to draw infants' attention toward the teether were coded from recordings of the pre- and post-training assessments. Five categories of attention-eliciting prompts were identified (see Table 1). One fifth (20%) of the pre- and post-training sessions were coded by a second observer (ICC = .96). In addition, the number of times that infants reoriented to the teether as a result of the experimenter's prompts during pre- and post-training sessions was coded by an observer, and a second observer coded 20% of these sessions as well (ICC = .89). We analyzed these experimenter behaviors, and infants' responses to them, to determine whether they could have systematically affected our results (see footnote 2 in Results below), and these results were not significant.

Training measures

The beginning of the training experience was coded when the experimenter fastened the Velcro strap around the infant's second mitten. The end of the training experience was coded when the experimenter began to remove the first mitten from the infant's hand. All of the start and end times of training sessions were coded by two observers (ICC = 1.00).

Two research assistants who were unaware of the specific hypotheses being tested coded the number of demonstration trials infants in the active mittens training condition experienced (ICC = .91) as well as the duration of demonstration trials (ICC = .97).

Custom software was also used to assess the amount of looking and touching that infants engaged in throughout the mittens training experience (see Fig. 3). A total of 8 participants' videos (4 from the active condition and 4 from the passive condition) were coded by a second observer. Agreement between observers for looking toward and touching the objects was good (ICC_{look} = .90, ICC_{touch} = .99).

The amount of time that infants in the passive condition (M = 4 min 17 s, SD = 32 s) and active condition (M = 3 min 41 s, SD = 1 min 32.45 s) spent looking at the objects during training did not significantly differ, $t(36) = 1.2$, $p = .237$, $d = 0.39$. In contrast, infants in the passive condition (M = 33.67 s, SD = 25.19) touched the objects significantly less during training than infants in the active condition (M = 3 min 17 s, SD = 1 min 34.07 s), $t(36) = -7.31$, $p < .001$, $d = -2.37$. This difference in amount of manual contact with toys was to be expected because of the nature of the training infants received (i.e., the amount of touching of the toys the infants could do in the passive training condition was prescribed by the training routine).

Results

Pre- and post-training assessments

Our final model included condition as a between-participant factor, phase as a within-participant factor, and duration of pre- and post-training assessments as a time-variant covariate.[2] We used two

[2] In preliminary analyses, the duration of infants' looking and touching during pre- and post-training assessments of object exploration was analyzed using analysis of covariance with phase of assessment (pre-training or post-training) as a within-participants factor and condition (active or passive) and sex as between-participants factors. The main effects of sex were nonsignificant. We also included a number of covariates in preliminary analyses that were nonsignificant and excluded from subsequent analyses: the number of toys infants interacted with during mittens training, the number of times the experimenter prompted infants to engage with the teether during object exploration assessments, and the number of times infants reoriented to the teether in response to the experimenters' prompts during pre- and post-training assessments. These covariates were tested both in isolation (i.e., putting one covariate into the model to see whether it was significant alone) and all together (i.e., putting all covariates into the model to see whether any were significant) (all ps > .10). None of these covariates was significant, so we did not include them in subsequent analyses. The duration of the pre- and post-training assessments of object exploration was a significant covariate in the analyses for looking, $F(1, 61.43) = 64.31$, $p < .001$, and touching, $F(1, 65.82) = 39.79$, $p = .029$, so this factor was included in subsequent analyses.

Table 1
Attention-eliciting behaviors during pre- and post-training assessments in Experiment 1.

Prompt	Active		Passive	
	Pre	Post	Pre	Post
Twirling/shaking/squeezing the teether	15	19	5	12
Placing infant's hand on the teether	16	11	18	23
Retrieving the teether when dropped	3	3	1	5
Tapping the teether or the table	3	10	11	12
Repositioning the teether	3	13	15	14
Sum of prompts	40	56	50	66
Number of reorienting responses	14	21	17	17

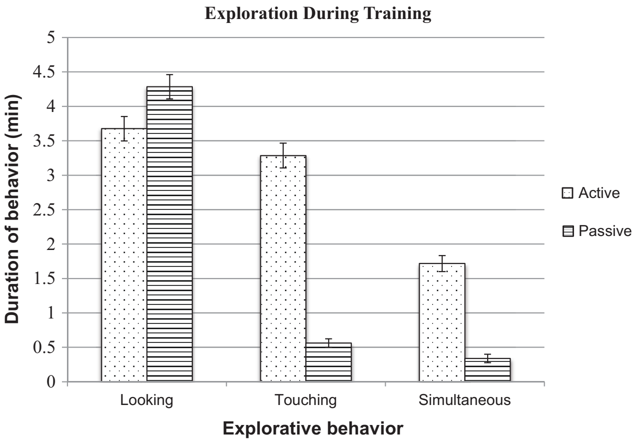

Fig. 3. The bars show the total average durations of looking toward, touching, and simultaneously looking toward and touching the objects during the mittens training experience for infants in the active and passive conditions of Experiment 1.

analyses of covariance (ANCOVAs) to test our hypotheses regarding infants' looking and touching from pre- to post-training in active and passive mittens training conditions. Specifically, we predicted that (a) infants in the active training condition would show increases in durations of looking and touching from pre- to post-training and that (b) infants in the passive training condition would maintain similar levels of object exploration from pre- to post-training. Thus, we were most interested in the interactions between condition and phase.

