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Investigating the Relation Between Infants' Manual Activity With Objects and Their Perception of Dynamic Events

Heidi A. Baumgartner and Lisa M. Oakes
Center for Mind and Brain & Department of Psychology University of California

We examined the relation between 6- and 7-month-old infants' (N = 60) manual activity with objects during free play and their perception of the features of dynamic, multimodal events. Infants were habituated to a single event in which a hand reached for and manipulated a colorful, multifeatured object, and a sound was heard (e.g., a hand squeezed a purple round object, causing a whistling sound) and then their response to events that involved a change in the appearance of the object, the action, or the sound was assessed. Infants responded least to changes in the appearance of the objects, and their sensitivity to this feature was related to their manual activity with objects during free play. Infants' responding to changes in the sound or action was unrelated to motor activity, suggesting that at this age motor achievements related to object exploration are associated with infants' perception of some, but not all, object features.

Although documenting the emergence and development of the abilities that infants possess is a critically important component of understanding development, developmental science must address the difficult question of *how* infants learn (Amso & Casey, 2006; Johnson, Slemmer & Amso, 2004; Thelen & Smith, 2006). Theorists have long been interested in relations between motor and perceptual development (Gibson, 1988), and research

Correspondence should be sent to Lisa M. Oakes, The Center for Mind and Brain, UC Davis, 267 Cousteau Place, Davis, CA 95618. E-mail: lmoakes@ucdavis.edu

has shown that changing motor abilities seem to influence relevant perceptual abilities (Adolph, 1997; Campos, Bertenthal & Kermoian, 1992). Moreover, there appear to be broad connections between perceptual and motor development. For example, crawling experience seems to influence infants' perception of causality (Cicchino & Rakison, 2008) and reaching and picking up objects seems to influence infants' visual perception of objects and events (Needham, 2000; Perone, Madole, Ross-Sheehy, Carey & Oakes, 2008; Soska, Adolph & Johnson, 2010). Increasing evidence suggests that motor experience actually can induce development in perceptual processes; for example, providing infants with "artificial" experience picking up objects (using "sticky mittens" in which infants who have not yet developed the ability to pick up objects are given experience picking up objects with a swiping action) demonstrate that manual acts actually *cause* changes in visual perception (Libertus & Needham, 2010, 2011).

In one study, Perone et al. (2008) found that infants' manual exploration of one set of objects during play was related to their perception of dynamic multimodal events involving a different set of objects. Perone et al. observed infants in two assessments. One task evaluated infants' perception of a dynamic, multimodal event in which a hand reached for a colorful, multifeatured object, grasped the object and performed an action (such as squeezing, inverting, or rolling), and an interesting sound (such as a click, a whistle, or a squeak) was heard. Following habituation to a single event, infants' responses two test events were observed: in one test event, only the appearance of the object changed (i.e., the hand performed the familiar action, resulting in the familiar sound, on a new object); in the other test event, the combination of action and sound (referred to in the study as *function*) changed (i.e., the hand performed a new action, resulting in a new sound, on the familiar object). In general, infants responded more to the change in function than to the change in appearance (see also Horst, Oakes & Madole, 2005). The other task assessed infants' manual exploration of objects (i.e., number of times infants picked up an object, latency to pick up an object) during a play session. Higher levels of manual activity during the play session were associated with stronger responses to a change in *appearance,* but manual activity was unrelated to responses to a change in *function* in the habituation task. These results suggest that infants' manual activity is related to only some aspects of infants' visual perception of objects in dynamic events. However, this study leaves unanswered questions about why infants' manual activity in the play session was related to their perception of some types of changes but not others.

We sought to provide further understanding into what specific aspects of visual inspection are related to manual activity. Processing such dynamic, multimodal events is demanding, and even 10-month-old infants seem to selectively attend to some of the features of these events (Horst et al., 2005). However, we know little about what aspects of infants' processing of such events are related to their manual activity. To address this question, we conducted a replication of Perone et al.'s (2008) study with several unique and important modifications. For example, we modified the habituation task to evaluate infants' responding to changes in *each of the individual features* of these events (the object appearance, the sound that was produced, and the action that was performed). Infants may more easily detect changes in multiple features (such as when both the sound and action changed in Perone et al.'s *function* condition), than changes in individual features (such as when only the appearance changed in Perone et al.'s *appearance* condition), presumably due to processes that are responsible for infants generally being more responsive to bigger changes than to smaller changes (Brennan, Ames & Moore, 1966; Hunter, Ames & Koopman, 1983; Kaplan & Werner, 1986). In this case, there may be a selective relation between manual activity and sensitivity to relatively small changes; in the present context, infants' manual activity may be related to their response to all changes of relatively small magnitude, such as when individual features change.

Alternatively, some features may simply elicit more attention from infants—they may be more salient or changes in those features may be more detectable than changes in other features. Individual differences may be observed only for infants' responding to the least salient features or least detectable changes. In general, when processing dynamic, multimodal events, infants attend to some features more than to others. Some studies have shown that infants are most sensitive to dynamic or action features. For example, Bahrick and colleagues (Bahrick, Gogate & Ruiz, 2002; Bahrick & Newell, 2008) observed that 5- to 7-month-old infants habituated to human actors performing actions (e.g., a woman brushing her hair) responded more to changes in the action than to changes in the physical appearance of the actor. In this case, motor development may be related to infants' attention to and perception of relatively static appearance features, but not to dynamic action features. Other work suggests that infants are most sensitive to features in some modalities. Robinson and Sloutsky (2004, 2007) observed that infants are differentially responsive to changes in auditory and visual features, supporting their claim that infants' perception of multimodal events is subject to *auditory overshadowing*. That is, modalities compete for attention and infants prioritize attention to auditory features over nonauditory features due to finite attentional resources and differences in processing speed by modality. In this case, motor development would be related to infants' attention to and perception of visual features but not auditory features in multimodal events.

