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Learning to Individuate: The Specificity of Labels Differentially Impacts Infant Visual Attention

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This study examined differences in visual attention as a function of label learning from 6 to 9 months of age. Before and after 3 months of parent-directed storybook training with computer-generated novel objects, event-related potentials and visual fixations were recorded while infants viewed trained and untrained images (n = 23). Relative to a pretraining, a no-training control group (n = 11), and to infants trained with category-level labels (e.g., all labeled "Hitchel"), infants trained with individual-level labels (e.g., "Boris," "Jamar") displayed increased visual attention and neural differentiation of objects after training.

In the 1st year of life, naming objects and people influences both perceptual and conceptual development, allowing infants to make connections between words and items in their visual environment. The specificity of words that parents use to label faces or objects for infants influences visual and neural processing immediately (Scott, 2011; Scott & Monesson, 2009, 2010) as well as later in childhood (Hadley, Pickron, & Scott, 2015). This previous work suggests a fundamental link between the development of language learning and visual perceptual representations of faces and objects. However, the mechanisms that contribute to this link are not well understood. In the present investigation, the impact of label learning on visual attention was examined using a multimethod longitudinal experiment.

Recently, top-down processing, defined here as the use of established conceptual knowledge and prior experience in directing attention, was proposed as important for the development of early face and object processing (Hadley, Rost, Fava, & Scott, 2014). By this account, visual attention is constrained by previous learning and is directed to task-relevant stimulus locations and features. In contrast, attention driven by a bottom-up mechanism is directed based solely on the perceptual features of the stimuli (Baluch & Itti, 2011; Sarter, Givens, & Bruno, 2001). The present investigation examined the top-down impact of verbal labeling experience on visual attention during the 1st year of life.

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Past investigations have examined the influence of previous experience on infant visual attention (Baldwin & Markman, 1989; Hurley, Kovack-Lesh, & Oakes, 2010; Kovack-Lesh, McMurray, & Oakes, 2014). For example, Hurley et al. (2010) found that 6-month-old infants who had pets looked significantly longer toward images of novel cats or dogs than those infants without pets. However, it is unclear why these attentional differences were present. One possibility is that infants with pets have the experience of learning a distinct name for their pet and this previous learning in turn biases their overall visual attention and strategies.

In toddlers, attention to visual features and properties of objects is influenced by verbal labeling (e.g., Samuelson & Smith, 1999; Smith, Jones, Landau, Gershkoff-Stowe, & Samuelson, 2002). For example, verbal labels led toddlers to attend to the diagnostic feature of a category and correctly categorize novel objects based on that feature (Smith et al., 2002). Naming distinct objects with the same word (but not tone) leads infants to form inclusive categories at both 6 and 12 months (Fulkerson & Waxman, 2007; Waxman & Braun, 2005). Hearing word–object associations also influences the number of categories infants form within a given scene (Althaus & Westermann, 2016; Havy & Waxman, 2016).

Changes in visual fixation strategies have previously been found to be important for learning commonalities across objects and within categories (Waxman & Markow, 1995). Recent eye-tracking data indicate that hearing labels directs infants' visual fixation strategies when viewing novel objects (Althaus & Mareschal, 2014; Althaus & Plunkett, 2016; Best, Robinson, & Sloutsky, 2010). Interestingly, the type or specificity of labels also impacts infants' visual attention. For example, when 12-month-old infants hear the same label for multiple items they attend more toward common features (Althaus & Mareschal, 2014; Althaus & Plunkett, 2016). In contrast, hearing unique labels results in greater visual attention toward individuating features of each image (Best et al., 2010). These findings suggest that label learning differentially directs and impacts attention, and is a key component of early concept formation.

Neural measures have also been used to examine the impact of labels on visual processing. Electroencephalography (EEG) recordings measure the electrical activity of the brain recorded from scalp electrodes. In one study, Gliga, Volein, and Csibra (2010) found increased EEG gamma-band activity in response to labeled objects in 12-month-old infants (Gliga et al., 2010). Interestingly, this effect was found both for infants who knew the labels prior to coming to the laboratory as well as infants who learned an object label during a 10-min training session. Object familiarity alone did not elicit enhanced activity suggesting that verbal label learning has top-down effects on visual object processing.

In another set of investigations, parents read their infants books with labeled monkey faces (Scott & Monesson, 2010) or strollers (Scott, 2011) from 6 to 9 months of age. During training infants heard parents label different monkeys or strollers with either (a) individual-level names (e.g., "Jamar" or "Anice"), (b) a category-level label (i.e., "monkey" or "stroller"), or (c) no label at all. Occipital–temporal event-related potential (ERP) components, thought to reflect perceptual processing (P1, N290, and the P400), were examined before and after book training. Results showed that hearing individual labels resulted in differential perceptual ERP responses when infants were presented with new exemplars within trained categories. Differential perceptual responses were not present after learning a generic or category label ("monkey" or "stroller") or after simple exposure and suggests that the specificity of labels impacts the development of visual representations. These training experiments provide robust neural evidence of top-down effects of verbal labeling on perceptual processing. However, it is unclear whether, in addition to these perceptual changes, visual attention and the underlying neural indices of attention are also impacted by labeling.