Looking. This analysis produced a significant interaction between condition and phase, $F(1, 36.06) = 9.32$, $p = .004$, $d = 0.68$. A t test on the difference scores (post-training looking minus pre-training looking) revealed that infants in the active condition significantly increased their looking toward the teether from pre-training ($M_{pre} = 28.87$ s, $SD = 17.84$) to post-training ($M_{post} = 41.98$ s, $SD = 25.18$; $M_{diff} = 13.11$ s, $SD = 25.18$), $t(18) = 2.27$, $p = .036$, $d = 0.52$. Although infants in the passive condition tended to look less toward the teether from pre-training ($M_{pre} = 29.25$ s, $SD = 16.39$) to post-training ($M_{post} = 21.19$ s, $SD = 13.79$; $M_{diff} = -8.06$ s, $SD = 19.94$), this tendency did not reach significance, $t(18) = -1.76$, $p = .095$, $d = -0.53$. There was a significant main effect of condition, $F(1, 35.58) = 7.83$, $p = .008$, $d = 0.30$. The main effect of phase was nonsignificant, $F(1, 36.83) = 0.10$, $p = .754$, $d = -0.08$.

Touching. This analysis revealed a significant phase by condition interaction, $F(1, 35.24) = 5.35$, $p = .027$, $d = 0.69$. Follow-up t tests revealed that infants in the active condition maintained the same amount of touching from pre-training ($M_{pre} = 28.78$ s, $SD = 20.81$) to post-training ($M_{post} = 32.54$ s, $SD = 25.68$; $M_{diff} = 3.76$ s, $SD = 24.64$), $t(18) = 0.66$, $p = .515$, $d = 0.16$. In contrast, infants in the passive condition touched the teether significantly less during post-training (M_{post} = 16.73 s, SD = 10.51) than during pre-training (M_{pre} = 29.28 s, SD = 13.54; M_{diff} = −12.55 s, SD = 14.01), $t(18) = -3.91$, $p = .001$, $d = -1.03$. The main effect of condition was marginally significant, $F(1, 35.41) = 3.31$, $p = .077$, $d = 0.32$, and there was a significant main effect of phase, $F(1, 36.06) = 5.93$, $p = .02$, $d = 0.18$.

Discussion

Infants in the active condition increased their looking at the teether, and they maintained the level of touching the teether from pre- to post-training. In contrast, infants in the passive condition maintained the level of looking at the teether, and they decreased the amount of touching of the teether between pre- and post-training measures.

This observed decrease in engagement over time is consistent with the well-known behavioral principle of habituation—a decrease in an organism's response to a stimulus over repeated exposure. This prevalent aspect of infant behavior has been noted in a large number of studies to date (e.g., Cohen, 2004; Fantz, 1964; Sirois & Mareschal, 2004). Indeed, a steady decrease in response (whether visual exploration or exploration in another modality) over trials is the pattern of results that would be the most straightforward prediction in any study with repeated trials. So, the fact that the infants in the active training condition did not show a decrease in their looking or touching behavior across this study is important.

According to previous research, 2 weeks of parent-led experience with active training boosted infants' object exploration (Libertus & Needham, 2010; Needham et al., 2002). The current findings reveal that just 10 min of experimenter-led active training can have similar effects, although we do not claim that these effects would be as robust or long-lasting as those obtained after a much longer period of time.

Our findings also show that simply receiving exposure to the training materials without active control over the toys (i.e., as experienced by the infants in the passive training condition) does not lead to an increase in exploratory behavior. Active movement of the toys via infants' own mittened hands increased infants' engagement in the teether after training, but wearing mittens while passively watching the experimenter move the toys did not lead to similar increases in exploration of the teether. The experiences provided in the passive condition of Experiment 1 are very similar to the typical play and exploration experiences of infants at this age and were not enough to lead to an increase in exploratory behavior.