A second modification we made to Perone et al.'s (2008) design concerned the order of the motor and visual perception assessments. Whereas in the previous study, the visual perception task was always administered first, we counterbalanced the order of the tasks. Counterbalancing task order allowed us to test the possibility that the correlation Perone et al. observed reflected infants' attention to (or lack of attention to) object appearance in the first task, inducing more or less activity with objects in the second task. To determine whether the relation between infants' manual activity and their perception of these events is general, and does not reflect the behavior in one task inducing behavior in the second task, we tested half of the infants with the habituation task before the object exploration task and half of the infants in the reverse test order.

Finally, in addition to the manual activity measures used by Perone et al. (2008), here we assessed infants' *coordinated visual-manual exploration*. Soska et al. (2010) found that infants' 3D completion in a visual habituation task was related to the duration of time they spent looking at an object, while holding and manipulating it in a separate task; other measures of manual exploration (that may or may not have been accompanied by looking) were unrelated to infants' performance on the 3D completion task. To determine whether this specific aspect of manual exploration is generally related to infants' responses in visual habituation tasks, we used a similar measure here.

We addressed these questions by assessing a sample of 6-month-old infants in habituation and play tasks like those used by Perone et al. (2008). We selected this age because the period between 5 and 7 months is when many aspects of motor development—including sitting and reaching—undergo dramatic changes (Adolph & Berger, 2006; Spencer, Vereijken, Diedrich & Thelen, 2000). During this time, there will be wide variation in the amount of experience infants will have in the acts of reaching for grasping and manipulating objects. Such differences may contribute to the developmental differences in infants' attention to and perception of the features in these dynamic events. We use individual differences in motor ability and activity as a proxy for developmental changes; we expect that in general such individual differences reflect differences in the aspects of development we are examining. Thus, when we test younger and older infants, we expect that their visual perceptual abilities are different, in part, due to differences in their motor abilities. To be clear, we do not believe that motor achievements are simply a general measure of overall developmental level. Indeed, we expect that motor achievements will be related to some aspects of infants' performance (such as their response to changes in appearance) but not to others (such as overall habituation performance), indicating that motor development has specific relations to aspects of visual perception.

METHOD

Participants

Participants were 60 6-month-old infants (*M* = 187.43 days, *SD* = 11.03 days, range = 162–207 days; 27 boys, 33 girls). All infants were healthy, full term, and typically developing. Thirty-six infants in the sample were White, eight were Asian, one was Black/African American, 11 were mixed race, one was reported as other race, and race was not reported for three infants; regardless of race, 13 of the infants in the sample were Hispanic. All of the mothers had attended college, and 47 mothers had at least a bachelor's degree.

A recruitment letter was sent to new parents in the area whose names were obtained from the state office of vital records. Parents who expressed an interest in participating were contacted to schedule an appointment. Infants received a small toy or book for participating.

An additional 29 infants were tested but excluded from the final analyses for the following reasons: fussiness (*n* = 3), experimenter error (*n* = 9), equipment failure (*n* = 1), parental interference (*n* = 2), outlier looking during test trials (their looking on the familiar test was more than 3 *SD* above the group mean, *n* = 2), or failure to meet the habituation criterion (*n* = 12, see Procedure section below).

We have reported elsewhere the results of the analyses of a different set of measures from this sample (Oakes & Baumgartner, 2012); all analyses reported here are unique.

Stimuli

The stimulus events presented during the habituation task were digitized movie clips of videotaped events. Each 7 sec event consisted of a hand reaching into the frame and acting on an object, producing a sound. The event was looped to play continuously for up to 35 sec. The objects were approximately 12.75 cm (7.30° visual angle) wide by 11.5 cm (6.58°) tall, and the actions occurred within a region approximately 18 cm (10.28°) wide by 14.5 cm (8.29°) high. Each event included one of four objects, one of four actions, and one of four sounds. The objects were different in color, overall shape, and the presence of features (see Figure 1; purple sphere, pink tube, yellow cube, multicolored pyramid); the actions were rolling, squeezing, inverting, pulling; the sounds were clicking, squeaking,

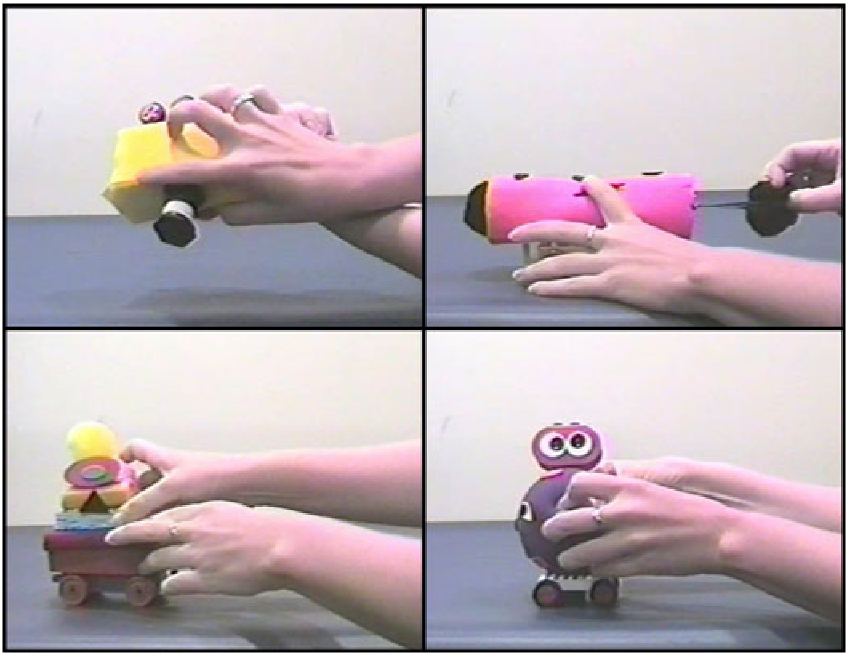

Figure 1 Examples of stimulus events used in the habituation task.

mooing, whistling. Each feature (object appearance, action, and sound) was completely crossed with each other feature to create 64 unique stimulus events (see also Baumgartner & Oakes, 2011; Perone et al., 2008).