The Nc, or negative central component, is one of the most frequently studied infant ERP components and is thought to index aspects of attention, attentional engagement, and stimulus salience (e.g., Courchesne, Ganz, & Norcia, 1981; de Haan & Nelson, 1997, 1999; Reynolds, 2015; Reynolds & Richards, 2005; Richards, 2003; Richards, Reynolds, & Courage, 2010). The Nc is recorded over frontal and central electrode locations and occurs between approximately 300–800 ms after stimulus onset. Prior studies have used the "oddball" ERP task to make inferences about infant attentional engagement and memory as well as their ability to discriminate stimuli. Overall, the Nc is greater in response to infrequently presented items if infants can distinguish the frequently from the infrequently presented stimuli (e.g., Reynolds & Richards, 2005; Richards, 2003). The Nc is also associated with behavioral displays of sustained attention such as longer overall looking time, visual discrimination, and object recognition (Ackles & Cook, 2007; Peltola, Leppänen, Mäki, & Hietanen, 2009; Reynolds, 2015; Reynolds, Courage, & Richards, 2010; Richards, 2003; Richards et al., 2010). The magnitude of the Nc response has also been reported to vary across individuals, such that 6-month-old infants displaying short-look durations show larger Nc responses to novel objects (Guy, Reynolds, & Zhang, 2013). The Nc has been described as an obligatory attentional response (Csibra, Kushnerenko, & Grossmann, 2008; de Haan, Johnson, & Halit, 2003; Nelson & Monk, 2001; Richards, 2003), suggesting that it is primarily driven by bottom-up, exogenous mechanisms. The present investigation aimed to determine the extent to which labels have a top-down effect on the infant Nc.

Although previous studies have linked verbal labeling to perceptual learning (Scott, 2011; Scott & Monesson, 2009, 2010), it is unclear how labeling at different levels of specificity impacts later attention to untrained stimuli. In the present study, 6-month-old infants were randomly assigned to one of two storybook training conditions. The books each contained two different "species" of computer-generated novel objects that either had unique, individual-level labels or the same general category-level label. Two different species were used to determine if including a label comparison impacted learning. Infants in the training groups (individual, category) were tested before and after 3 months of storybook training (at 6 and 9 months), and those in the no-training control group were only tested at 9 months of age. At pretest and posttest, infants completed an eye-tracking serial presentation task and an ERP oddball task. Here it was predicted that learning labels for novel objects, from 6 to 9 months of age, would result in label-dependent attention differences. More specifically, it was expected that individual-level labeling but not category-level labeling would increase visual attention to trained objects and generalize to untrained exemplars within trained categories. Top-down label-dependent effects were also predicted for the Nc ERP component.

Method

The university's institutional review board approved all methods and procedures used in this study. Data collection for this study was completed between September 2012 and September 2013.

Participants

Parents of all infants gave informed consent before testing. All infants were born full term and had no visual or neurological abnormalities. At each session, families were paid $10 and given a small toy for their participation. Fifty-nine infants were recruited for the study. Forty-three infants were recruited at 6 months of age for storybook training. The remaining 16 were recruited at 9 months of age to participate in a no-training control group.

The final sample included 34 infants (17 boys) who contributed to both eye-tracking and ERP results. Thirty infants were racially identified as White or Caucasian, two were Black or African American and Caucasian, one was Black or African American, and one was Asian and Caucasian. One infant was ethnically identified as Hispanic or Latino. Infants came from English speaking homes (information about additional languages spoken in the home was not collected) and from families with an average of 3.67 people living at home with an average income of $60–70,000. Infants were randomly assigned to receive either individual-level (n = 12), category-level (n = 11), or no training (n = 11). Trained participants were tested at 6 months (M_{age} = 184.78 days, SD = 9.83) and 9 months (M_{age} = 281.55 days, SD = 7.48 days) of age. The no-training control group was only tested at 9 months of age (M_{age} = 280.27 days, SD = 11.08). Twenty-five infants were excluded from the final analyses because they did not return for their 9-month visit (n = 6), they refused to wear the EEG net (n = 4), there was a computer error (n = 3), or they did not contribute at least 12 artifact-free ERP trials to each condition at either their 6- (n = 3) or 9-month (n = 9) visit. This 57% retention rate is typical of infant longitudinal ERP investigations (Scott, 2011; Scott & Monesson, 2010; Stets, Stahl, & Reid, 2012).

Stimuli

Sixteen digitized color photographs of computer-generated artificial objects were used as stimuli. Two "species" of objects were created using Modo (Version 601). Two species were used to create a category comparison within each of the training books. Across both species, object exemplars varied in size, shape, orientation, and color pattern. Individuating features were primarily located in the lower half of the image on the external appendages. Eight images (four from species "A" and four from species "B") were used for training and were presented within a storybook (see Figure 1). The other eight images (four from each species) were not included in the storybooks and were used to test generalization of learning at both the pre- and post-training visits (see Figures 1 and 2 for stimulus examples and Figure S1 for all the stimuli).