One possibility to consider is that experience with any contingency could have had the same results as those obtained in Experiment 1. According to this argument, any kind of contingent experience is arousing and may serve to activate infants' exploratory systems. However, according to a recent experiment, this seems unlikely to be the case (Needham, Joh, Wiesen, & Williams, 2014). In this study, infants in the experimental condition were able to control the movement of a nearby mobile via a ribbon attached to their wrist and to the mobile. By pulling their arms toward their bodies, they could cause the mobile to move. Infants in the control condition also had a ribbon attached to their wrist, but the other end of the ribbon was attached to an empty mobile stand (the experimenter surreptitiously moved the mobile for them). Infants in both conditions saw the same overall amount of mobile movement, but for the infants in the experimental condition that movement was contingent on their actions, whereas for the infants in the control condition it was not.

If simply being exposed to object movement that was contingent on their own actions produced an increase in infants' object exploration, there should have been a difference in the amount of object exploration produced by the infants in the experimental and control conditions. Specifically, the infants in the experimental condition, who could control the movement of the mobile, should have explored objects more than the infants the control condition, who could not control the mobile's movement (Needham et al., 2014). However, there were no statistically significant differences in object exploration between the experimental and control groups. The infants in the experimental condition did reach more for the objects in test compared with infants in the control condition, a finding that makes sense because reach-like movements (the pulls of the ribbon connected to the mobile) were being reinforced for these infants. These findings indicate that contingent reinforcement alone is not sufficient to produce the increases in infants' object exploration that we observed in Experiment

1. Perhaps acting on objects directly using their own hands plays an important role in infants' increased engagement in object exploration.

Experiment 2

One of the primary goals of this research was to understand the characteristics of sticky mittens experience that lead to increases in object exploration. As discussed in the Introduction, we expected that auditory feedback from infants' actions could be an especially useful component of their experience to investigate this question, in Experiment 2 we compared two different versions of active sticky mittens training. The infants in this experiment were randomly assigned to one of two mittens training groups; one interacting with objects that had more potential for auditory feedback and one interacting with objects that had less potential for auditory feedback.

Because both groups of infants in this study had sticky mittens experience, we expected all of the infants in Experiment 2 to show benefits from the training procedure. However, we hypothesized that infants in the *more* auditory feedback condition would show significantly more pronounced effects from pre- to post-training than infants in the *less* auditory feedback condition. If auditory feedback from their actions is an important component of infants' experience during sticky mittens training, we should see differences in the object exploration behaviors between the two groups in this experiment. Specifically, we predicted that the infants interacting with the toys that had more potential for auditory feedback would show larger increases in their object exploration behaviors compared with the infants whose toys had less potential for auditory feedback.

Method

The methods followed were the same as those in Experiment 1 with the following exceptions.

Participants

Participants were 36 healthy full-term infants who had not participated in Experiment 1. Random assignment placed 18 of the infants (9 girls) in the *more* auditory feedback condition (M_{age} = 3 months 19 days, SD = 7.22 days) and 18 (9 girls) in the *less* auditory feedback condition (M_{age} = 3 months 17 days, SD = 9.29 days). Data from 19 additional infants were collected and excluded from the final sample due to fussiness (n = 13), experimenter error (n = 4), and successful independent reaching in the pre-training session (n = 2).[3]

Stimuli

Infants in both the more auditory feedback and less auditory feedback conditions were trained using a set of five brightly colored soft plastic bath toys (commercially available Munchkin Sea Squirts; dolphin, octopus, turtle, pelican, and crab; see Fig. 1). The toys were approximately 7 × 7 cm in size and weighed about 28 g. In the less auditory feedback condition, the table was covered with foam core that was itself covered with thin foam to reduce sounds the soft toys might make when contacting the table. In the less auditory feedback condition, the toys were silent while moving. In the more auditory feedback condition, no foam was used on the table and the toys made loud impact noises when hitting the table. In addition, in the more auditory feedback condition, bells were sewn onto the sticky mittens and a few small bells were placed inside the toys to produce rattling and jingling sounds during the movement of the toys.

Procedure

Otherwise, the two groups' experiences were as similar as possible. The toys were always presented in the order listed above, although the toy that started the sequence was counterbalanced

[3] As described in Experiment 1, the procedure followed in both of these experiments pushed infants' attentional abilities to their limit. Any infant who was not able to complete the entire session did not have a post-training trial and so would require elimination from the final sample. The attrition rate shown in Experiment 2 was likely a result of our demanding procedure and the characteristics of the age range we recruited for this study.

across infants. Infants in the more auditory feedback condition received an average of 9 min 54 s of training (SD = 2 min 1 s), and infants in the less auditory feedback condition received an average of 9 min 52 s of training (SD = 2 min).[4]

