Developmental Psychology

Four-Month-Old Infants' Visual Investigation of Cats and Dogs: Relations With Pet Experience and Attentional Strategy

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We assessed the eye-movements of 4-month-old infants ($N = 38$) as they visually inspected pairs of images of cats or dogs. In general, infants who had previous experience with pets exhibited more sophisticated inspection than did infants without pet experience, both directing more visual attention to the informative head regions of the animals, particularly when comparing stimuli, and maintaining their attention to an individual animal, resisting the pull on their attention by the other visible animal. Individual differences in general attentional strategies as assessed during a pretest had similar but weaker relations to visual scanning patterns. There was some evidence that the 2 factors were interactively associated with visual inspection, supporting the findings of Kovack-Lesh and colleagues (Kovack-Lesh, Horst, & Oakes, 2008; Kovack-Lesh, Oakes, & McMurray, 2012) that infants' learning about and memory for this type of stimuli is jointly determined by pet experience and attentional style.

Keywords: infancy, eye-tracking, comparison, pets

Research on infants' cognitive development has revealed an impressive range of early skills: young infants can form categories, recognize physical violations, detect animacy, and remember events (see Carey, 2009, for review). Often in this research, looking is used to infer infants' knowledge or abilities. However, researchers disagree about the extent to which infants' looking reflects in the moment learning versus pre existing knowledge (e.g., Aslin, 2007; Haith, 1998; Mareschal, 2000; Pauen, 2002;

Schöner & Thelen, 2006; Willatts, 1997). Here, we elaborate a dynamic view that infants' pre existing knowledge in part shapes how they scan images in the moment, and this in turn influences what they learn. We address this by systematically examining how infants' visually inspect a set of stimuli as a function of their previous experience with similar items, their attentional abilities, and features of the stimuli.

Overlapping Influences in Infant Looking

The motivation for this work derives, in part, from the fact that gains in understanding infants' cognitive abilities have largely come from variants of familiarization and habituation/dishabituation paradigms. In such paradigms, infants are exposed to a series of stimuli, and their looking decreases as they become familiarized with those stimuli. At this point, infants' looking to novel stimuli is recorded. These procedures were originally developed to study memory and were adapted to assess other cognitive processes like categorization, face perception, and object representation (see Colombo & Mitchell, 2009, for a review). Importantly, inferences about infants' mental representations are made based on their looking to different stimuli (e.g., familiar vs. unfamiliar, possible vs. impossible). While this approach is widespread, researchers make different assumptions about whether infants' responding reflects their existing knowledge, or what they have learned about the statistical properties of the stimuli (Figure 1).

Infants' Looking as Reflecting Existing Knowledge

Some researchers have assumed that infants' looking largely reflects pre existing knowledge (Figure 1A). Novelty preferences after familiarization have been argued to reflect prior conceptual
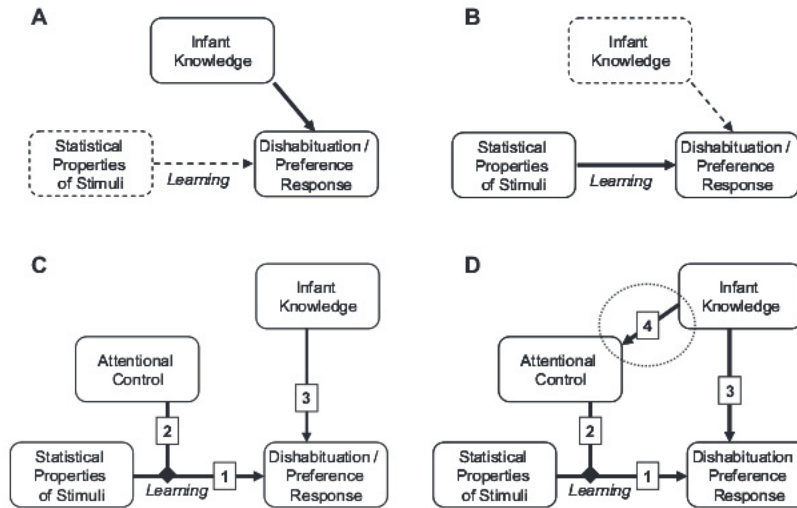
Figure 1. Theoretical accounts for the causes of behavior during infant looking studies. (A) Account stressing the primary role of pre-existing knowledge and skills in shaping dishabituation performance. (B) Learning accounts in which performance at test is largely constructed in the moment. (C) An additive account in which multiple factors influence performance. (D) A "learning-to-learn" account in which knowledge shapes how attention is deployed (Path 4) and that shapes learning.

knowledge rather than in-the-moment learning (Mandler & Mc-Donough, 1993; Pauen, 2002), and the violation-of-expectation response is assumed to reflect the understanding of the physical world that infants had coming into the lab (Baillargeon, 1987; Hespos & Baillargeon, 2001).

A less extreme assumption is that infants' looking need not *solely* reflect conceptual understanding, and work examining the role of experience in shaping learning about novel stimuli supports this assumption. Indeed, infants' face processing reflects differences in their daily experiences with particular types of faces (e.g., Asian or White faces; Bar-Haim, Ziv, Lamy, & Hodes, 2006; Kelly et al., 2005), and infants' looking in the lab to images of dogs and cats differs with daily exposure to pets (Hurley, Kovack-Lesh, & Oakes, 2010; Kovack-Lesh, Horst, & Oakes, 2008; Kovack-Lesh, Oakes, & McMurray, 2012). Daily experience can also *causally* influence visual processing. Bornstein and Mash (2010) provided infants with daily home exposure to a set of stimuli and on subsequent laboratory testing found them to be "pre-habituated." Scott and Monesson (2009) found that infants whose parents presented and labeled monkey faces at home over several months showed better discrimination of monkey faces. Clearly even if looking does not *solely* reflect conceptual understanding, it does to some extent reflect learning over long time scales (Figure 1A).

Infants' Looking as Reflecting Real-Time Learning Processes

Other researchers have assumed that infants' looking largely reflects in-the-moment learning of the statistical properties of the stimuli (Figure 1B), and at the extreme reflects no prior knowledge (e.g., Schöner & Thelen, 2006). For example, infants respond to different categorical contrasts (broad categories like "animal" vs. narrow categories like "dog" and "cat") depending on the variabil-

ity among familiarization stimuli (Oakes, Coppage, & Dingel, 1997; Quinn, Eimas, & Rosenkrantz, 1993; Younger, 1985), and this bottom-up learning has been confirmed in connectionist models of this task (e.g., Mareschal, Quinn, & French, 2002). Such findings might be taken to support an extreme view that infants do not "have" categories at all but learn them quickly in the laboratory.

Other research has shown that infants' on-line visual inspection *strategies* determine, in part, what they learn, consistent with the perspective that looking reflects in-the-moment learning. For example, infants who during a pretest exhibit briefer and more numerous looks with more shifts (i.e., *short lookers*), remember more or different information in a later task with different stimuli (e.g., Colombo, Mitchell, Coldren, & Freeseman, 1991; Freeseman, Colombo, & Coldren, 1993; Jankowski, Rose, & Feldman, 2001; Rose, Feldman, & Jankowski, 2003). Moreover, by experimentally manipulating infants' looking-styles, Jankowski et al. (2001) confirmed that these differences were *causally* related to their performance at test.