Infants were given four commercially available graspable toys to play with during the object manipulation task. The toys were a multicolored cube with protruding shapes, an orange dog toy covered in bumps, a multicolored beaded loop, and a tubular "worm" toy (Figure 2).

Apparatus

Infants participated in two tasks: a habituation task and an object manipulation task. The habituation task took place in a dimly lit experimental room. The stimulus events were presented on a 61 cm (33.92° visual angle) by 46 cm (25.91°) region in the center of a 93.98 cm LCD monitor. A black curtain separated the room and had holes for the monitor and for a video camera located below the monitor. A trained experimenter sat behind the curtain and presented the stimulus events on the LCD monitor using an Apple G5 computer and specialized software (Cohen, Atkinson & Chaput, 2004). The object manipulation task took place in a different,

Figure 2 An infant in the object manipulation task.

brightly lit experimental room. A camcorder was used to capture a video recording of the session, which was later digitized.

Design and procedure

When they came to the laboratory, parents were asked about their infant's ability to sit independently (e.g., "Can your infant sit on his or her own?"); an experimenter who did not conduct any of the online observations posed this question out of hearing of the online observer, who remained unaware of the parent's response. Using the response to this question, infants were classified as "sitters" if parents reported that their infant could sit unassisted without using their hands (n = 24) and as "non-sitters" if parents reported that their infant could not sit unassisted or only could sit by supporting themselves with their hands (i.e., tripod sitters; n = 36). [Note that our primary interest was in manual activity, but infants' reaching and manual activity with objects is significantly influenced by their ability to sit independently (Adolph & Berger, 2006; Spencer et al., 2000); we therefore asked parents about sitting to allow us to determine how reaching is related to visual perception independent of sitting (i.e., by controlling for sitting in our analyses).] We did not conduct the sitting assessment used by Perone et al. (2008) to keep our sessions short. Although not reported there, Perone et al. observed a high level of agreement between in-laboratory assessments and parental report of sitting.

We conducted two experimental tasks (Habituation and Object Manipulation), order counterbalanced across infants (31 infants completed the habituation task first, and 29 infants completed the object manipulation task first). The particular order of the tasks was determined randomly, with the constraint that approximately equal numbers of boys and girls were tested in each order.

Habituation task

During the habituation task, the infant was seated on his or her parent's lap approximately 100 cm from the monitor. The experimenter observed the infant's looking behavior on a second monitor connected to the video camera located beneath the stimulus monitor. To minimize bias, parents wore felt-lined sunglasses and headphones playing classical music for the duration of the study to prevent them from seeing and hearing the stimulus events during the session.

Trials involved the presentation of a single event on the monitor. Both the onset and offset of the trials were infant-controlled. Prior to each trial, a green circle loomed in the center of the monitor and made a chirping noise to attract the infant's attention to the monitor. When the observer determined that the infant fixated this attention-getter, he or she initiated the trial by pressing a computer key, and recorded infants' looking time by pressing and holding a second computer key when the infant looked at the stimulus. The duration of this key press was recorded as the duration of the infant's looking on that trial. Trials continued until the infant looked away from the stimulus for at least 1 sec following at least 1 sec of looking, or until a maximum of 35 sec had elapsed. If no looking was recorded in the first 10 sec, the trial terminated and was repeated. A second trained observer recorded looking times from video for 23% of the infants. Agreement between observers for the duration of looking on each trial was high, average $r > .98$, and the mean difference in the duration of looking on each trial was low, $M < .62$ sec.

Infants were habituated to a single stimulus event of a hand acting on an object, producing a sound (across the 60 infants included, 31 different stimulus events were used as the habituation event). We used an overlapping window of three trials to calculate our habituation criterion. Infants were shown the same event on each trial until the look duration of any block of three consecutive trials decreased to 50% of the duration of looking on the first block of three trials, or until 18 trials had been presented. Therefore, the fewest possible number of trials to reach the habituation criterion was 4 (i.e., looking on Trials 2–4 was <50% of looking on Trials 1–3). Infants who completed all 18 habituation trials were only included in the final analyses if the duration of their looking to the final block of three trials (Trials 16–18) met the criterion for habituation (50% of looking to block 1).

Once this habituation criterion was met, infants were presented with five test events to assess their learning of each of the individual features contained in the habituation event. On the first test trial, infants were presented with the *familiar* event one more time to provide a measure of baseline looking that was not artificially low due to the use of a habituation criterion (Cohen & Menten, 1981; Oakes, 2010). Next, infants were shown three change test events: an *appearance change* event in which the familiar action and sound from the habituation event were presented with an unfamiliar object appearance, an *action change* event in which the familiar object and sound were presented with a novel action, and a *sound change* event in which the familiar object and action were paired with a novel sound. The order of these three test events was counterbalanced across infants. The last test was a *completely novel* test event that consisted of a novel object, action, and sound. This event was always presented last to ensure that infants were still engaged in the task and would dishabituate to a completely novel event.

Object manipulation task

During the object manipulation task, the infant was seated on a blanket on the floor (see Figure 2). Parents sat on the floor behind their infants, providing support as needed to prevent their infant from falling over; parents were instructed to provide support, but not to interact with the infant or toys. Providing support allowed all of the infants to use their arms to reach for objects, regardless of their ability to sit independently. Once the infant was settled, an experimenter placed the four toys within reach of the infant on the blanket. The location of the toys was randomized for each infant. Infants were then allowed to explore the toys for a 2 min videotaped natural play session. If the infant dropped or threw a toy out of reach, the experimenter returned the toy to within reach of the infant.