During the pre- and post-training trials, instead of the experimenter holding the teether up near the infant's line of sight as in Experiment 1, the teether was placed on the table (at midline very close to the infant) and the infant was allowed to freely explore the teether for approximately 1 min. The average duration of the pre-training assessments of object exploration was 1 min 6 s for the more auditory feedback group (SD = 8.38 s) and also 1 min 6 s for the less auditory feedback group (SD = 6.55 s). The average duration of post-training assessments of object exploration was 1 min 15 s for infants in the more auditory feedback group (SD = 19.03 s) and also 1 min 15 s for infants in the less auditory feedback group (SD = 15.27 s). As in Experiment 1, the experimenter attempted to bring infants' attention back to the teether if they had looked away for several seconds in a row. During the pre-training assessments of object exploration, infants in the more auditory feedback condition were prompted an average of 2.25 times (SD = 1.61), and infants in the less auditory feedback condition were prompted an average of 2.17 times (SD = 1.42). During the post-training assessments, infants in the more auditory feedback condition were prompted an average of 3.13 times (SD = 2.22), and infants in the less auditory feedback condition were prompted an average of 3.50 times (SD = 1.29).

Measures

Coding was conducted as in Experiment 1 with the following additions. Each infant was coded twice by different coders who were blind to the infant's condition. Reliability was high for looking and touching during pre-training assessments (ICC_{look} = .95, ICC_{touch} = .99) and post-training assessments (ICC_{look} = .91, ICC_{touch} = .95). The average of the two codes was used for the final analyses. Two research assistants coded 50% of participants' data for reorienting toward the teether (ICC = .87) and the number of times that the experimenter prompted the infant to attend to the teether (ICC = .90) during pre- and post-training assessments.

Results

Pre- and post-training assessments

Two analyses of variance (ANOVAs) were used to assess whether looking and touching directed toward the teether differed from pre- to post-training assessments of object exploration between the two conditions. Each ANOVA model included condition (more or less auditory feedback) as a between-participants factor and phase (pre-training or post-training) as a within-participants factor.[5]

Looking. The interaction between condition and phase was significant, $F(1, 34) = 6.36$, $p = .016$, $d = 0.84$. A t test using difference scores (post-training looking minus pre-training looking) revealed that infants in the more auditory feedback group significantly increased their looking toward the teether from pre-training (M_{pre} = 30.78 s, SD = 13.71) to post-training (M_{post} = 42.50 s, SD = 11.47; M_{diff} = 11.72 s, SD = 14.06), $t(17) = 3.54$, $p = .003$, $d = 0.92$. In contrast, infants in the less auditory feedback condition looked about the same amount toward the teether from pre-training (M_{pre} = 37.56 s, SD = 16.26) to post-training (M_{post} = 36.82 s, SD = 16.27; M_{diff} = −0.74 s, SD = 15.57), $t(17) = -0.20$, $p = .842$, $d = -0.05$. Finally, there was a significant main effect of phase, $F(1, 34) = 4.93$, $p = .033$, $d = 0.74$.

[4] Unfortunately, the videos for 3 participants in the more auditory feedback condition were inadvertently destroyed before training time had been coded. These statistics are based on the training time from 15 participants rather than the 18 participants in the high intersensory redundancy condition.

[5] In preliminary analyses, we used two analyses of covariance to test our hypotheses about infants' looking and touching directed toward the teether during pre- and post-training assessments. Preliminary tests of the main effects of sex were nonsignificant. As in Experiment 1, we initially included three covariates in this model: the number of prompts experimenters used to encourage infants to attend to the teether, the number of times infants reoriented to the teether in response to these prompts, and the duration of pre- and post-training assessments of object exploration. All three covariates were nonsignificant, so we did not include them in subsequent analyses (all ps > .20).

Touching. Our analysis yielded a significant interaction between condition and phase, $F(1, 34) = 4.12$, $p = .050$, $d = 0.68$. t Tests on the difference scores showed that infants in the more auditory feedback group touched the teether significantly more during post-training ($M_{\text{post}} = 24.26$ s, $SD = 17.66$) than during pre-training ($M_{\text{pre}} = 9.96$ s, $SD = 15.61$; $M_{\text{diff}} = 14.30$ s, $SD = 13.42$), $t(17) = 4.52$, $p < .001$, $d = 0.85$. Although infants in the less auditory feedback group also touched the teether more from pre-training ($M_{\text{pre}} = 13.50$ s, $SD = 15.77$) to post-training ($M_{\text{post}} = 19.03$ s, $SD = 15.59$; $M_{\text{diff}} = 5.53$ s, $SD = 12.50$), this increase was not statistically significant, $t(17) = 1.91$, $p = .072$, $d = 0.36$. The main effect of phase was significant, $F(1, 34) = 21.02$, $p < .001$, $d = 1.53$, but there was no effect of condition ($p = .865$).

Discussion

These results showed that the infants in the more auditory feedback condition showed significant increases in both measures of object exploration over the course of training, but the infants in the less auditory feedback condition did not. These results provide evidence for the importance of the simultaneous auditory–visual feedback infants receive during active mittens training for subsequent object manipulation and learning, and they indicate that more auditory feedback led to larger increases in object exploration. The amount of feedback possible during pre- and post-training assessments was the same for both groups and, therefore, could not have accounted for the higher levels of exploration in the more auditory feedback condition.