Eye-tracking studies further confirm that such differences in scanning style contribute to learning by demonstrating that precisely *what* infants look at shapes learning. Amso, Fitzgerald, Davidow, Gilhooly, and Tottenham (2010) found the proportion of time infants spent inspecting eye regions during familiarization with faces predicted their differentiation of facial expressions. Similarly, S. P. Johnson, Slemmer, and Amso (2004) found that when familiarized with a rod moving horizontally behind an occluder (e.g., Kellman & Spelke, 1983), infants who scanned the rod pieces and the path of motion more were more likely to prefer a broken rod over a complete rod (suggesting they perceived the original display as a unified rod). Thus, infants' learning is related to how looking is distributed—that is, how much time they spent looking at relevant features (eyes, rod pieces), and resisting irrel-

evant features (hairline, box)—establishing a connection between real-time attentional deployment (Figure 1B) and learning.

Interactions Between Familiarity and Attentional Control

An alternative, less extreme assumption is that looking in familiarity/preference paradigms reflects the interaction of preexisting knowledge and real-time learning processes (Figure 1C). That is, infants' responding during test may reflect their real-time processing of the stimuli given their existing knowledge. For example, Kovack-Lesh and colleagues (Kovack-Lesh et al., 2008; Kovack-Lesh et al., 2012) found that the only group of infants who learned images of cats were those who had relevant experience (a pet in their home) *and* engaged in more switching between stimuli during familiarization. The simplest explanation for this finding is that switching and background knowledge are largely independent and that only infants with enough background knowledge benefit from switching. In this case, Pathways 2 and 3 in Figure 1C account for this.

A more developmental alternative is that infants' background knowledge leads to differences in *how* they learn, as prior knowledge shapes how attention is deployed during learning (Figure 1D, Pathway 4). Indeed, much (if not all) of the effect of familiarity on learning (or test performance) may derive from differences in real-time attention, obviating the need for Pathway 3. This idea is consistent with what Adolph (2008) discussed as *learning to learn* in motor development, a concept that derives from ideas in animal learning (Harlow, 1949) and connectionism (Kehoe, 1988). Infants do not just acquire information or skills, but rather they learn how to adaptively and flexibly acquire information and use the skills demanded by context.

This idea leads to two predictions about the interaction between pre-existing knowledge and in-the-moment learning strategies. First, pre-existing knowledge should help infants more effectively learn about visual stimuli by focusing attention on the most relevant features and ignoring less diagnostic or important features (Figure 1D: Pathway 4). For animals, heads are more diagnostic than nonhead regions (Quinn, Doran, Reiss, & Hoffman, 2009; Quinn & Eimas, 1996). Thus, when presented with animals, infants with relevant experience (pets at home) are more effective at directing their attention to the heads than those without such experience. We can further illuminate this system by challenging attentional control with stimuli that are more difficult to process. In this case, two patterns of results are possible. On the one hand, infants with experience could be better at maintaining looks to informative head regions despite perceptual difficulty, suggesting a role of background knowledge in overcoming challenging situations. Alternatively, infants with relevant experience may respond *adaptively* (e.g., exhibit more looking to the head region), indicating that they can adjust their learning strategy in light of stimulus variations. In this case, attentional deployment would be more influenced by stimulus properties for experienced infants (i.e., infants with pets may show heightened looking to the head region when stimuli are in different poses).

The second prediction about how pre-existing knowledge and in-the-moment learning strategies interact is that prior knowledge should help infants *maintain* attention to particular stimuli in the face of distraction. For example, when presented with two stimuli that compete for attention (e.g., one at fixation and one in the periphery), infants generally have difficulty inhibiting the distracting stimulus (Oakes & Tellinghuisen, 1994); such distraction may make it difficult for infants to learn about the target stimulus, as their attention is pulled to the distracting stimulus before they have fully processed it. However, attentional control is influenced by target familiarity (Blaga & Colombo, 2006; Peltola, Leppänen, Palokangas, & Hietanen, 2008); thus infants with more relevant pre-existing knowledge may be able to better maintain attention to individual items than infants with less relevant pre-existing knowledge, allowing them to more fully process the initial target.

At first blush, this prediction may seem counterintuitive and contrary to previous findings that background knowledge and high levels of comparison of stimuli (as indicated by switching glances) together predicted learning (Kovack-Lesh et al., 2008; Kovack-Lesh et al., 2012). However, we assume that learning is a function of both being able to maintain attention in the face of distraction (e.g., inhibiting distraction when in the midst of processing) and being able to effectively compare stimuli. Previous research has shown that over development infants become increasingly good at inhibiting distraction during active processing (Oakes & Tellinghuisen, 1994), and infants are better at inhibiting distraction when processing stimuli that present more new information than when processing stimuli with less new information (Oakes, Kannass, & Shaddy, 2002). Thus, background knowledge may both help infants to maintain attention while they are learning about new stimuli and help them to effectively compare (by focusing on the most relevant features of the stimuli) when they do switch their gaze from one stimulus to the other. This should appear in different aspects of the fixation record, with better attentional maintenance appearing as enhanced fixations *within a stimulus*, while better comparison processes should only appear once infants have transitioned *between* stimuli as more transitions to and from informative regions of the stimulus.

The Present Investigation

We tested these predictions using eye tracking to assess 4-month-old infants' inspection of images of dogs and cats. We used the presence of a pet in the home as a quasi-experimental manipulation of background knowledge and presented pairs of items simultaneously to create a situation in which individual items must compete for attention. To challenge the perceptual system, we manipulated the nature of the pairs—whether the two animals were of the same type (e.g., two dogs) or different types (e.g., a dog and a cat), and whether the animals were in the same pose (e.g., both sitting) or in different poses (e.g., one sitting and the other standing). This manipulation allowed us to examine whether stimulus variation would have a greater influence on attentional control of infants with less relevant prior knowledge (i.e., those without pets at home). To map the predictions above onto dependent variables, we examined the looking time to head-and nonhead regions as a measure of whether infants were directing attention to the most relevant features, the number of transitions *within* an animal as a measure of how effectively infants could maintain attention in the face of a distractor, and the types of transitions *between* animals as a measure of what information was most relevant during comparison.

All of our predictions concerned real-time attentional deployment; however, a critical piece of our theoretical puzzle was how background knowledge and in-the-moment attention are related to learning. The predictions we outlined demanded a precise analysis of looking, necessitating an eye-tracking approach with a large number of trials. We also needed to manipulate perceptual difficulty (in particular, whether pairs came from same or different categories) to determine how familiarity changes attentional deployment in a variety of situations. To add a measure of learning, we would have needed to structure the trials to encourage habituation (using more similar stimuli from the same category) and examine posthabituation performance as a measure of learning. This protocol would have made it more difficult to evaluate our hypotheses as there would likely be fewer trials and less time looking at the screen (habituated infants are more likely to look away). Moreover, the critical perceptual manipulations would have needed to be between subjects (in addition to between-subjects variation in animal knowledge and looking), requiring a huge sample.