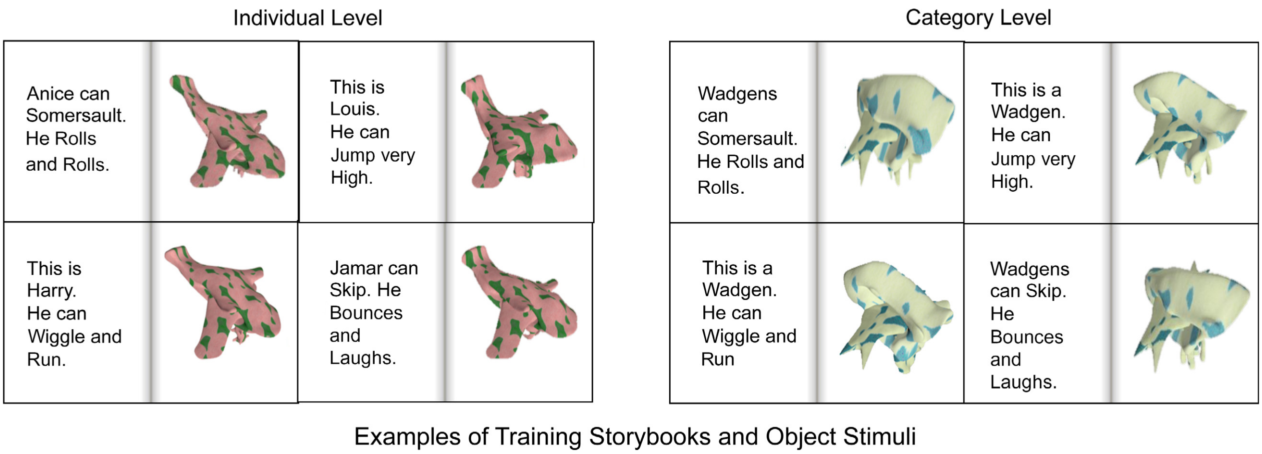

Figure 1. Examples of novel objects within the two object "species" and the stories used for the storybooks. Participants were either sent home with individual-level storybooks (examples on the left) or category-level storybooks (examples on the right). All images were used for both conditions. [Color figure can be viewed at wileyonlinelibrary.com]

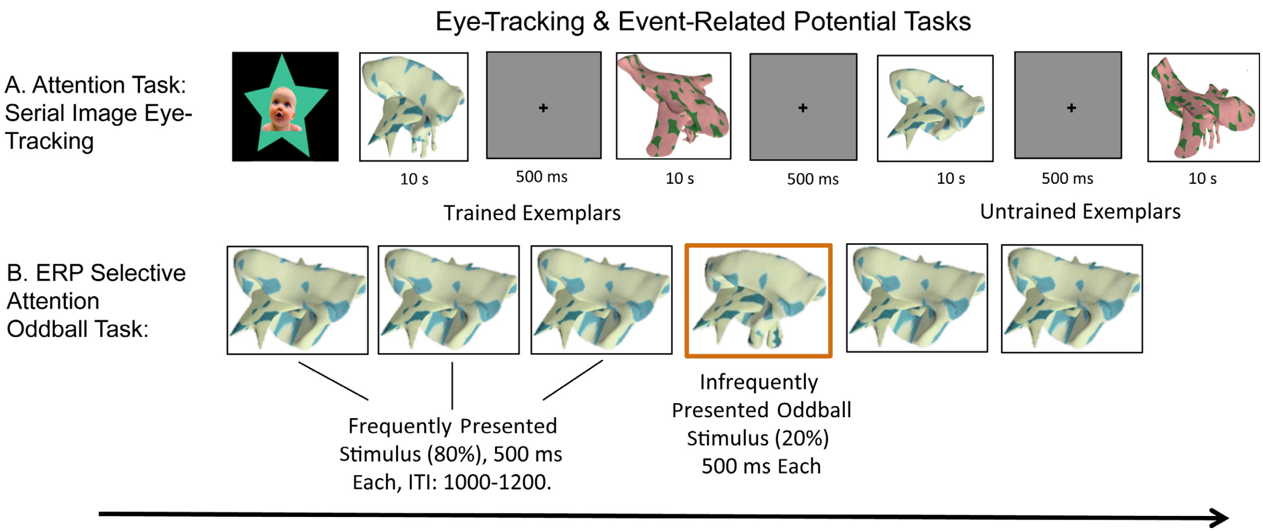

Figure 2. Example trials for the serial image eye-tracking (A) and event-related potential (ERP) oddball (B) tasks. [Color figure can be viewed at wileyonlinelibrary.com]

Storybooks

Training books contained eight images (one image per page) presented on a white background. For the category-level books, four exemplars of each species were labeled with the corresponding species label "wadgen" or "hitchel." Category-level labels were selected by matching the phonological properties within, "wadgen" and "hitchel" (Vitevitch & Luce, 2004). For the individual-level training books, each image was associated with a unique name (e.g., "Boris," "Harry," "Jamar," "Bobby," "Carlos," "Anice," "Louis," and "Billy"). Individual-level names were selected by choosing names that were similarly popular in the 1990 U.S. census and had similar phonological composition and properties (Vitevitch & Luce, 2004). Training books included a story on each page corresponding with an image (Figure 1). The stories were identical across individual- and category-level conditions, aside from the specificity of the labels used. Stories consisted of two sentences. One sentence included syntax designed to deliver strong cues to infants regarding the level of labeling (i.e., individual or category). The second, included syntax designed to deliver relatively weaker cues regarding the label level (for discussion of syntactic referencing, see Gelman, Chesnick, & Waxman, 2005).

Procedure and Apparatus

Storybook Training Procedure

For infants in the training groups, each family was randomly assigned to take home one of two storybooks (individual labels, category labels). Within each training group, half of the infants were trained with one set of eight images and the other half were trained with another set of eight images. Parents were given a diary and training schedule with instructions to read the book for a total of 10 min with their infant every day for the first 2 weeks, every other day for the following 2 weeks, every third day for the next 2 weeks, and every fourth day until their 9-month posttraining assessment (Pascalis et al., 2005; Scott, 2011; Scott & Monesson, 2009, 2010). Parents were instructed to only use the provided labels and stories when referring to images in the training books. No other instructions were provided. Parents recorded their training efforts and were considered compliant with training if they followed the schedule for at least 75% of the time. In between the pre- and posttraining assessments, parents were contacted once a month to check compliance and answer questions about the training books or schedule. Infants in the 9-month-old control group were randomly assigned to one of the two sets of images for testing.

Eye-Tracking Serial Presentation Procedure

Infants were seated in a high chair approximately 55 cm away from a 17-in. LCD monitor as they passively viewed the serial presentation task. Images were presented on a dark gray background and were 603 pixels tall × 508 pixels wide with a visual angle of 18.53° (vertically) by 15.65° (horizontally). A target sticker was placed on the forehead and allowed for tracking of head position even when the pupil could not be captured (i.e., during blinks or sudden movements). Three points, including a center top, bottom right, and left corners were used to calibrate the eye tracker to each infant. Following calibration and before each trial, an experimenter manually completed a drift-correct procedure. The targets used for calibration and drift correction were approximately 100 × 100 pixels in size. An experimenter judged the infant's eye fixation as close as possible to the target.