General discussion

In the current experiments, 3.5- to 4-month-old infants' object exploration behaviors were boosted by about 10 min of self-produced movement of toys. In Experiment 1, the infants in the active condition showed increased exploration over the course of a single laboratory session, whereas the infants in the passive condition showed a decrease in exploration. In Experiment 2, all infants received active sticky mittens training, but infants received differing amounts of auditory feedback during that training. Infants in the more auditory feedback condition showed a more robust increase in their exploration of the teether from pre- to post-training compared with infants in the less auditory feedback condition. Experiment 2 serves as a replication of the effect shown in Experiment 1 and shows that the sounds made by the objects during training play an important role in increasing infants' exploration behaviors from pre- to post-training.

Together, the findings reported here complement and extend previous research using the sticky mittens training paradigm and other training paradigms to understand the development of infants' object-directed actions. These findings also address questions regarding the characteristics of sticky mittens experience that lead to increases in object exploration. In contrast to Needham et al. (2002), Libertus and Needham (2010, 2011), Libertus and Landa (2014, 2014), the current study involved only one short (10-min) experimenter-guided training session. Thus, we had complete experimental control over the infants' experiences with the sticky mittens. Our findings indicate that observed changes in object exploration are dependent on infants' active control over the objects (Experiment 1) and are facilitated by auditory feedback (Experiment 2).

Another possible explanation for the pattern of results we obtained is that the infants in the more auditory feedback condition were processing the objects and events at a deeper level, and this deeper level of processing may have produced more detailed representations of the objects and the infants' actions on them. Our experiments were not intended to test this hypothesis and do not allow us to evaluate this possibility directly, but it could be addressed in future research.

In any training study, one must be concerned about the influence of training objects on performance in test. We designed these experiments to minimize such concerns. In both experiments, we used different objects during the training and test trials. Within each experiment, infants in both conditions (active and passive conditions in Experiment 1 and more and less auditory feedback conditions in Experiment 2) interacted with nearly identical toys and mittens during their training experiences. Our use of different objects in training and during assessments of object exploration, together with the findings of these two experiments, provides strong evidence against the possible influences of transient training effects such as priming or familiarization to the toys seen during training or of the teether used in the pre- and post-training assessments of object exploration.

Comparing across experiments

The results of the two experiments reported here indicate that infants who participated in the more auditory feedback training condition (Experiment 2) benefitted the most from their training experience (as measured by their increases in object exploration), followed by the infants in the active training condition (Experiment 1), then the less auditory feedback condition (Experiment 2), and finally the passive training condition (Experiment 1). Reflecting on this overall pattern of results leads us to speculate that the more auditory feedback and active training conditions encouraged infants' object exploration the most, the less auditory feedback condition led to less pronounced increases in infants' object exploration, and the passive training condition did not facilitate infants' interest in exploring objects at all.

To further explore this pattern of findings, we have graphed the effect sizes from the four mittens training conditions in these two experiments (see Fig. 4). These graphs illustrate changes in infants' looking and touching behaviors. They show negative effect sizes in the passive training condition, positive effect sizes in the less auditory feedback and active training conditions, and the strongest positive effect sizes in the more auditory feedback condition. These results indicate that the effect sizes are aligned with the amount of overall feedback that infants received in the four conditions across these two studies. Together, these findings indicate that infants are sensitive to the different amounts of feedback they receive through manipulating objects during mittens training.

This analysis raises the question of what infants who participate in active mittens training are learning. We believe that when infants experience these concentrated bouts of success in producing object movement, it helps them to learn about their own agentive abilities—how their own actions can affect nearby objects. This success could contribute to the development of a sense of self-control and self-efficacy that keeps them motivated enough to engage in the practice and other activity required to persist through their next motor transition (in this case, independent reaching; we imagine that similar processes take place during all of infants' motor transitions). The onset of infants' actions on objects could also serve as a catalyst for infants' learning about objects. Making the transition to independent reaching and grasping may increase the extent to which infants seek information about objects, and it provides consistent access to information such as weight, texture, and material that was not previously available. These changes mean that the rate at which infants learn about objects may show a marked increase when they begin independent reaching.

Our results demonstrate that one short 10-min training session using sticky mittens can alter infants' object exploration and object engagement. These findings raise many questions and open up new directions for future research and applications of the sticky mittens paradigm. For example, must infants have achieved a certain level of behavioral or cognitive skill before they can benefit from sticky mittens experiences? If so, how can we assess a particular infant's readiness to benefit from this training procedure? Looking for individual differences in the responses of a wider range of ages (e.g., 2- to 4.5-month-olds' responses to the intervention) and seeking commonalities among the demographic or experiential characteristics of similarly responding infants could be a promising approach to these questions.