As an alternative, then, we developed an experimental paradigm in which we could be confident which infants would show learning, but we adapted the stimuli and trial structure to the unique demands of eye-tracking. Thus, we used items from the same stimulus set and with similar familiarization parameters (timing, spacing) as two previous studies with this age-group (Kovack-Lesh et al., 2008; Kovack-Lesh et al., 2012). In these studies, exposure to pets was related to categorization, particularly among infants who switched frequently. Thus, we knew which infants were most likely to learn, allowing us to relate the differences in scanning during training to the groups of infants who were likely to learn. Therefore, we could present all of the infants with the same conditions and measure how their responses differed, over many trials constructed to mimic the *familiarization* trials from prior categorization paradigms.

Method

Participants

The final sample included 38 infants who were 4 months old ($M = 124.59$ days, $SD = 6.84$; 20 girls and 18 boys). To determine whether infants had previous experience with pets, we asked the parents whether they had a pet that lived indoors at home or whether their infant was exposed to indoor pets elsewhere for at least 20 hr/week. From this information, we divided the sample into two groups: the *pet* group had 21 infants (13 with just dogs and eight with just cats) and the *no-pet* group had 17 infants. An additional 24 infants were excluded from the final analyses due to fussiness or excessive movement ($n = 4$), fixations to only one side (coded data were only to the left side, $n = 1$), experimenter error ($n = 3$), sibling interference ($n = 1$), failure to get a good track ($n = 8$), equipment error ($n = 3$), failure to complete the pretest ($n = 1$), or failure to complete the required number of trials (see Results section, $n = 2$). We also excluded one infant who had both a cat *and* dog at home because this situation seemed potentially different from daily exposure to a dog *or* cat. Thirty-six infants were White (not Hispanic), one infant was Hispanic, and one infant was biracial (American Indian and White). All mothers had completed high school, and 27 of them had a bachelor's degree

or higher. Participants were recruited from county birth records. They received a letter describing the study and then a follow-up phone call inviting them to participate.

Design

The experiment used two tasks. The first task presented was a standard *pretest*, identical to that used by Kovack-Lesh et al. (2012; see also, Jankowski et al., 2001) to capture attentional style. In this task, an observer recorded infants' looking to abstract, black-and-white geometric patterns online. The second task was the *experimental task*, which examined infants' inspection of pairs of dogs and cats. During this task, we recorded infants' point of gaze (POG) using an automatic eye tracker as they visually investigated pairs of animals presented side by side on a large monitor. Pairs varied on two factors: (a) whether the two animals were from the same categories (two cats or two dogs) or different categories (a cat and a dog) and (b) whether the two animals were in the same pose (sitting, standing facing right, or lying down). These two factors were crossed to create four types of pairs: same-category/same-pose, same-category/different-poses, cross-category/same-pose, and cross-category/different-poses pairs. A dog pair and a cat pair were created for each of the same-category pairs for a total of six pair-types.

Stimuli

Pretest stimuli were identical to those used previously (Kovack-Lesh et al., 2012) and were digitized images of the pretest stimuli used by Jankowski et al. (2001). They were approximately 19 cm wide by 42.5 cm, subtending approximately $27° \times 56°$ at 40 cm viewing distance. These were presented in pairs with a center-to-center distance of 60 cm.

Test stimuli consisted of 24 dogs and 24 cats used by Kovack-Lesh et al. (2012). Each individual image extended a maximum width of 32 cm and a maximum height of 24 cm (approximately $24° \times 18°$ visual angle at 75 cm viewing distance), and the center-to-center distance between the animals was 51 cm ($37.5°$ visual angle). Thus, the width of the total display was 83 cm ($58°$ visual angle). The pairs were presented on a gray background.

Attention-getting stimuli consisted of a repeated cycle in which a randomly selected colored shape loomed in the center of the monitor from a size of $0° \times 0°$ to $24° \times 24°$ visual angle in 1 s accompanied by randomly selected sound; when the shape reached its maximum size, the cycle repeated with a new shape and sound. There were six shapes (red and black triangle, green and blue circle, purple and white diamond, yellow and white star, blue and white hexagon, purple and green rectangle) and five sounds (purr, whistle, ping, glass chime, blowing sound).

Apparatus

Visual stimuli were presented on a 42-in Panasonic plasma monitor (Panasonic Corp. of North America, Secaucus, New Jersey) at 1024×768 resolution. Auditory stimuli were presented through Boston Acoustics speakers (Boston Acoustics, Inc., Peabody, Massachusetts) on either side. During the pretest, Habit software (Cohen, Atkinson, & Chaput, 2000) was used for stimulus presentation and for recording looking times, and infant look-

ing was monitored via a video camera below the monitor. A custom-built Macromedia Director script (Adobe Systems, Inc.) was used to present the experimental trials.

We used an ASL Pan/Tilt Model R6 remote eye tracker (Applied Science Laboratories, Bedford, Massachusetts) to assess infants' eye movements during the *experimental task* (see Aslin & McMurray, 2004; Oakes & Ellis, 2013, for a description of this set-up and infant eye-tracking in general). The eye tracker consists of an infrared camera that focuses on the eye and locates the pupil and corneal reflection. The camera was directly under the 42-in plasma monitor, approximately 75 cm from the infant. Infants wore a headband equipped with an Ascension Minibird magnetic head tracker (Ascension Technology Corp., Milton, Vermont) to compute head position, which the eye tracker used to refocus the camera on the eye if needed. The video output from the eye tracker was digitized at 30 fps on an Imagenation PXC200AL video capture card (CyberOptics Semiconductor, Minneapolis, MN), at a resolution of 320×240 pixels and saved as audio–video interleaves (AVIs) with MPEG-4 encoding.

Procedure

Infants were seated on their parents' lap approximately 40 cm (for pretest) or 75 cm (for eye tracking) from the monitor. Parents wore dark, occluding sunglasses to minimize bias.

The pretest was always administered first.[1] An experimenter, seated out of sight, initiated each trial. Before each pretest trial, an attention-getting gray circle loomed in the center of the screen accompanied by a whistle sound. When infants looked at this circle, the experimenter presented the two identical copies of the pretest stimuli, side by side, on each of two 15-s trials. An experienced experimenter recorded infants' looks to the left or right image. Reliability for the observers in this task is very good (see Kovack-Lesh et al., 2012, for details). After pretest, all infants received a 2–3 min break in another room.

After the break, an *observer* and a *stimulus-presenter* conducted the experimental phase. First, the stimulus-presenter presented animated movie clips to direct the infant's attention to the monitor, while the observer used the manual controls on the ASL system to move the camera so the eye was in view and focused. Once the eye was located, the eye tracker's automatic routines were initiated, allowing the camera to maintain focus using the pupil and corneal reflection as well as head position from the magnetic head tracker. Next, the eye tracker was calibrated. A colorful looming circle (accompanied by a sound) was presented first at the top left and then at bottom right of the monitor (11.5° above and to the left of center or 11.5° below and to the right of it). When the infant fixated the circle, the observer recorded the eye-position, and the next calibration stimulus was presented. Calibration generally took 1–3 min.