The serial image presentation task consisted of six trials with four object trials and two face trials (face findings not reported here). The object trials included one trained and one untrained exemplar from each of the two species (see Figure 2A). For this task, infants were randomly assigned to one of six exemplar counterbalance conditions for pre- and posttests; this ensured the exemplars varied across subjects and differed between pretest and posttest. Each trial included a single image centrally located on the computer monitor and lasted for 10 s (countdown). Infants included in the final sample completed all four object trials.

An EyeLink 1000 arm mount remote camera eye tracker (SR Research Ltd., Mississauga, Ontario, Canada) was used to record infants' fixations during the serial image presentation task. Fixation location and duration were recorded with an average accuracy of 0.5° and a sampling rate of 500 Hz using a 16-mm lens and a 940-nm infrared illuminator. Allowable head movement without accuracy reduction was approximately 22 × 18 × 20 cm (horizontally × vertically × depth). Tracking range was approximately 32° horizontally and 25° vertically. An eye track was recovered within 3 ms (SD = 1.11 ms) of losing it; however, if data were missing due to excessive head movement, loss of head target sticker, or pupil track, it was recorded as an eye blink and removed.

The EyeLink 1000 uses a heuristic filter to remove noise when detecting saccades and fixations as well as to reduce the frequency of false fixations being recorded during online data collection (see Stampe, 1993). During each trial, a saccade-pick algorithm was used to identify fixations. A fixation was registered if the eye moved at least 15° and did not exceed saccade thresholds for velocity (30°/s) or acceleration (8,000°/s^2). Areas of interest were hand drawn and encompassed the entire object including approximately 30 pixels of background space surrounding the object. Thirty pixels were selected as a "buffer region" as this size is approximately equivalent to 1° of visual angle. Total dwell time for each trial was exported for each group (individual, category, and control), conditions (trained objects, untrained objects), and age (6 and 9 months). The two trials for each condition (trained objects, untrained objects) were averaged for each subject.

ERP Oddball Procedure

Infants passively viewed untrained exemplars from each of the two trained object species for the ERP oddball task to examine label effects on the Nc component. Infants were seated on their parent's lap approximately 70 cm away from a 20-in. computer monitor. Images were 206 pixels tall × 250 pixels wide and viewed at a vertical visual angle of 5.02° and a horizontal visual angle of 6.09°.

Infants viewed three blocks of 45 trials, with object species separated by block. Each block included a single, frequently presented untrained and six infrequently presented untrained object exemplars (randomly presented). Within the three blocks, each infant saw two blocks of one species and one block of the other species. The species seen twice was counterbalanced across participants and based on initial analyses suggesting no differences across species, responses to both species (all three blocks) were averaged within conditions. The frequently presented object was seen 80% of the time (36 trials), and the infrequent objects were seen 20% of the time (9 trials). Infants completed an average of 124.35 (*SD* = 39.56) trials at 6 months and 123.22 (*SD* = 41.37) at 9 months. Each image was presented for 500 ms followed by a randomly varying intertrial interval (ITI) of 1,000–1,200 ms. During the ITI, infants viewed a gray screen with a white fixation cross in the center (see Figure 2B).

ERPs were collected with a 128-channel Geodesic Sensor Net connected to a DC-coupled 128-channel, high-input impedance amplifier (Net Amps 300 TM; Electrical Geodesics, Eugene, OR). Amplified analog voltages (1–100 Hz bandpass) were collected continuously and digitized at 500 Hz. Individual electrodes were adjusted until impedances were < 50 kΩ. Postrecording processing was completed with Netstation 4.3 (Electrical Geodesics). EEG was first digitally low-pass filtered at 40 Hz, then segmented and baseline corrected with a 100-ms prestimulus recording interval. Trials were discarded from analyses if there were more than 12 bad electrodes (changing more than 300 μV in the entire segment). Individual channels that were consistently bad (off-scale on more than 70% of the trials) were replaced using a spherical interpolation algorithm (Srinivasan et al., 1996). Following artifact detection, each trial was visually inspected for noise and rejected if a significant amount of noise or drift was present. An average reference was used to minimize the effects of reference site activity and accurately estimate the scalp topography of the measured electrical fields.

Participants with fewer than 12 artifact-free trials per condition were excluded from analyses. At 6 months, infants who subsequently received category-level training had an average of 25.09 (*SD* = 3.21) trials for frequent and 16.18 (*SD* = 1.89) trials for infrequent objects. Infants in the individual-level training group had an average of 28.00 (*SD* = 8.11) for frequent and 16.00 (*SD* = 2.59) trials for infrequent objects. At posttest (9 months), infants in the category-level training group had an average of 26.73 (*SD* = 10.95) trials for frequent and 16.00 (*SD* = 3.52) trials for infrequent objects. Following individual-level training, infants contributed a mean of 22.75 (*SD* = 7.81) trials for frequent and 13.50 (*SD* = 1.98) trials for infrequent objects. Infants in the control group (i.e., no training) had an average of 20.00 (*SD* = 6.05) trials for frequently and 15.36 (*SD* = 2.96) trials infrequently presented objects.

Data Analyses

A boxplot with 1.5 interquartile range (IQR) was used to determine whether there were any outliers within the current sample for both the ERP and eye-tracking data. None of the participants were flagged above the threshold of 1.5 IQR (Tukey's Hinges third quartile at 6 months (2,799.5 ms) or 9 months (4,005.00 ms).

For both eye-tracking and ERP analyses, significant effects were followed up with paired-sample *t* tests, which were corrected for multiple comparisons using the Bonferroni method. Both uncorrected and corrected *p* values are included.