Integration across sensory modalites

One possibility for the mechanism through which infants' exploration skills are facilitated in the more auditory feedback condition is intersensory redundancy. Infants' object exploration usually involves multiple sensory modalities: infants look at an object while banging it against a table surface, or they explore an object manually, orally, and visually in quick succession (Bourgeois, Khawar, Neal, & Lockman, 2005; Palmer, 1989; Rochat, 1989; Ruff, 1984, 1986). This naturally creates intersensory redundancy (redundant perceptual input available through more than one sensory modality), which facilitates attentional selectivity, perception of object properties, and learning about objects

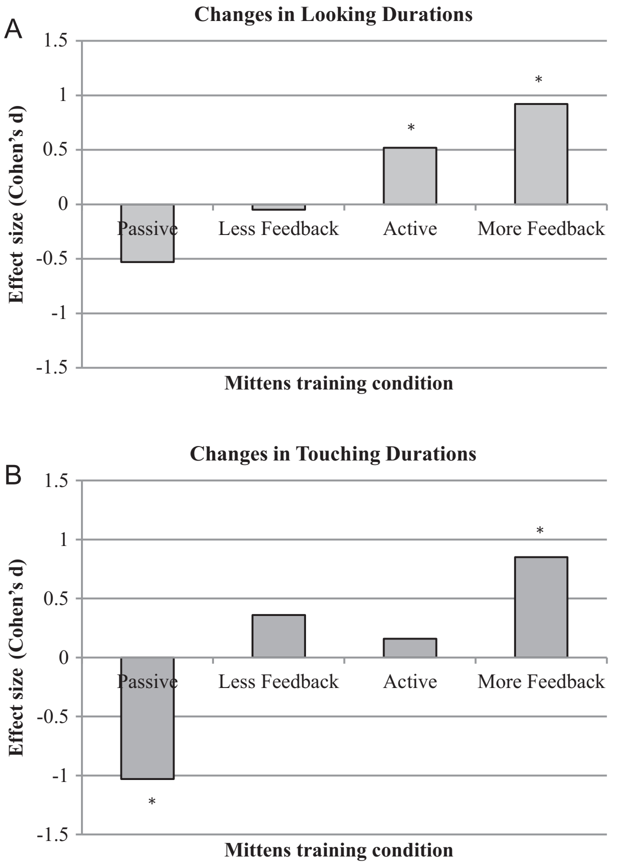

Fig. 4. Effect sizes (Cohen's *d*) of changes in looking (A) and touching (B) are compared across the four mittens training conditions from Experiment 1 and Experiment 2. Asterisks indicate significance at the .05 level.

(Bahrick & Lickliter, 2000, 2002). In the current research, intersensory redundancy was clearly present in the active condition of Experiment 1 and in both of the conditions of Experiment 2, although there was more intersensory redundancy available in the more auditory feedback condition than in the less auditory feedback condition.

In their work, Bahrick and Lickliter have established that infants learn more from stimuli containing intersensory redundancy than from similar stimuli without this redundancy (for a review, see Bahrick & Lickliter, 2002). Furthermore, their work shows that the amount of intersensory redundancy is predictive of infant learning. Specifically, the concept of salience hierarchies predicts that the more intersensory redundancy a stimulus possesses, the more infants will learn from it (Bahrick & Lickliter, 2012). Other evidence shows that, in comparison with single-modality stimuli, multimodal stimuli recruit more attention from infants, and this greater task engagement leads to more effective learning (ter Schure, Mandell, Escudero, Raijmakers, & Johnson, 2014). Thus, there is clear support for the idea that intersensory redundancy makes learning from object exploration more efficient and effective.

Effectiveness of sticky mittens experience

The current findings, together with previous studies using active sticky mittens training, indicate that this training paradigm influences cognitive, motor, and social development (Gerson &

Woodward, 2013; Libertus & Needham, 2010, 2011; Libertus et al., 2016; Rakison & Krogh, 2012; Skerry et al., 2013; Sommerville et al., 2005; Wiesen, Watkins, & Needham, 2016). Based on what we know about the nature of development, it is likely that experiences that stem from infants' own actions with their bodies (like sticky mittens training) would have beneficial effects on learning and development (e.g., Needham & Libertus, 2011). Consequently, sticky mittens may be used as part of an intervention for young infants with motor impairments or delays such as infants with Down syndrome, infants at risk for autism spectrum disorder (ASD), and infants with cerebral palsy. For example, recent findings suggest that 6-month-olds later diagnosed with ASD show poor grasping-related fine motor skills (Libertus, Sheperd, Ross, & Landa, 2014)—the same behaviors that increase following active sticky mittens training. Indeed, active mittens training has been found to encourage grasping behaviors in infants at high familial risk for ASD (Libertus & Landa, 2014). Although improvements in infants' object exploration and focused attention on objects have been demonstrated in typically developing infants (Libertus et al., 2016; Wiesen et al., 2016), long-term effects of sticky mittens training for at-risk infants remains unknown. Future research is needed to resolve these questions.