Next, the stimulus-presenter initiated the experimental trials. Each trial began with the looming attention-getter. When the stimulus-presenter (observing the infant via the low-light video camera), judged that the infant was looking at this, he or she initiated an experimental trial on which pairs of animals were presented for 10 s, accompanied by a randomly selected classical music clip from Pachelbel's *Canon in D* or Vivaldi's *Four Seasons: Spring*.[2]

On each trial, one of the six types of pairs described in the Design section was presented. Trials were grouped into blocks of six trials (one of each type, see Figure 2 for an example of a block) for up to eight blocks (for a total of 48 trials maximum). Note that because we had 48 individual stimuli and on each trial two images were presented, infants who completed all 48 trials would see each animal on more than one trial (but would be presented with a different animal on those trials). Given the large number of stimuli that were all similar to one another, it is unlikely that infants would remember those individual items. Within each block, each infant saw (in a random order) four *same-category* trials (two cat–cat trials and two dog–dog trials) and two *cross-category* trials; half the trials of each type were *same pose* trials. Trials continued until the infant became fussy or until all 48 trials were presented.

Coding

The recording produced by the eye tracker consisted of the stimuli presented on each trial with cross-hairs superimposed that indicated the location of the infants' point of gaze (POG) and an image of the infants' eye superimposed in the bottom right hand corner. Highly trained coders, unaware of the infants' pet status or the hypotheses being tested, used the Observer XT (Version 10; Noldus Information Technology, Leesburg, VA) to code POG. To ensure the cross-hairs reflected the infants' POG, coders recorded the location of the POG only when both the cross-hairs were superimposed on the stimulus and the right eye was visible (occasionally, the eye camera would focus on the left eye for which the right-eye calibration would not be valid). Coders did not code the POG if the eye was closed or if the right eye was not visible.

For each frame, the coders indicated whether the infants' POG was in one of five locations: head of the left animal, a nonhead region of the left animal, the head of the right animal, a nonhead region of the right animal, or not on either animal. POG was coded only when the cross-hairs remained in that region for three consecutive frames or 180 ms (to eliminate single frames in which the POG crossed through a region while moving between regions). Routines in the Observer calculated continued looking to that region until the coder indicated that the POG was directed to a different region. To establish reliability, two highly trained independent coders recorded the POG in this way for 11 infants. Reliability for the particular region coded on each frame was good, $\kappa = .83$, concordance between the two coders of 86%.

From the raw frame by frame coding, we extracted a number of key variables. First, we computed the total amount of looking accumulated to each of four target regions (head of left animal,

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[1] Although testing infants in a short pretest phase first may have introduced an order effect, this is the typical procedure (e.g., Freeseman et al., 1993; Jankowski et al., 2001; Kovack-Lesh et al., 2012). Moreover, individual differences are more easily interpreted if all infants receive the tasks in the same order. Therefore, because all infants were tested in the pretest before the experimental task, there should not be any systematic differences between groups of infants that may detract from our main goal.

[2] Although not widely reported, music is commonly presented during experimental trials in eye-tracking experiments (see, for example, Oakes & Ellis, 2013). The inclusion of music may influence infants' attention to visual stimuli, but because the music was present on every trial, and the particular musical selection on each trial was chosen at random, any effect of music on attention would not have had a systematic effect on infants' visual attention.
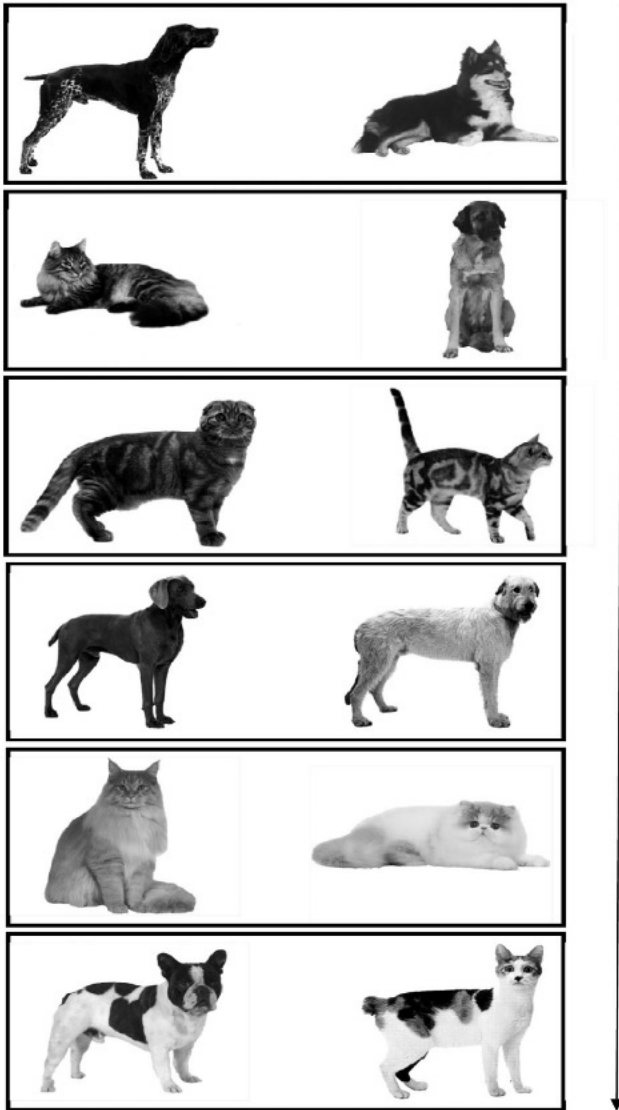
Figure 2. A block of six trials.

body of left animal, head of right animal, and body of right animal). Next, we determined the number of transitions between regions (head□ body within an animal, head□ head across animals and so on). Transitions (which are not the same as saccades) were identified each time the POG moved out of a region. Both within-animal transitions (from one region to the other region of the same animal) and between animal transitions were coded for the region (head or body) from which they originated and the region in which they terminated. In computing transitions from the raw coding, we ignored looks away from the stimulus (e.g., left-head□ nothing□ right-head was counted as a head□ head transitions), and transitions from one region to an off-stimulus location and back to that region (e.g., left-head□ nothing□ head) were not counted as transitions. We chose this method because we were not interested in oculomotor dynamics but rather in how infants compared different features of the animals.

Results

We evaluated a number of different measures to determine the relations among pet experience, general attentional strategies, and infants' visual inspection of these pairs. Our most important question was whether infants' background knowledge of animals was related to how they pick up information from the visual displays. To answer this question, we evaluated (a) looking time, both overall and to specific regions of interest, and (b) the number of transitions between one region or animal and the other. As in prior work (Kovack-Lesh et al., 2008), preliminary analyses revealed no differences in these measures as a function of whether infants in the pet group had dogs or cats. Thus, we collapsed across this variable and compared infants without pets with those with a pet of either kind.

These analyses included all infants who completed at least one trial for each of the six trial types. On average, infants contributed 24.11 ($SD = 11.61$, range 7–46) trials to the analyses. Infants without pets contributed marginally more trials ($M = 27.76$, $SD = 10.57$, range 7–46) than did infants with pets ($M = 21.14$, $SD = 11.80$, range 8–46), $t(36) = 1.80$, $p = .08$, $d = 0.58$.

This study was a "natural" experiment, as children could not be randomly assigned to pet groups or to exhibit a particular looking strategy during pretest. One concern with such a design is that the groups of infants may differ in other ways. For example, parents with pets may treat infants differently than parents without pets, resulting in general differences in development, or the two groups may have other spurious differences (e.g., if more boys, by chance, had pets than did girls). Although it is impossible to completely equate the groups, we did draw them from the same general population and equated them for variables such as age and gender distribution. However, to further rule out such factors, we first evaluated pretest performance to show that our groups were comparable on several variables that could have affected looking performance. After establishing that these groups are roughly equivalent, we turn to our primary analyses.