Coding

The play sessions were coded off-line from digitized recordings by a trained coder, unaware of parental report of sitting or the infants' responding during the habituation task. Coders used The Observer 5.0 (Noldus, 1991) to code infants' behavior for the 2 min following the moment the experimenter exited the frame after placing the toys in front of the infant. The sessions were coded frame by frame for each time the infant picked up and held an object, with one or two hands. *Holding* was defined as grasping an object, picking it up off the ground, and holding it above the ground for at least 1 sec. The coder pressed keys to record the start and end of each target behavior. A second trained coder coded 28% of the sessions and the agreement between raters was high, $\kappa = .89$, and the percent agreement between the two coders for the behavior coded at any moment was 91.7%. From this coding, we used routines in The Observer 5.0 to determine the three primary measures used by Perone et al. (2008) to allow a direct comparison of our results to those previous results: the number of times infants picked up an object, the latency to the first pick up, and the duration of holding episodes during the session.

The measures used by Perone et al. (2008) provide a good understanding to some aspects of infants' manual exploration, but they are limited in key ways. Soska et al. (2010) argue that *coordinated visual-manual exploration* is particularly important for object perception. In this previous investigation, infants' looking while holding and manipulating a single object was related to visual perception. Therefore, we also had coders record the duration that infants were looking at an object, while they held it with either one or two hands and conducted a separate set of analyses on this measure.

RESULTS

We conducted several different sets of analyses on these data. First, we analyzed the habituation and object manipulation tasks separately to provide descriptive information about how infants performed in these tasks, as well as to establish any effects of sitting status or task order on infants' responding. We tested our primary hypotheses about the relation between infants' behavior in the two tasks with a series of correlations. Initial analyses confirmed no effect of gender on any of the measures, so this factor was not included in any of the reported analyses.

Habituation task

We analyzed infants' responding during habituation and test phases separately. Their responding during habituation will provide insight into any differences in infants' behavior during learning (i.e., when they are attending to and encoding the habituation event) and their responding during test will provide insight into any differences in what infants actually learned and remembered about those events.

Tests of habituation

On average, infants required 8.2 trials to reach the habituation criterion. An analysis of variance (ANOVA) conducted on the number of trials required to reach criterion with Sitting Status (sitter, nonsitter) and Task Order (habituation task first or second) as between-subjects factors revealed no effect of sitting status, $F(1, 56) = 0.27$, $p = .61$, $\eta_p^2 = .005$, or task order, $F(1, 56) = 3.23$, $p = .08$, $\eta_p^2 = .05$. In general, infants did not vary in the number of trials they required to reach habituation as a function of these variables.

Next, we evaluated differences in infants' looking durations during habituation. The duration of infants' looking to the first block of habituation trials, the criterion block, the familiar test event, and the completely novel test event are presented in Figure 3. Clearly, infants decreased their looking over the course of habituation (as ensured by our inclusion only of infants who reached the habituation criterion) and increased their looking to a novel event. To confirm this impression and to investigate possible differences based on sitting ability or task order, infants' looking to each of these events was compared using a Trial Type (first habituation block, criterion block, familiar test, novel test) × Sitting Status (sitter, nonsitter) × Task Order (habituation task first or second) ANOVA. There

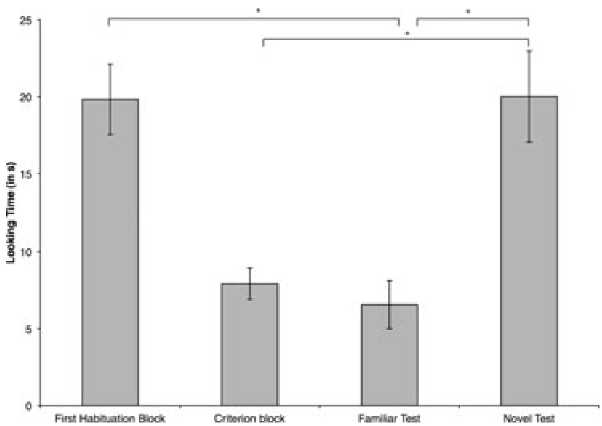

Figure 3 Infants' looking to the first block of habituation trials, the criterion block, familiar test trial, and completely novel test trial. Infants decreased their looking over the course of habituation, and increased their looking to a novel, but not familiar, test event. Error bars indicate 95% confidence intervals. Means that differed are indicated by an asterisk ($p < .001$). We did not compare infants' looking on the first habituation block and the criterion block as we used a habituation criterion, therefore this decrease will be significant by definition.

was a main effect of trial type, $F(3, 168) = 55.28$, $p < .001$, $\eta_p^2 = .50$ (see Figure 3). We evaluated this main effect with a series of paired two-tailed t-tests. We used Benjamini and Hochberg's (1995) false discovery rate (FDR) adjustment for evaluating the significance of these comparisons. In contrast to procedures that control for familywise error rate, such as Bonferroni, FDR procedures evaluate the probability that any of the "discoveries" (i.e., significant comparisons observed) are false. Benjamini and Hochberg's FDR adjustment provides a way of calculating the expected proportion of type I errors among all the observed significant results (see Verhoeven, Simonsen & Mcintyre, 2005 for a discussion), controlling for multiple comparisons when probing the source of an observed effect.