Finally, it is unlikely that infants' learning during a single 10-min training period is truly the same as the learning that takes place during daily 10-min sessions over 2 weeks. This short-term learning is probably less robust in many ways—more easily disrupted, shorter lasting, and possibly less generalizable. However, the short-term effects observed here may provide a foundation for further learning such as the longer term effects observed in previous studies. Clearly, there are many questions still to be addressed about how infants learn about the world around them. Working to find answers to these questions will help to solve the many remaining mysteries regarding how infants learn from the experiences they encounter early in life.

Acknowledgments

This research was supported by National Institute of Child Health and Human Development (NICHD) Grant HD057120 to A.W.N. We thank Meg Saylor for suggestions on a previous version of the manuscript, Kate O'Doherty and Gabrielle Strouse for help with the statistics, Stephanie Diguiseppi and the undergraduates working at the Infant Perception Lab at Duke University for their help with the data collection and coding, the research team at the Infant Learning Lab at Vanderbilt University, and the parents who graciously allowed their infants to participate in these studies.

References

Adolph, K. E. (1997). Learning in the development of infant locomotion. *Monographs of the Society for Research in Child Development, 62*(3, Serial No. 251).
Adolph, K. E. (2000). Specificity of learning: Why infants fall over a veritable cliff. *Psychological Science, 11*, 290–295.
Adolph, K. E., & Avolio, A. M. (2000). Walking infants adapt locomotion to changing body dimensions. *Journal of Experimental Psychology: Human Perception and Performance, 26*, 1148–1166.
Bahrick, L. E., & Lickliter, R. (2000). Intersensory redundancy guides attentional selectivity and perceptual learning in infancy. *Developmental Psychology, 36*, 190–201.
Bahrick, L. E., & Lickliter, R. (2002). Intersensory redundancy guides early perceptual and cognitive development. *Advances in Child Development and Behavior, 30*, 153–187.
Bahrick, L. E., & Lickliter, R. (2012). The role of intersensory redundancy in early perceptual, cognitive, and social development. In A. Bremner, D. J. Lewkowicz, & C. Spence (Eds.), *Multisensory development* (pp. 183–205). Oxford, UK: Oxford University Press.
Bahrick, L. E., & Watson, J. S. (1985). Detection of intermodal proprioceptive–visual contingency as a potential basis of self-perception in infancy. *Developmental Psychology, 21*, 963–973.
Bornstein, M. H., Hahn, C.-S., & Suwalsky, J. T. D. (2013). Physically developed and exploratory young infants contribute to their own long-term academic achievement. *Psychological Science, 24*, 1906–1917.
Bourgeois, K. S., Khawar, A. W., Neal, S. A., & Lockman, J. J. (2005). Infant manual exploration of objects, surfaces, and their interrelations. *Infancy, 8*, 233–252.
Clarkson, M. G., & Clifton, R. K. (1985). The effects of sound duration on newborns' head orientation. *Journal of Experimental Child Psychology, 39*, 20–36.
Clarkson, M. G., Morrongiello, B. A., & Clifton, R. K. (1982). Stimulus–presentation probability influences newborns' head orientation to sound. *Perceptual and Motor Skills, 55*, 1239–1246.
Cohen, L. B. (2004). Uses and misuses of habituation and related preference paradigms. *Infant and Child Development, 13*, 349–352.
DeCasper, A. J., & Carstens, A. A. (1981). Contingencies of stimulation: Effects on learning and emotion in neonates. *Infant Behavior and Development, 4*, 19–35.