Preliminary Analyses

Comparing pet-groups. The pet groups were well balanced. They had similar proportions of boys (52% in the pet group and 41% in the no pet group) and did not differ in age—pet group: $M = 125.52$ days, $SD = 6.42$, and no pet group: $M = 123.41$ days, $SD = 7.37$, $t(36) = 0.95$, $p = .35$. More important, the groups did not differ on looking during pretest with abstract "neutral" stimuli: there were no significant differences between pet groups in the number of switches, pet group: $M = 2.88$, $SD = 1.77$, and no pet group: $M = 3.12$, $SD = 3.30$, $t(36) = 0.28$, $p = .78$; the duration of the peak look, pet group: $M = 2.90$ s, $SD = 1.41$ s, and no pet group: $M = 3.32$ s, $SD = 1.78$, $t(36) = 0.82$, $p = .42$; or the average total looking on the two trials, pet group: $M = 6.05$ s, $SD = 2.63$, and no pet group: $M = 6.73$, $SD = 2.91$, $t(36) = 0.76$, $p = .45$. This is crucial as these measures are closely related to the measures we evaluate on experimental trials but reflect looking to stimuli that are equally novel to both groups. Thus, any differences between groups on experimental trials are not likely due to general differences in looking but rather to effects of specific experience with animals on infants' processing of animal images.

Evaluating individual differences in looking. We next looked at differences in general attentional strategies. As in prior

studies (Colombo et al., 1991; Freeseman et al., 1993; Jankowski et al., 2001; Rose et al., 2003), we used the duration of the peak look during the pretest as a measure of general looking behavior. Because our infants did not cluster around a mean, we used peak look as a continuous variable. It was not correlated with age, $r(36) = .03$, or number of experimental trials completed, $r(36) = -.13$. T tests also revealed that boys ($M = 2.97$, $SD = 1.50$) did not differ from girls ($M = 3.19$, $SD = 1.68$), $t(36) = 0.41$, and that infants with pets ($M = 2.90$, $SD = 1.41$) did not differ from infants without pets ($M = 3.32$, $SD = 1.78$), $t(36) = 0.82$.

Experimental Trials

Our primary analyses were those of the experimental trials. Our design included pet group (pet/no pet) as a between-subjects factor, peak look as a continuous between-subjects factor and trial type (same-category/cross-category) and pose (same/different) as within-subject factors. To examine the interrelations among these variables and each derived measure of looking behavior, we conducted analyses of covariances (ANCOVAs) with these factors, using a fully saturated model in which longest peak look was treated as a continuous factor and allowed to interact with all other factors.[3] Peak look was centered before being entered into the model.

Total looking time. We first examined the coarsest measure, infants' total looking time to either animal during the trial. An ANCOVA with total look duration as the dependent variable revealed only a main effect of peak look, $F(1, 34) = 6.13$, $p = .02$, $\eta_p^2 = .15$. Infants who had longer peak looks during pretest (and would have been classified as *long lookers*) had shorter looking durations during the experimental trials, $r = -.37$. This effect is not surprising given that in previous studies infants who were classified as short lookers generally have been found to be more sophisticated on subsequent perception and memory tasks than long lookers (e.g., Colombo et al., 1991; Freeseman et al., 1993; Jankowski et al., 2001; Rose et al., 2003).

Looking to specific features. Although overall looking time had little relation to the variables of interest, we expected to see differences in how infants distributed their looking to the head regions versus the nonhead regions, as prior work has shown heads to be more diagnostic (Quinn & Eimas, 1996), and even naïve 6 month old infants are biased to fixate heads of dogs and cats (Quinn et al., 2009). For each trial type, we computed the proportion of total looking time devoted to heads by dividing the duration spent on the heads by the duration of looking to both regions. We used this proportional measure (rather than absolute looking time) to control for differences in overall looking. These scores were entered into the ANCOVA described earlier.

The analysis revealed a significant effect of pet group, $F(1, 34) = 5.31$, $p = .03$, $\eta_p^2 = .14$. Infants with pets devoted proportionately more looking to the head region ($M = 0.54$, $SD = 0.17$) than did infants without pets ($M = 0.49$, $SD = 0.18$). This finding supports our main prediction: Infants with pets are better able to direct attention to the most meaningful region of novel images of cats and dogs. Peak look was also significant, $F(1, 34) = 9.96$, $p = .003$, $\eta_p^2 = .23$. Infants with longer peak looks looked less at heads, $r = -.49$, consistent with the idea that long-looking infants are less sophisticated in learning new stimuli (Colombo et

al., 1991; Freeseman et al., 1993; Jankowski et al., 2001; Rose et al., 2003). Pet group and peak look did not interact, $F < 1$.

The main effect of pose also was significant, $F(1, 34) = 5.44$, $p = .03$, $\eta_p^2 = .14$. Infants devoted proportionately more looking to heads when viewing pairs of animals in different poses ($M = 0.51$, $SD = 0.21$) than in the same pose ($M = 0.44$, $SD = 0.19$; see Figure 3). There was also a significant three-way interaction of trial type, pose, and peak look, $F(1, 34) = 6.92$, $p = .01$, $\eta_p^2 = .17$. To examine this interaction, we analyzed each trial type separately (Figure 3, left and right sides). For same-category trial types, we found a main effect of pose, $F(1, 34) = 9.88$, $p = .003$, $\eta_p^2 = .23$, and no interaction with looking ($F < 1$). Regardless of level of peak looking, infants had higher proportion of looking to the heads when the animals were in different poses. In contrast, for cross-category trial types the effect of pose was not significant, $F(1, 34) = 1.48$, $p = .23$, $\eta_p^2 = .04$, but the interaction of pose and peak look was significant, $F(1, 34) = 5.64$, $p = .023$, $\eta_p^2 = .14$. When infants had longer peak looks, the proportion of their looking to the head region was uniformly low, regardless of whether the animals were in the same or different poses.

As a whole, short lookers and pet owners tended to fixate the more relevant head regions more, suggesting a role of background knowledge and individual differences in visual attention. At the same time stimulus factors also played a role as animals with different poses tended to drive infants to focus on the more diagnostic head-regions. However, when the animals differed, only the more advanced short lookers maintained this strategy.

Transition analyses. In the final analyses, we evaluated the quality of infants' visual scanning by analyzing the transitions between regions. Transitions were defined as any time infants' gaze moved from one region to another, whether within the same animal (e.g., from the head to the body) or between two animals (e.g., from one head to the other head).

Transitions within and between animals. First, we compared the proportion of transitions within and between animals (regardless of the specific region). We calculated the proportion of within animal transition by dividing the number of transitions within an animal by the total number of transitions. A high proportion of within-animal transitions indicates that infants *focus* their attention on an individual animal, resist attending to the other animal, and maintain attention in the face of distraction. A lower proportion of within-animal transitions would indicate that infants are more easily distracted by the competitor, shifting attention between the two animals. Infants of this age have difficulty maintaining attentional focus in this way (Ruff & Rothbart, 1996).