We conducted three comparisons: first habituation block vs. the familiar test, criterion block vs. novel test, and familiar test vs. novel test (because we used a criterion, we did not compare infants' looking to the first habituation block and the criterion block). All of these comparisons had p-values of $<.05$; thus, after applying the FDR our criterion for significance was $p \leq .05$. Infants' looked longer during the first habituation block than during the familiar test, $t(59) = 10.40$, $p < .001$, $d = 1.34$, indicating that they actually decreased their looking over the course of habituation. In addition, infants looked more during the novel test than during the criterion block, $t(59) = 8.22$ $p < .001$, $d = 1.06$, or the familiar test, $t(59) = 8.17$, $p < .001$, $d = 1.05$, indicating that they increased looking to novel events relative to the familiar item at the end of habituation. We can be confident, therefore, that infants habituated and that the familiar test is a good baseline for evaluating infants' dishabituation.

The ANOVA on infants' looking also revealed a significant interaction between trial type and sitting status, $F(3, 168) = 4.43$, $p = .005$, $\eta_p^2 = .07$. An inspection of the data revealed that this interaction is due to longer looking to the novel test trial by infants reported to be nonsitters ($M = 23$ sec) than sitters ($M = 15.5$ sec), $t(58) = 2.62$, $p = .01$, $d = .69$. Looking to the other trial types did not differ by sitting status, ps $> .13$. We conducted additional analyses to confirm that both groups of infants actually habituated to the familiar test and dishabituated to the novel test. Infants reported to be sitters robustly looked less to the familiar test than they did during the first habituation block, and they increased their looking to the novel test relative to both the familiar test and the criterion block, all $ps \leq .001$. These same comparisons for the nonsitting infants were significant, all ps $< .001$. Thus, although nonsitting infants looked longer to the novel test than did sitting infants, the interaction is not the result of only one group of infants habituating and responding to the novel test.

Importantly, there was no interaction between trial type and task order, $F(3, 168) = .24$, $p = .87$, $\eta_p^2 = .004$.

Tests of recovery of interest to novelty

We calculated dishabituation scores for each change test event by subtracting an infant's looking to the familiar test event from their looking to that test event; scores >0 indicate a preference for the change test. The scores in Figure 4 are all above zero, indicating that overall, infants looked longer to all three change trials (appearance, action, sound) than to the familiar test event. Our first analyses compared each of these scores to chance (0) to determine whether infants' dishabituation to any of the changes was significant, using one-sample, two-tailed *t*-tests. As a group, infants significantly increased their looking to a change in appearance, $t(59) = 3.64$, $p = .001$, $d = 0.47$, a change in action, $t(59) = 5.76$, $p < .001$, $d = 0.74$, and a change in sound, $t(59) = 5.58$, $p < .001$, $d = 0.72$.

To determine whether the dishabituation scores for the three types of change tests differed from each other, we entered these scores into a Change Type (appearance, action, sound) × Sitting Status (sitter, nonsitter) × Task Order (habituation task first vs. second) ANOVA. This analysis revealed that our predicted main effect of change type was marginally significant, $F(2, 112) = 2.77$, $p = .07$, $\eta_p^2 = .05$. We predicted, based on other work showing that infants respond more to auditory than to visual features in multimodal events (Lewkowicz, 1988; Robinson & Sloutsky, 2004, 2007), and the results reported by Perone et al. (2008), that infants would respond least to a change in appearance and most to a change in

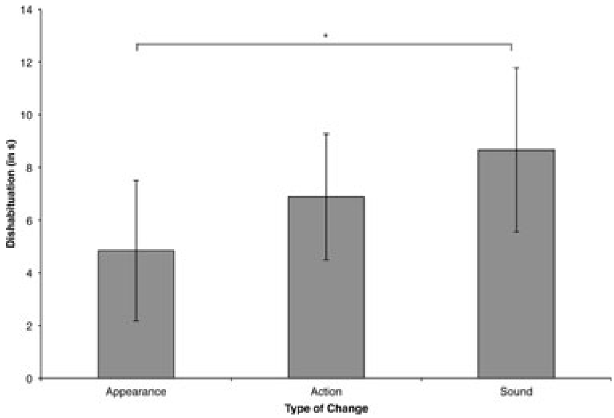

Figure 4 Infants' dishabituation scores for appearance change, action change, and sound change test trials. Dishabituation scores were calculated by subtracting looking to familiar test trial from looking to change trial. Error bars indicate 95% confidence intervals. All dishabituation scores were significantly greater than chance (0); scores that differed from each other ($p < .01$) are indicated by an asterisk.

sound. We tested these predictions by conducting a series of paired two-tailed *t*-tests on these dishabituation scores. In this case, because we are not probing the source of a significant effect, we used Bonferroni's correction to adjust for type 1 error. Infants dishabituated more to a change in sound than to a change in appearance, $t(59) = 2.69$, $p < .009$, $d = 0.35$; the other dishabituation scores did not differ significantly from one another. This pattern of results is generally consistent with previous findings that auditory features are more salient than other features in events (Lewkowicz, 1988; Robinson & Sloutsky, 2004, 2007) and suggest that the results reported by Perone et al. (2008), in which infants in this age range dishabituated more to a test event that involved a change in sound and action than to a test event that involved a change in appearance may have reflected infants' response to a change in sound alone.

The main ANOVA on the dishabituation scores did not reveal any effect of or interaction with task order, suggesting that there were no differences in infants' responding to the tests as a function of whether the habituation task came before or after the object manipulation task. In addition, the ANOVA did not reveal any effect of or interaction with sitting status. Because manual object exploration and sitting skill are related (Adolph & Berger, 2006; Spencer et al., 2000), this lack of an effect of sitting status on dishabituation may seem surprising. However, this pattern is generally consistent with Perone et al.'s (2008) observation that manual activity, but not sitting status, was related to dishabituation.

In general, therefore, infants in this sample attended to perceived and detected a change in the object appearance, the action performed, and the sound. However, infants responded more to changes in sound features than changes in appearance features, consistent with previous findings.