Eye-Tracking Serial Presentation Analyses

Two separate analyses were conducted to assess changes in visual attention across groups as well as before to after training. The first was designed to examine change over time, and the second to compare the three groups at 9 months. To examine training-related change, total dwell time was submitted to a three-factor 2 × 2 × 2 mixed measures multivariate analysis of variance (MANOVA). Within-subjects factors included infant age (6 and 9 months) and object condition (trained, untrained). Storybook training level (individual, category) was the between-subjects factor. Second, 9-month-old total dwell time was submitted to a two-factor mixed measures MANOVA with the between-subjects factor of group (individual, category, control) and the within-subjects factor of object condition (trained, untrained). Means and standard deviations are presented in Table S1.

ERP Oddball Analyses

Mean amplitude for the frequently and infrequently presented object was measured for the Nc component. The analysis time window and electrode channels were chosen based on visual inspection of the ERP waveforms and previous infant ERP studies using an oddball task (Reynolds & Richards, 2005; Reynolds et al., 2010). The Nc was measured from 470 to 720 ms after stimulus onset. Electrodes over the frontal region of the left hemisphere, middle, and right hemisphere were averaged within each region for analysis (left hemisphere: 23, 24, 26, 27 [corresponding to F3]; middle: 10, 11, 16, 18 [corresponding to Fz]; right hemisphere: 2, 3, 123, 124 [corresponding to F4]). To examine training-related change, mean Nc amplitudes were submitted to a four-factor 2 × 2 × 3 × 2 mixed measures MANOVA. Within-subject factors included infant age (6 and 9 months), object frequency (frequent, infrequent), and region (left, middle, right). Training group (individual, category) was the between-subjects factor. A second three-factor 2 × 3 × 3 mixed measures MANOVA was conducted to compare 9-month-old groups. Within-subjects factors included object frequency (frequent, infrequent) and region (left, middle, right). Training group (individual, category, control) was the between-subjects factor. Means and standard deviations are presented in Table S2.

Results

Eye-Tracking Serial Presentation Results

Training-Related Dwell Time Change

For the three-factor 2 × 2 × 2 mixed measures MANOVA, a significant main effect of age was found, $F(1, 21) = 13.55$, $p = .001$, $\eta^2 = .392$ (for the complete MANOVA table, see Table S3). Infants fixated the images significantly longer during their 9-month visit (M = 3,123.03 ms, SD = 1,319.47) compared to the 6-month visit (M = 2,193.26 ms, SD = 785.00). Additionally, there was a significant two-way interaction between age and training group, $F(1, 21) = 5.33$, $p = .031$, $\eta^2 = .202$ (see Figure 3). Follow-up paired comparisons revealed infants in the individual-level training group looked significantly longer toward objects at 9 months (M = 3,668.00 ms, SD = 1,426.75) than at 6 months (M = 2,155.00 ms, SD = 774.33), $t(11) = -4.12$, $p = .002$, $p < .05$ corrected. This significant training-related difference was not found for the category-level training group (6 months M = 2,231.95 ms, SD = 794.98; 9 months M = 2,578.55 ms, SD =