The average proportions of within-animal transitions were entered into an ANCOVA with pet group and peak look (continuous) as between-subjects factors, and trial type and pose as within-subject factors (Figure 4). Two infants with pets failed to make any transitions in one of the cells; these two missing means were replaced with the Trial Type $\times$ Pose cell means (an analysis excluding these infants yielded the same results).

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[3] Note that in the SPSS implementation of ANCOVA (general linear model), shared variance between covariates and factors is split between them, rather than being assigned to the covariate. Thus, this model is more similar to an analysis of variance with continuous factors (or a hierarchical regression) than the traditional conception of an ANCOVA.
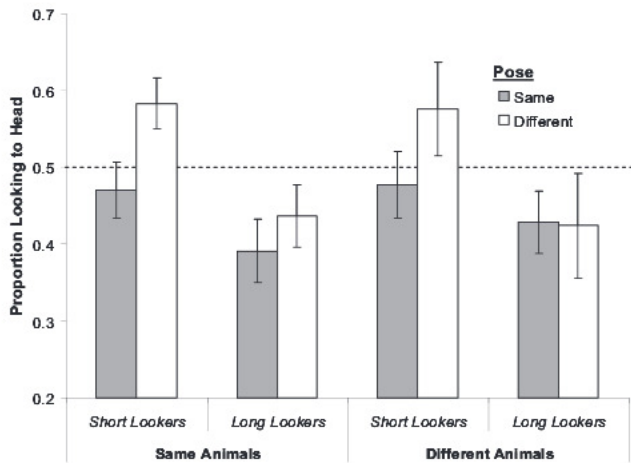
Figure 3. Proportion of looking time to head as a function of peak looking, trial type, and pose. Note that for ease of presentation, peak looking has been collapsed to a dichotomous factor with a median split (even as it was treated as continuous in the analysis). Error bars represent ± 1 standard error computed across subjects within the Trial Type $\times$ Pose $\times$ Peak-Look Group. Dashed line indicates equibiased looking. Values below this line indicate that infants were more likely to look away from the head (toward the body); values above this line indicate that infants were biased to look to the head.

This analysis revealed a significant main effect of pet group, $F(1, 34) = 7.97$, $p = .008$, $\eta_p^2 = .19$. Infants with pets made a higher proportion of their transitions within animals ($M = 0.62$, $SD = 0.11$) than did infants without pets ($M = 0.51$, $SD = 0.12$). This finding suggests that infants with pets were better able to resist the distracting effect of the other item (and therefore spent longer times looking at one animal before moving to the other animal).

The analysis also revealed a significant effect of peak look, $F(1, 34) = 5.73$, $p = .02$, $\eta_p^2 = .14$. Infants with longer peak looks had fewer within-animal transitions, $r = -.41$. Again, as short looking is assumed to reflect a more sophisticated attentional strategy (Colombo et al., 1991; Freeseman et al., 1993; Jankowski et al., 2001; Rose et al., 2003), the higher proportion of within-animal transitions shown by short lookers, like the pet group, may reflect more sophisticated attentional control, perhaps reflecting greater ability to resist the distracting influence of the second animal.

This analysis revealed three additional marginally significant interactions: Trial Type $\times$ Peak Look, $F(1, 34) = 2.93$, $p = .096$, $\eta_p^2 = .079$; Pose $\times$ Pet-group, $F(1, 34) = 3.1$, $p = .088$, $\eta_p^2 = .083$; and Trial Type $\times$ Pose $\times$ Pet Group, $F(1, 34) = 3.4$, $p = .074$, $\eta_p^2 = .091$. We did not analyze these marginal effects further but as will be seen later the Trial Type $\times$ Pose $\times$ Pet Group interaction emerged as significant in our next analyses of the transitions.

Transitions involving head. In our final analyses, we evaluated only transitions *between* animals, as we were interested in what information infants use specifically when comparing animals. In particular, we examined the likelihood that a transition involved the head regions to determine if infants were more likely to direct their gaze to the highly informative head regions when comparing animals. This question was examined as a function of pet group, peak look, and stimulus characteristics. We report here an analysis

of the proportion of between-animal transitions that involved the head of either animal (either as the starting or ending location). An additional analysis on the proportion of just those between-animal transitions that ended in the head yielded highly similar results, so we report here just the first measure.[4]

Seven infants failed to have transitions between animals in at least one Trial Type $\times$ Pose cell (all of these had pets). We replaced these missing data points with the Trial Type $\times$ Pose cell means (an analysis that ignored the subjects with missing data showed similar results). Infants with pets had more between-animal transitions involving the head ($M = 0.71$, $SD = 0.19$) than did infants without pets ($M = 0.50$, $SD = 0.19$), $F(1, 34) = 13.58$, $p = .001$, $\eta_p^2 = .29$ (see Figure 5A). Thus, not only did the analysis described earlier of infants' looking revealed that infants with pets looked more at the heads, but this analysis of the transitions involving heads revealed that they were more likely to be comparing animals while they did so. This did not necessarily need to be the case; infants with pets may have spent longer looking at heads when they fixated them, and at the same time the two groups may have had similar numbers of transitions into or out of the head. There was no significant effect of peak look, $F(1, 34) = 1.46$.

This analysis revealed two significant interactions: The Pet $\times$ Peak Look interaction was very close to significant, $F(1, 34) = 4.0$, $p = .052$, $\eta_p^2 = .11$, and the Trial Type $\times$ Pose $\times$ Pet Group interaction was significant, $F(1, 34) = 7.23$, $p = .01$, $\eta_p^2 = .18$, Figure 5B. Finally, the Pose $\times$ Pet Group $\times$ Peak Look interaction was marginal, $F(1, 34) = 3.2$, $p = .083$, $\eta_p^2 = .09$.

To further examine these interactions, we conducted separate ANCOVAs on infants with and without pets (since all three interactions involved pet group). With respect to the Pet $\times$ Peak Look interaction, we found that infants *without* pets had a main effect of peak look, $F(1, 15) = 6.13$, $p = .03$, $\eta_p^2 = .29$, while those with pets had no significant effect of peak look, $F(1, 19) = 0.16$. For infants without pets, peak look was positively correlated with the transitions involving the head, $r = .54$. Here, for infants with background knowledge, attentional style made little difference as they were already making many transitions to the head; in contrast, infants with little familiarity were able to partially compensate if they were short lookers.