Object manipulation task

Three measures were adapted from Perone et al. (2008) and allowed for a direct comparison with the object exploration measures reported in that previous study: (a) the total duration of successful holds, (b) the latency to the first successful hold from the beginning of the session, and (c) the number of successful discrete "holds" of an object. In addition, we evaluated the duration of looking while holding individual objects, to approximate Soska et al.'s (2010) measure of coordinated visual-manual exploration.

To determine whether these object manipulation measures varied as a function of sitting ability or the order of the habituation and object manipulation tasks, we performed separate univariate ANOVAs for each target variable, with Sitting Status and Task Order entered as independent variables. Somewhat surprisingly, none of our measures varied with sitting ability (see Table 1; all *F*s < 1.65, *p*s > .21). Unlike other reports (Rochat & Goubet, 1995; Spencer et al., 2000), infants who could sit independently did not appear to have better object manipulation skills than infants who did not sit independently. The analyses also did not reveal significant main effects of task order (all *F*s < 2.57, *p*s > .11), indicating that the level of infants' activity with objects did not vary in general as a function of whether that task came first or second. In none of the analyses was the interaction between sitting status and task order significant (all *F*s < 2.00, *p*s > .16).

Correlations between infants' responding in the two tasks

Finally, we tested our main hypothesis that infants' manual activity with objects would be related to their visual perception of dynamic multimodal events by conducting correlations between the variables of interest. First, we conducted simple, or zero-order, correlations examining the relation between infants' dishabituation scores for each type of change in the habituation task and their total hold duration, latency to first hold, number of holds during the object manipulation task, and duration of looking while holding (see Table 2). Infants' dishabituation to a change in object appearance was significantly related to three of the object manipulation measures: holding duration, latency to first hold, and coordinated visual-manual exploration.

Replicating Perone et al. (2008), we found that longer duration of holding objects and shorter latencies to pick up objects were associated with greater dishabituation to a change in appearance in the habituation task.

TABLE 1
Measures of Object Manipulation Ability

	First Task	*N*	*Total Hold Duration (sec)*	*Latency to First Hold (sec)*	*Number of Holds*	*Looking While Holding (sec)*
Nonsitters	Object manipulation	15	39.12 (35.75)	56.29 (49.42)	2.80 (2.83)	11.62 (13.41)
	Habituation	21	31.19 (29.51)	49.57 (40.96)	2.71 (2.37)	11.09 (12.07)
	Total	**36**	**34.49 (32.02)**	**52.37 (44.12)**	**2.75 (2.53)**	**11.31 (12.46)**
Sitters	Object manipulation	14	43.27 (35.73)	30.65 (39.82)	4.29 (3.05)	14.52 (14.41)
	Habituation	10	23.85 (24.34)	57.88 (52.48)	3.10 (3.03)	8.68 (13.51)
	Total	**24**	**35.17 (32.39)**	**41.99 (46.50)**	**3.79 (3.04)**	**12.09 (14.05)**

Note. Values in parentheses are standard deviations.

TABLE 2
Zero-order and Partial Correlations Between Measures of Object Manipulation Ability and Infants' Dishabituation to Changes in Object Appearance, Action, and Sound

Dishabituation Scores	*Total Holding Duration (sec)*	*Latency to First Hold (sec)*	*Number of Holds*	*Looking While Holding (sec)*
Appearance dishabituation				
Zero-order correlation	.288*	−.320*	.142	.299*
Partial correlation[a]	.291*	−.306*	.111	.299*
Action dishabituation				
Zero-order correlation	.118	−.083	.056	.198
Partial correlation[a]	.166	−.127	.108	.215
Sound dishabituation				
Zero-order correlation	.034	.032	−.067	.016
Partial correlation[a]	.038	.062	−.111	.021

Note. Dishabituation scores were calculated by subtracting looking time measured in seconds to the familiar test event from looking time to each change test event.
[a]Controlling for age, sitting ability, and task order.
*$p < .05$.

No relations were found between measures of object manipulation and infants' looking to changes in action or sound (see Figure 5).[1] This pattern of correlations with the duration of holding replicated that reported by Perone et al. (2008). Unlike in Perone et al., however, the number of successful holds was not significantly correlated to any of the dishabituation scores.

Extending the results of Perone et al. (2008), we also found that infants' looking while holding was significantly correlated with infants' dishabituation to an appearance change, but not their dishabituation to a sound change or action change (see Table 2 and Figure 5). Infants who spent more time looking at objects while holding them during the toy play session dishabituated more to a change in appearance than did infants who spent less time engaged in visual-manual object exploration. This significant correlation shows that not only was the holding measure used by Perone et al. predictive of infants' attention to the features in the dynamic events use here, but the measure of coordinated visual-manual exploration used by Soska et al. (2010) also is predictive of infants' perception of the

[1]It should be pointed out that the same pattern was obtained when conducting these correlations just on infants' dishabituation to the first test item they received; the action measures were related to the dishabituation scores for infants who first received an appearance change ($n = 22$), not for infants who first received an action change ($n = 22$) or sound change ($n = 16$).