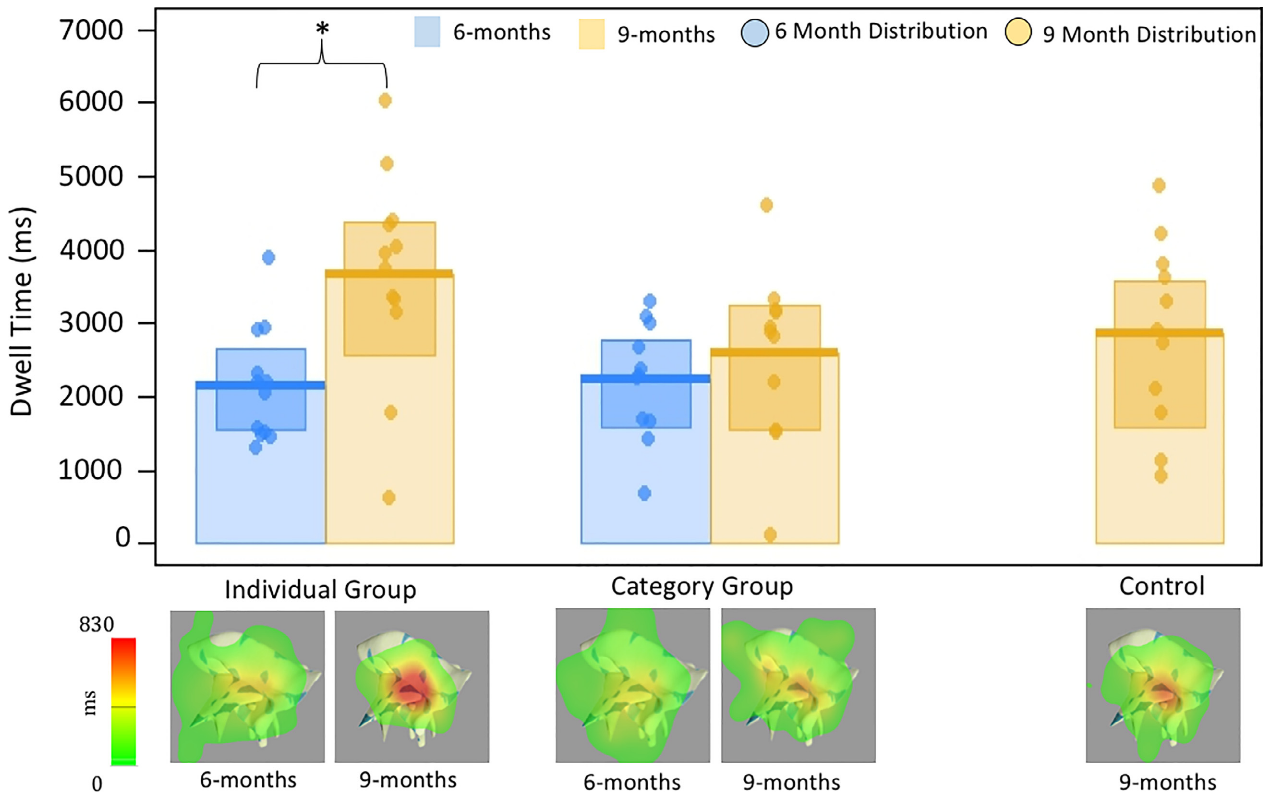

Figure 3. Average dwell time (ms) to trained and untrained objects before and after training and for the 9-month-old control group. Darker colored boxes are 95% confidence intervals, and the dots represent individual subject means. Dwell time fixation maps are averaged for each age, condition, and stimuli. *$p < .05$ corrected.

1,187.55), $p > .05$. All nonsignificant differences are reported in Table S4.

Dwell Time Differences at 9 Months

There were no significant main effects or interactions between training groups (individual, category, and control) at 9 months (see Table S5 for the complete MANOVA results).

ERP Oddball Results

Training-Related Nc Amplitude Change

From the four-factor $2 \times 2 \times 3 \times 2$ mixed measures MANOVA there were two significant main effects found. First, a significant main effect of object frequency, $F(1, 21) = 16.60$, $p < .001$, $\eta^2 = .483$, due to infants' mean amplitude being significantly larger (more negative) for infrequently presented objects ($M = -3.84$ μV, $SD = 4.21$) compared to frequently presented objects ($M = -1.30$ μV, $SD = 2.80$). Second, there was a significant main effect of region, $F(2, 20) = 4.15$, $p = .031$, $\eta^2 = .293$, such that the middle region ($M = -3.43$ μV, $SD = 3.70$) was significantly greater than the left region ($M = -2.210$ μV, $SD = 3.803$) and marginally greater than the right region ($M = -2.124$ μV, $SD = 3.871$). A complete report of the four-factor MANOVA can be found in Table S6.

These main effects are qualified by two significant interactions. First, a significant two-way interaction between object frequency and training group (individual and category), $F(1, 21) = 4.58$, $p = .044$, $\eta^2 = .179$. Follow-up paired comparisons revealed that infants in the individual-level training group had a significantly greater mean amplitude for the infrequently presented objects ($M = -4.87$ μV, $SD = 4.33$) relative to frequently ($M = -1.11$ μV, $SD = 3.12$) presented objects, $t(11) = 4.83$, $p = .001$, $p < .05$ corrected. This significant difference was not found for the category training condition (infrequent: $M = -2.81$ μV, $SD = 4.06$, frequent: $M = -1.50$ μV, $SD = 2.38$; $p > .05$; see Table S7 for nonsignificant results). The second significant interaction was a four-way interaction between object frequency, region, age, and training group, $F(2, 20) = 3.77$, $p = .041$, $\eta^2 = .274$ (see Figure 4). Follow-up paired t tests were conducted between frequently and infrequently presented objects for the left, middle, and right regions at both 6 and 9 months, and between individual- and category-level training. Paired comparisons revealed that only 9-month-old infants who received individual-level storybook training displayed significantly larger mean amplitude to the infrequently compared to frequently presented objects for the left region (infrequent: $M = -7.67$ μV, $SD = 8.09$; frequent: $M = 0.89$ μV, $SD = 4.92$), $t(11) = 3.63$, $p = .004$, $p < .05$ corrected, middle region (infrequent: $M = -6.86$ μV, $SD = 4.56$; frequent: $M = -0.35$ μV, $SD = 3.62$), $t(11) = 3.95$, $p = .002$, $p < .05$ corrected, and right region (infrequent $M = -4.12$ μV, $SD = 5.28$; frequent $M = 1.78$ μV, $SD = 5.82$), $t(11) = 2.49$, $p = .030$, $p = ns$ corrected (see Figure 5). These significant differences were neither found for 6-month-old infants in the individual-level training group nor for the pre- or post-training visits for infants in the category-level training group. Nonsignificant results from 6-month pretest and 9-month category posttest results are reported in Table S8.

Nc Amplitude Differences at 9 Months

To determine whether the attention changes present in 9-month-olds after individual-level learning, but not category-level learning, were different from a naïve group of 9-month-old infants, a separate three-factor $2 \times 3 \times 3$ mixed measures MANOVA was conducted comparing the three 9-month-old groups. A main effect of object frequency, $F(1, 31) = 12.25$, $p = .001$, $\eta^2 = .28$, and region, $F(2, 30) = 6.13$, $p = .006$, $\eta^2 = .29$, were found (see Table S9 for complete MANOVA results). Nine-month-old infants had a significantly greater mean amplitude for infrequently ($M = -3.49$ μV, $SD = 5.23$) compared to frequently presented objects ($M = -0.159$ μV, $SD = 4.54$), and the middle region ($M = -2.54$ μV, $SD = 4.22$) was significantly greater than the right region ($M = -0.769$ μV, $SD = 5.03$).