The Trial Type $\times$ Pose $\times$ Pet Group interaction (Figure 5B), however, suggests differences as a function of stimulus characteristics. The no-pet group showed no significant main effects or interactions with trial type or pose. In contrast, the pet group showed a significant effect of pose, $F(1, 19) = 4.95$, $p = .038$, $\eta_p^2 = .21$, and a significant interaction of trial type and pose, $F(1, 19) = 5.19$, $p = .034$, $\eta_p^2 = .21$, suggesting an effect of stimulus characteristics for infants with experience. As shown in Figure 5B, for the infants with pets, there as a large effect of pose when the trial featured the same animals, $t(20) = 3.33$, $p = .003$, $d = 0.73$, with the most transitions involving the head when the animals were in the same pose. However, there was no effect when the animals differed, $t < 1$. This finding implies that infants with pets were strongly likely to be comparing animals on the basis of

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[4] Note that we did not conduct an analysis on just those transitions from one head region to the other. Such transitions were relatively infrequent, making it difficult to interpret the results obtained from such an analysis.
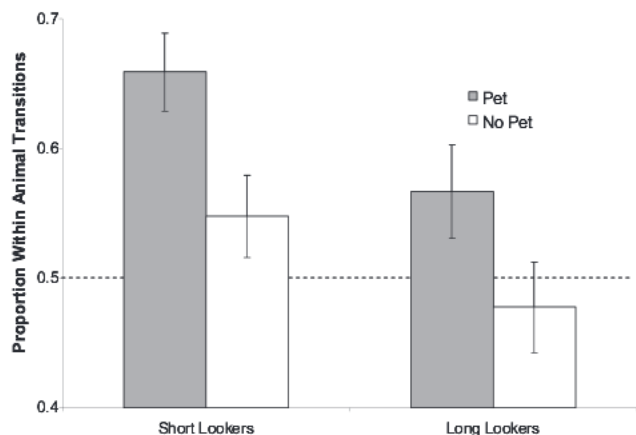
Figure 4. Proportion of within-animal transitions as a function of pet group and peak looking (dichotomized with a median split). Error bars represent ±1 standard error computed relative to the subjects in a given Pet × Look Group, across all of the within-subject factors.

heads for perceptually challenging nonalignable pairs that were in the same category.

Discussion

These results provide significant understanding into relations among infants' experience with pets, general attentional strategies, and visual inspection of animal stimuli. Our predictions about the relation between prior knowledge and attentional control were supported, suggesting that differences in experience and prior knowledge contribute to differences in in-the-moment learning strategies or processes (Figure 1D: Pathway 4).

First, we found that infants' adaptive control of attention directed to the most relevant features of the stimuli (for animals, the head regions; Quinn & Eimas, 1996) was related to their preexisting knowledge and experience. Infants with pets were more biased to look at the heads than were infants without pets. They spent a greater proportion of their looking time on the head, and more of their transitions between animals involved at least one head. Previously, Quinn et al. (2009) observed a head bias in 6- to 7-month-old infants without prior pet experience; Hurley and Oakes (2013) found that 4-month-old infants with and without pets preferred looking at the head regions, though the bias was stronger for infants who had pets at home. The present study extends these findings by showing that infants are biased toward head regions when presented with pairs of animals and that the bias does not vary whether the animals are from the same or different categories. In addition, by examining not only infants' overall looking durations but also their transitions between animals, we observed that this head bias can be observed when infants move their glance from one animal to another. We also once again demonstrated that the head bias is stronger in 4-month-old infants with pets. This finding fills a crucial missing gap suggesting that infants can bring background knowledge to bear on attentional deployment when comparing stimuli, a process that has been found to facilitate early categorization (Kovack-Lesh & Oakes, 2007; Oakes & Ribar, 2005).

Moreover, the present results indicate that infants with pets were better able to adaptively modulate their attentional strategies to facilitate learning about these stimuli. Not only did infants with pets show a stronger bias to look at the heads than did infants without pets, but they adjusted their scanning strategy in response to differences in the stimuli. When two items from the same category were more difficult to compare (i.e., they were in different poses), infants with pets showed a dramatic increase in the proportion of their transitions that involved head regions, perhaps because focusing more attention to the informative head regions may have facilitated detecting similarities and differences in this challenging stimulus context. In contrast, infants without pets did not adjust their scanning pattern in response to differences in the stimuli.

A similar finding was observed in overall proportion of looking to the head, where when animals were in different poses (the most challenging situation), infants devoted more looks to the head. However, here while pet familiarity did not play a role, the
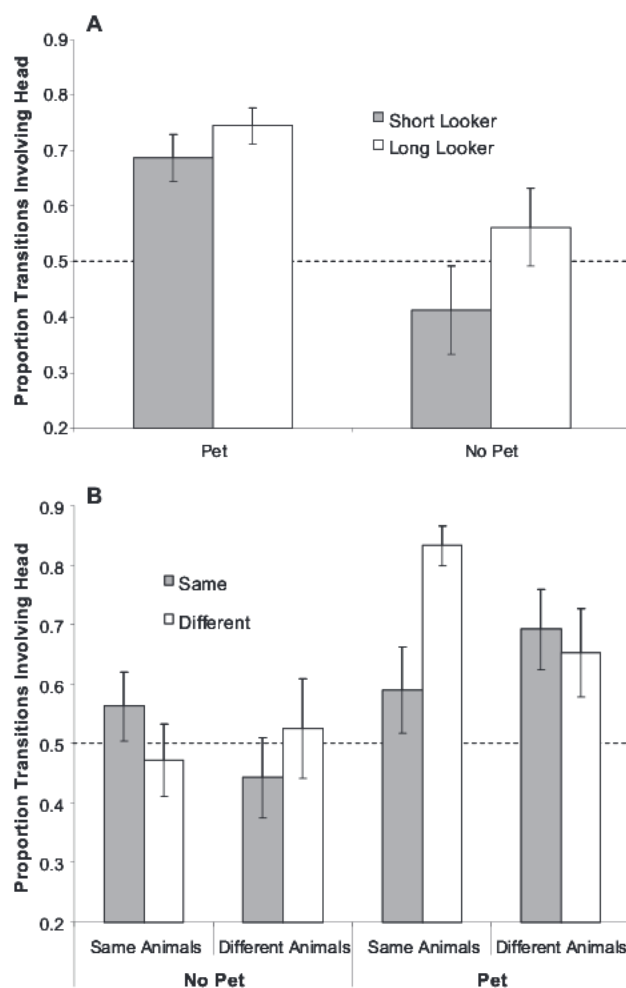

Figure 5. Proportion of transitions involving the head: (A) as a function of pet group and peak look (median split) and (B) as a function of pet group, pose, and trial type. Error bars are ±1 standard error computed across subjects within the cell being displayed.

relatively less advanced long lookers were less likely to show this effect (and did not show it at all for different animals).

The differences in how adaptively learners approach a new situation is a hallmark of *learning to learn* (Adolph, 2008). Learners who have not simply acquired a situation-specific strategy but who have learned strategies for learning about a particular kind of situation, stimuli, or context will adapt their learning strategy in the face of variation in the situation, stimuli, or context. The present results are consistent with the notion that by the age of 4 months, daily experience with pets has induced this learning process in infants and that more attentionally advanced infants (with or without pets) may show different adaptations.

Our second prediction was that when faced with competition for attention, infants with prior knowledge would be better able to maintain looking at one stimulus and inhibit responding to the competitor. This is precisely what we observed. Infants with pets were more likely than infants without pets to continue inspecting one animal, ignoring the other one, suggesting they could better maintain their attention to the animal currently being inspected. In contrast, infants without pets appeared to be more distracted by the presence of the other animal and were unable to inhibit shifting their glance between the two. It is interesting that we found the same effect for peak look, indicating that more sophisticated short lookers were also better able to inhibit responding to distraction, consistent with previous work suggesting that such resistance increases with development (Colombo et al., 1991; Freeseman et al., 1993; Jankowski et al., 2001; Rose et al., 2003). These two factors did not interact, however, indicating that the variables have independent relations with this aspect of attentional control.