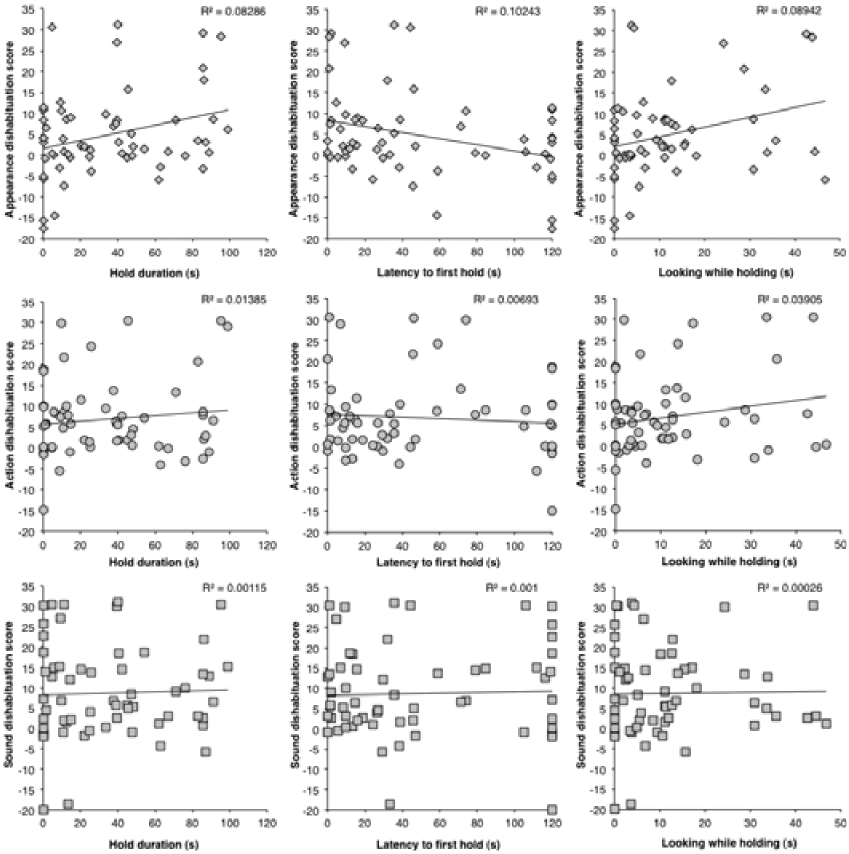

Figure 5 Scatter plots of the zero-order correlations between appearance (top row), action (middle row), and sound (bottom row) dishabituation scores from the habituation task and measures of object manipulation. Only the correlations shown in the top row (featuring the appearance dishabituation score) are significant.

events. Thus, this investigation not only provides more detailed understanding into how infants' attention to specific features is related to manual exploration, but also more detailed understanding into what aspects of manual activity are related to visual perception.

It is possible that the lack of a correlation between dishabituation to some tests and object manipulation may be due to ceiling effects—that is, all infants may dishabituate to a change in sound if that change is highly salient, and therefore, it would be difficult to observe a correlation between the level of dishabituation and infants' object exploration. However, as is clear in Figure 5, infants' responding to changes in all three features was highly variable. Thus, although the group mean was higher for sound and action change tests than for the appearance change test, the ranges of scores were comparable. In addition, infants' looking to the completely novel test was significantly longer than looking to the appearance change, action change, and sound change tests, all *p*s $< .024$, indicating that there was room to show greater dishabituation for all three change trials. Thus, the absence of a relation between object manipulation measures and changes in action or sound is not due to ceiling effects on those trials.

Finally, we performed partial correlations to ensure that the pattern of relations we found was not due to potentially mediating variables. Specifically, in these partial correlations, we controlled for age and sitting ability to address the possibility that the observed relations were due to general motor development rather than specific object manipulation abilities. We also controlled for task order to ensure that the relations between measures were not a function of the order in which infants completed the tasks. The partial correlations replicated the zero-order correlations and confirmed that object manipulation was associated with dishabituation to a change in appearance but not changes in sound or action (see Table 2). These partial correlations are particularly important given the possibility that the level of object manipulation may have varied for infants who could sit independently depending on whether it came before or after the habituation task. The fact that infants' activity with objects during the object manipulation task was correlated with their dishabituation to a change in appearance, even when sitting status and task order were controlled for, means that this effect is robust and is not influenced by small variations in the level of activity as a function of task order. Moreover, the fact that we observed these correlations when comparing the group as a whole means that the correlations observed by Perone et al. (2008) did not simply reflect the effect of infants' response during habituation on their subsequent object manipulation.

DISCUSSION

This experiment supports two conclusions. First, in these dynamic multimodal events, infants are less responsive to changes in object appearance than to changes in other features, confirming previous findings with these events (Baumgartner & Oakes, 2011; Perone et al., 2008). Second, infants' object manipulation abilities are related to their attention to the appearance of objects, but not their attention to the sound or action. Infants' duration of holding, latency to first hold, and the duration of looking while holding during the object manipulation task were related to their attention to changes in appearance during the habituation task.

Moreover, infants' exploration of one set of objects in one context is related to their perception of a completely different set of objects in a different context. Thus, infants' activity with items *in general* appears to be related to their attention and sensitivity to appearance of objects in such events *in general*. Indeed, we observed this relation regardless of the order in which the tasks were administered and when completely different sets of objects were used in the two tasks. This finding adds to a body of literature showing such relations between manual activity and perception when different objects are used in the two assessments. For example, Libertus and Needham (2010) found that sticky mittens training with one set of objects induced changes in infants' visual inspection of a different set of objects in a very different task. Soska et al. (2010) found a relation between infants' manual activity with toys and their ability to visually complete novel, computer-generated 3-D objects. This connection is not universal, however, as some studies have shown that manual experience with one set of objects generalizes only to infants' perception of events or actions with those same objects (Rakison & Krogh, 2012). Nonetheless, it does appear that in some contexts and for some aspects of visual perception, how infants explore objects *in general* is related to perception of objects *in general*.