DeCasper, A. J., & Spence, M. J. (1986). Prenatal maternal speech influences newborns' perception of speech sounds. *Infant Behavior and Development, 9*, 133–150.
Fantz, R. L. (1964). Visual experience in infants: Decreased attention to familiar patterns relative to novel ones. *Science, 146*, 668–670.
Gerson, S. A., & Woodward, A. L. (2013). Learning from their own actions: The unique effect of producing actions on infants' action understanding. *Child Development, 85*, 264–277.
Gibson, E. J. (1988). Exploratory behavior in the development of perceiving, acting, and the acquiring of knowledge. *Annual Review of Psychology, 39*, 1–41.
Held, R., & Hein, A. (1963). Movement-produced stimulation in the development of visually guided behavior. *Journal of Comparative and Physiological Psychology, 56*, 872–876.
Hepper, P. G. (1991). An examination of fetal learning before and after birth. *Irish Journal of Psychology, 12*(2), 95–107.
Kaplan, P., Fox, K., Scheuneman, D., & Jenkins, L. (1991). Cross-modal facilitation of infant visual fixation: Temporal and intensity effects. *Infant Behavior and Development, 14*, 83–109.
Kisilevsky, B. S., Hains, S. M. J., Jacquet, A.-Y., Granier-Deferre, C., & Lecanuet, J. P. (2004). Maturation of fetal responses to music. *Developmental Science, 7*, 550–559.
Libertus, K., Joh, A. S., & Needham, A. W. (2016). Motor training at three months affects object exploration 12 months later. *Developmental Science, 19*, 1058–1066.
Libertus, K., & Landa, R. J. (2014). Scaffolded reaching experiences encourage grasping activity in infants at high risk for autism. *Frontiers in Psychology, 5*. http://dx.doi.org/10.3389/fpsyg.2014.01071.
Libertus, K., & Needham, A. (2010). Teach to reach: The effects of active vs. passive reaching experiences on action and perception. *Vision Research, 50*, 2750–2757.
Libertus, K., & Needham, A. (2011). Reaching experience increases face preference in 3-month-old infants. *Developmental Science, 14*, 1355–1364.
Libertus, K., & Needham, A. (2014). Encouragement is nothing without control: Factors influencing the development of reaching and face preference. *Journal of Motor Learning and Development, 2*, 16–27.
Libertus, K., Sheperd, K. A., Ross, S. W., & Landa, R. J. (2014). Limited fine motor and grasping skills in 6-month-old infants at high risk for autism. *Child Development, 85*, 2218–2231.
Morrongiello, B. A., Clifton, R. K., & Kulig, J. W. (1982). Newborn cardiac and behavioral orienting responses to sound under varying precedence–effect conditions. *Infant Behavior and Development, 5*, 249–259.
Needham, A., Barrett, T., & Peterman, K. (2002). A pick-me-up for infants' exploratory skills: Early simulated experiences reaching for objects using "sticky mittens" enhances young infants' object exploration skills. *Infant Behavior and Development, 25*, 279–295.
Needham, A., Joh, A. S., Wiesen, S., & Williams, N. (2014). Effects of contingent reinforcement on infants' object-directed reaching. *Infancy, 19*, 496–517.
Needham, A., & Libertus, K. (2011). Embodiment in early development. *Wiley Interdisciplinary Reviews: Cognitive Science, 2*, 117–123.
Palmer, C. F. (1989). The discriminating nature of infants' exploratory actions. *Developmental Psychology, 25*, 885–893.
Rakison, D. H., & Krogh, L. (2012). Does causal action facilitate causal perception in infants younger than 6 months of age? *Developmental Science, 15*, 43–53.
Rochat, P. (1989). Object manipulation and exploration in 2- to 5-month-old infants. *Developmental Psychology, 25*, 871–884.
Rochat, P., & Striano, T. (1999). Emerging self-exploration by 2-month-old infants. *Developmental Science, 2*, 206–218.
Rovee-Collier, C. K., & Gekoski, M. (1979). The economics of infancy: A review of conjugate reinforcement. In H. Reese & L. Lipsitt (Eds.). *Advances in child development and behavior* (Vol. 13, pp. 195–255). New York: Academic Press.
Ruff, H. A. (1984). Infants' manipulative exploration of objects: Effects of age and object characteristics. *Developmental Psychology, 20*, 9–20.
Ruff, H. A. (1986). Components of attention during infants' manipulative exploration. *Child Development, 57*, 105–114.
Sirois, S., & Mareschal, D. (2004). An interacting systems model of infant habituation. *Journal of Cognitive Neuroscience, 16*, 1352–1362.
Skerry, A. E., Carey, S. E., & Spelke, E. S. (2013). First-person experience reveals sensitivity to action efficiency in prereaching infants. *Proceedings of the National Academy of Sciences of the United States of America, 110*, 18728–18733.
Sommerville, J. A., Woodward, A. L., & Needham, A. (2005). Action experience alters 3-month-old infants' perception of others' actions. *Cognition, 96*, B1–B11.
ter Schure, S., Mandell, D. J., Escudero, P., Raijmakers, M. E. J., & Johnson, S. P. (2014). Learning stimulus–location associations in 8- and 11-month-old infants: Multimodal versus unimodal information. *Infancy, 19*, 476–495.
Thelen, E. (2005). Dynamic systems theory and the complexity of change. *Psychoanalytic Dialogues, 15*, 255–283.
Wiesen, S. E., Watkins, R. M., & Needham, A. W. (2016). Active motor training has long-term effects on infants' object exploration. *Frontiers in Psychology, 7*. http://dx.doi.org/10.3389/fpsyg.2016.00599.