These main effects are qualified by two significant interactions. The first was a two-way interaction between object frequency and training group, $F(2, 31) = 3.93$, $p = .030$, $\eta^2 = .202$. This interaction was driven by a significantly larger mean Nc amplitude for the infrequently ($M = -6.22$ μV, $SD = 5.31$) relative to the frequently ($M = 0.776$ μV, $SD = 4.46$) presented object for 9-month-old infants trained at the individual level, $t(11) = 3.66$, $p = .004$, $p < .05$ corrected. Nine-month-olds in the category group did not show significant differences between frequently ($M = -0.46$ μV, $SD = 4.21$) and infrequently presented objects ($M = -1.34$ μV, $SD = 3.27'$), $p > .05$ (see Figure 5). In addition, the 9-month-old control group also did not show any significant differences (frequently presented: $M = -0.79$ μV, $SD = 4.91$; infrequently presented: $M = -2.92$ μV, $SD = 6.56$), $p > .05$. All nonsignificant 9-month category and control training group results are reported in

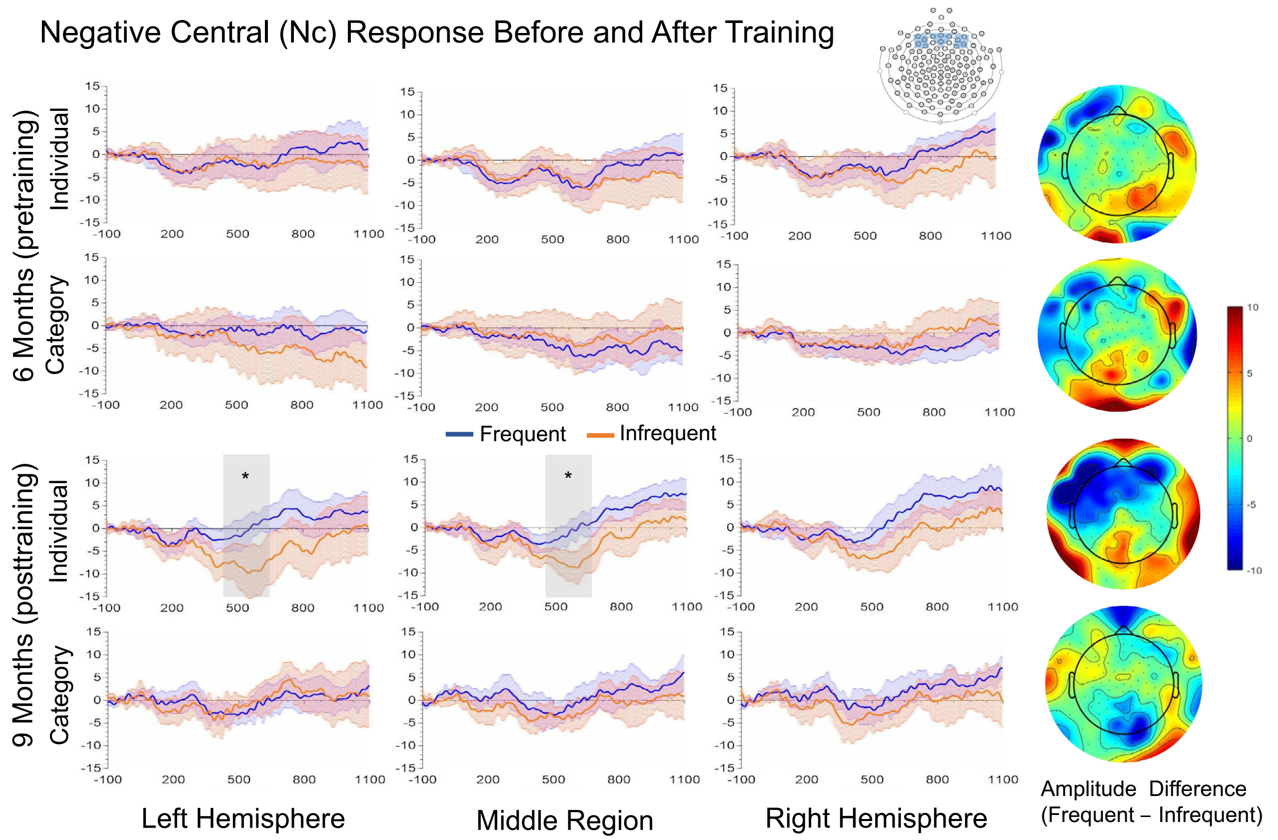

Figure 4. Infant negative central responses to frequently presented (blue) and infrequently presented (orange) untrained objects before and after 3 months of individual-level or category-level training across the left, middle, and right regions (averaged electrodes within each region) of interest. 95% Confidence intervals are plotted across time for each waveform. The topographic distribution of the amplitude difference between frequently presented and infrequently presented stimuli is plotted to the right of the corresponding waveforms and reflect an average of the amplitude difference within the time window of 470–720 ms. The electrode groups used for analyses are shown in the upper right corner. Significant effects are highlighted with gray boxes and $^{*}p < .05$, after correcting for multiple comparisons.

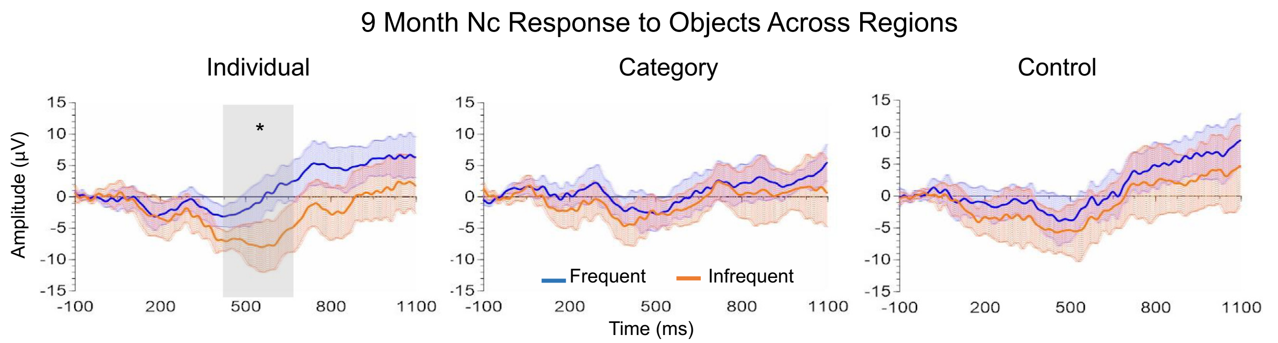

Figure 5. Infant negative central (Nc) responses at 9 months to frequently presented (blue) and infrequently presented (orange) untrained objects after 3 months of individual-level or category-level training and in a 9-month no-training control group. Waveforms reflect averaged electrodes over the left, middle, and right frontal brain regions. 95% Confidence intervals are plotted across time for each waveform. $^{*}p < .05$, after correcting for multiple comparisons.