Why is infants' manual activity related to their perception of or response to a change in appearance but not sound or action? It is important to recall that *appearance*, or the relatively stable surface features of the objects, in these events is the general type of feature that has been shown to be less salient or attended to in other studies (Bahrick et al., 2002; Perone et al., 2008; Robinson & Sloutsky, 2004). The events we used here are very complex—they involve objects with multiple parts, actions performed by a human hand, and sounds. We know that depending on the context, some features of such events are more salient than others (Bahrick, Hernandez-Reif & Flom, 2005; Bahrick et al., 2002) and that with age infants become responsive to more features in such complex dynamic events (Horst et al., 2005; Perone et al., 2008). One possible explanation for infants' selective attention to only some features in complex dynamic events is that when infants are overwhelmed with more information than they can successfully process, they select some information to focus on at the expense of other information. Robinson and Sloutsky (2004, 2007) have suggested that auditory information takes priority in such contexts. In this auditory overshadowing hypothesis, infants viewing multimodal displays preferentially attend to auditory information at the expense of visual processing. In the present study, infants' attention to the sound over appearance is consistent with the auditory overshadowing hypothesis and shows that in infancy, sound features in multimodal events are extremely salient. However, infants' responding to a change in action creates some ambiguity, and casts doubt that the effect reflects solely prioritized processing of auditory features. Specifically, infants' dishabituation to a change in action did not differ from either their dishabituation to a change in appearance or to a change in sound. However, the pattern of correlations with manual activity was similar for the dishabituation to sound and action changes. Thus, the results may also be seen as consistent with the conclusion that manual activity is related to infants' sensitivity to *dynamic* features (not just auditory features). For example, Bahrick et al. (2002) observed that when familiarized with a movie of a woman performing an action (e.g., brushing her hair), infants dishabituated to a movie of that same woman performing a different action (e.g., brushing her teeth) but not to a movie of a different woman performing the familiar action. Given that infants regularly encounter more information than they can process, they must select some information to process at the expense of other information. The results reported here, in combination with the general pattern of results from the work on auditory overshadowing and the work of Bahrick and her colleagues, suggest that when viewing complex, multimodal events infants selectively attend to and process the most dynamic, transient features at the expense of relatively static features such as object appearance.

Of course, the present results do not allow direct conclusions about how perceptual and motor abilities are related, but they suggest several possibilities. One possibility is that changes in motor abilities induce changes in visual perception. For example, Gibson (1988) suggested that changes in infants' abilities to act on the world provide new opportunities for learning about the physical properties of objects, such as shape, that offer affordances for action. In the present case, infants may become more attentive to physical properties of objects that afford action as they gain experience acting on objects. A different conception is that increased manual skill at manipulating objects induces new perceptual strategies for learning about the surface features of objects. The acts of fingering, rotating, grasping, holding, and so on, may help infants develop new visual inspection strategies for learning about object appearance. When presented with new information, infants use these strategies, revealing that infants with more experience manipulating objects are more sophisticated in their learning about object appearance, particularly in demanding contexts.

Although our data do not allow a direct test of this hypothesis, other reported findings suggest a causal explanation for the relation between manual activity and attention to object appearance observed here. For example, the work showing how experience with "sticky mittens" actually induces changes in visual perception is consistent with this explanation (Libertus & Needham, 2010; Sommerville, Woodward & Needham, 2005). Sommerville et al. (2005) showed how experience manipulating a set of objects (with the aid of sticky mittens) induced changes in how infants' perceived events involving those same objects. Libertus and Needham (2010) showed that experience with picking up objects induced changes in how infants perceived and explored new objects in a different context. These two studies show that at least under some conditions, infants' visual perception can be altered by experience manipulating objects.

Alternatively, infants' perception of events and objects may actually induce changes in motor development. This possibility is less well understood. Nevertheless, it is possible that changes in the perceptual system bootstrap motor development. As infants become more efficient processors, they might be better able to attend to less salient features (e.g., object appearance) as highly salient features (e.g., sound and action) become less dominant, and the relative salience of these features might in fact change over time (Bahrick et al., 2002; Robinson & Sloutsky, 2004). These changes to the way that infants process different types of information might increase infants' attention to the physical properties of objects relevant to object function, induce development of motor activities related to object manipulation (e.g., reaching, manipulating, fingering), and motivate infants to increase their exploration of objects in their environment. Indeed, investigations of computer vision algorithms have shown that functional features of objects are visually salient, particularly when seen in events in which actors manipulate objects, even to a viewer (i.e., a computer vision algorithm) that cannot act on objects itself (Nagai & Rohlfing, 2008, 2009).

A third possibility is that there are bi-directional influences between these two developing systems as predicted from a dynamic systems perspective (Thelen & Smith, 2006). That is, the two previously described possibilities are not mutually exclusive. It may be that not only do increasing motor skills induce changes in perception, but also that perceptual changes induce changes in motor abilities. Soska et al. (2010) make the dynamic systems argument that object exploration skills and perception are inextricably linked, with both abilities influencing the other. According to this perspective, both of the previous explanations are valid and are in fact two sides of the same coin. The acquisition of new motor skills allows for new opportunities to perceive objects, and perceptual abilities guide exploratory behaviors.

Of course, it is also possible that both object exploration and response during the habituation task may reflect general cognitive development, and there may not be a meaningful relationship between the measures used in this study. Rather, behavior in the two tasks might be related to a third, causal factor. However, age was not correlated to any of the object manipulation measures, *p*s > .08, and the relation between object manipulation and infants' attention to changes in appearance remained even when age and sitting experience were partialed out of the correlations. Therefore, any maturational effects would be independent of age in this narrow age range.

The results presented here, along with a growing body of the literature showing such relations (e.g., Libertus & Needham, 2010; Perone et al., 2008; Soska et al., 2010), strongly indicate that the relation between object exploration and object perception abilities is real and not simply a reflection of general development. Motor and perceptual abilities appear to be codeveloping, and rather than considering these two domains as isolated abilities that develop independently, results like these underscore the fact that these are aspects of the same developing individual. An important goal for infant research is to solve the "Humpty Dumpty" problem (Oakes, 2009), and to consider not only the development of isolated abilities, but to understand how abilities develop together as part of the whole child, allowing the emergence of new skills and abilities.

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