These findings are important given that in general, over the first postnatal year infants' attention is less driven by exogenous stimulus factors and increasingly controlled by endogenous factors (Oakes et al., 2002; Ruff & Rothbart, 1996), a developmental change typically attributed to neuroanatomical changes in frontal brain regions (M. H. Johnson, 2005). Our results suggest additional potential mechanisms for developmental change in such inhibitory control: increased background knowledge about or familiarity with a stimulus class may allow more endogenous control over attentional focus and less control by exogenous factors (in this case, the presence of an attractive stimulus). Indeed, infants' ability to maintain attention to a fixated stimulus, ignoring a distracting stimulus, is related to features of that fixated stimulus (Blaga & Colombo, 2006; Oakes et al., 2002; Peltola et al., 2008).

Note that in this study, we observed few interactions between pet group and peak look—in most analyses, these two variables were independently related to infants' looking behavior. The only hints that the two variables may have a joint relation to infants' looking behavior were in the proportion of transitions between animals that involved the head. For infants without pets, but not for infants with pets, longer peak look during the pretest was associated with higher proportion of transitions involving the head.

At first glance, this lack of overall Pet Group × Look Group interaction seems to conflict with previously reported findings suggesting interactions between attentional style and previous knowledge. For example, Kovack-Lesh et al. (2008, 2012) observed that infants who were more effective learners had both high levels of between-animal switching and relevant pet experience. However, there are significant differences between the procedures used in those investigations and the procedure used here. These

prior studies presented infants with pairs of items all from the *same* category, whereas in the present experiment infants saw trials with items from two different categories and a mixture of same-category and different-category pairs. Such differences may elicit different kinds of comparison strategies, as infants likely learn different things in these two contexts. Presentation with a series of pairs of animals from the same category may induce infants to learn about the *category*, cuing effective learners to engage in more comparison. In contrast, presentation of different types of animals from trial to trial, not to mention trials with two different types of animals presented side by side, may induce infants to learn about the individuals, cuing effective learners to focus on one item at a time. Comparison may actually inhibit learning about the individual items, and infants may be more effective at learning in this context if they maintain their attention to one item in the pair (see Gentner & Namy, 1999, for a discussion about how comparison induces recognition of commonalities between items). Consistent with this speculation, Ruff (1975) observed that infants shifted more between two similar stimuli than between two different stimuli. In the present context—in which the types of animals, types of pairs varied from trial to trial—the most effective strategy for learning about the individual animals may have been to maintain attention to one animal, inhibiting responding to the other.

A more intriguing explanation for the lack of any Pet Group × Look Group interactions like those seen in Kovack-Lesh et al. (2008, 2012) is that these previous studies measured *learning outcomes*, while the present study focused on *attentional deployment during learning*. The previously observed effect of pet familiarity and attentional style on learning likely is not entirely driven by how infants deploy their attention; rather, infants with pets who show frequent switching during learning may actually learn more from each fixation. In general, short lookers may be used to picking up information from shorter fixations, and they may be particularly good at it when it is in a familiar domain. This would suggest that in addition to familiarity affecting attentional control (Figure 6, Path 4)—and indirectly, learning (Path 2)—it may also interact with the learning process itself, a pathway we had not initially hypothesized (the new Path, 5). Clearly, these conclusions are speculative at this point, but the results reported here provide an important step in understanding these relations.

The present results also suggest some association with attentional control independent of background knowledge. That is,
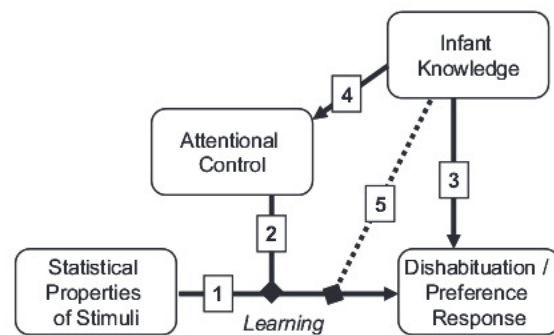

Figure 6. Final set of causal pathways relating stimulus properties, attentional control, and the preference response.

infants' peak look length in an unrelated task was related to their inspection of these stimuli. Shorter peak look length during pretest was associated with devoting a greater proportion of looking to the informative head regions and a higher proportion of transitions within a single animal. These effects are consistent with the conclusion that short looking in this pretest reflects more sophisticated attentional skills (e.g., Colombo et al., 1991; Jankowski et al., 2001; Rose et al., 2003). Thus, some aspects of in-the-moment learning appear to be independent of relevant experience and reflect general differences in how infants approach learning in such tasks (Figure 1C, Pathway 2).

These differences in inspection strategies are important because such differences likely reflect or cause differences in learning. Recall that Amso et al. (2010) and S.P. Johnson et al. (2004) both found that scanning patterns during learning were related to what infants learned. Similarly, Jankowski et al. (2001) manipulated visual inspection strategies and *caused* differences in what was learned: by encouraging long-lookers to switch more frequently during familiarization, they performed on a memory test like short lookers, showing more robust memory for the familiar stimulus. Together, these studies point to the importance of understanding differences in visual inspection strategies for understanding differences in learning. Our results, then, suggest that these inspection strategies may emerge from a complex set of developmental phenomena—the ongoing development of general attentional strategies and background knowledge about the stimuli used, as well as the real-time effects of the perceptual properties of those stimuli.

Our results contribute to the literature showing how infants' previous experience with animals or animal images can contribute to their laboratory performance in tasks involving animals as stimuli (Furrer & Younger, 2008; Kovack-Lesh et al., 2008; Kovack-Lesh et al., 2012; Pascalis et al., 2005; Scott & Monesson, 2009). The present experiment suggests that such previous findings may reflect changes over development in how infants visually inspect these animal images. Overall, we conclude the results that a key difference between younger and older infants in general is difference in experience—a 6-month-old infant has more experience than a 4-month-old infant with dogs, faces, and so on. Indeed, one speculation about age-related differences in face processing in infancy is that such differences reflect a narrowing or specificity in perception that arises from experience (e.g., Kelly et al., 2005). Although critically important demonstrations, conclusions about the role of experience in such experiments are only speculative because age differences are confounded with many other changes, including physical, neuroanatomical, and motor changes. Yet, studies of development typically use age as a proxy for differences in experience, developmental level, and learning, employing cross-sectional designs to uncover age-related differences in aspects of cognitive ability (e.g., Kelly et al., 2005; Oakes & Ellis, 2013; Oakes & Ribar, 2005; Pascalis et al., 2005). In this study, we used differences in experience as a proxy for developmental change. By evaluating two groups of infants who were the same age and who did not differ on an assessment of general visual attention, we could evaluate the relation between one aspect of experience and infants' visual attention to stimuli related to that experience. Thus, the present design, in which age is held constant and experience is varied, is an important complementary approach to understanding the development of these processes.

In summary, these results add to our understanding of the factors that contribute to infants' learning. By examining the association between experience, and individual differences in attentional strategies, and infants' visual inspection of stimuli, we gain insight into how such factors are related to their *sampling* of information about those stimuli. In future studies, researchers can directly assess whether those sampling difference map onto differences in the products of learning. In the meantime, we have evidence that not only do the products of learning vary with such factors but that the strategies infants employ when actively exploring new stimuli reflect differences in their experiences with similar stimuli and their general attentional strategies.

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