Table S10. The second significant interaction was a three-way interaction between object frequency, region, and training group, $F(4, 62) = 3.07$, $p = .023$, $\eta^2 = .165$. This interaction mirrors the findings reported above and shown in Figure 4 (see nonsignificant results in Table S11). An additional analysis was run that collapsed the 9-month-old category trained group with the 9-month-old no-training control group, and no significant mean amplitude differences between the frequently and infrequently presented stimuli were present.

Discussion

The present investigation examined the impact of label learning on object attention using eye-tracking and ERP methods. Families of 6-month-old infants were sent home with storybooks containing two "species" of novel objects and were asked to read these books to their infants for 3 months. Infants were randomly assigned to receive books with objects labeled at either the individual level or at the category level. Overall, within-subject ERP and eye-tracking results converge and suggest that infants increased their attention to novel images from within the trained category after 3 months of learning to individuate labeled object exemplars.

Infants trained with individual-level labels displayed an increase in dwell time, from 6 to 9 months of age, when viewing trained object exemplars. This increase in dwell time generalized to exemplars of objects that are within the trained "species," but were not in the storybooks. These same infants (trained with individual-level labels) exhibited a larger ERP Nc amplitude response to infrequently relative to frequently presented untrained exemplars of objects within the trained "species." Infants who received category-level storybooks or no training did not show changes in dwell time or differential ERP responses. These results indicate that the specificity of labels that infants heard over the course of training led to increased attention when presented with both trained and untrained exemplars of objects within trained categories.

The present findings extend past research related to the effects of prior experience on visual attention (Hurley et al., 2010; Kovack-Lesh et al., 2014) and suggest that the specificity of labels function to differentially direct visual attention during learning. Consistent with Smith et al. (2002), our findings suggest that infants use labels to direct their attention and develop either detailed (after individual-level training) or general (after category-level training) representations of objects within the visual world. We propose that labels act as a top-down facilitator for visual attention and that attentional changes associated with label learning generalize to novel exemplars. The current attention effects are not present prior to training and generalize to untrained images and therefore are not likely due to bottom-up features of the stimuli. These label-driven effects offer robust support for a recent hypothesis that suggests a top-down mechanistic framework is critical to understanding the development of object and face processing (Hadley et al., 2014).

One unanswered question is whether the category-level labels benefited infants above and beyond no training. We did not find any significant differences between the 9-month-olds trained with category labels and the no-training control group. The lack of differences between these two groups suggests that without individual-level training infants may not notice differences between the object exemplars. It is also possible that in the absence of individual-level names infants are creating perceptually inclusive object representations that led to no differences in attention across conditions for either task. Although this possibility remains speculative, future work incorporating an additional categorization measure would allow us to contrast individuation and categorization learning, and examine whether category training leads to performance advantages for categorization tasks. It is also possible that the top-down effects found here for individual-level labels will not be present for category-level labels when using a categorization task. Increased categorization abilities after category-level label training would be consistent with previous studies that find shared labels direct attention to shared features (Althaus & Mareschal, 2014; Althaus & Plunkett, 2016) and lead to category formation (Fulkerson & Waxman, 2007; Waxman & Braun, 2005; Waxman & Markow, 1995). Finally, one other important factor to consider is whether stimulus properties (bottom-up) interact with labels (top-down) to promote infant attention and learning. For example, does the amount of exemplar variability or the number of diagnostic visual features impact infants' ability to use labels to differentially direct attention and learning?

Consistent with prior visual perceptual ERP studies (Scott, 2011; Scott & Monesson, 2010), here infants' Nc ERP component was uniquely impacted by previous individual-level label experience. The increases in Nc differentiation after label learning also extends our understanding of the Nc and challenges the notion that its response is primarily driven by bottom-up stimulus features and obligatory attention. Our results are consistent with the interpretation that the Nc is an index of selective and sustained attention (Reynolds et al., 2010) and further suggests that top-down factors, such as label learning, modulate the specificity of the Nc.

Although the present results highlight the importance of label learning from 6 to 9 months of age, it is currently unknown whether this period of development also marks a sensitive period or whether the infants are similarly receptive to labeling experience across development. One previous investigation found that individual-level training, from 6 to 9 months of age, was associated with process-specific learning that directs attention and broadly influences perceptual and cognitive processes 4 years later (Hadley et al., 2015). This previous result highlights the importance of 6–9 months but still does not rule out the possibility that learning during other developmental periods may also have long-lasting benefits on development.

Depending on the specific analysis, the present investigation has limited statistical power. Although problematic, our sample size is similar to several previously published reports within this field (Balas, Westerlund, Hung, & Nelson, 2011; Gredebäck et al., 2015; Guy, Zieber, & Richards, 2016; Hoehl, 2015; Kopp & Lindenberger, 2011; Reid, Striano, Kaufman, & Johnson, 2004; Scott, 2011; Scott & Monesson, 2010). As a field, we need to strive to increase power. However, it is also important to examine development using longitudinal and multimethod approaches, and to replicate previous findings using a variety of approaches. The results reported here are consistent with several previous investigations (Hadley et al., 2015; Scott, 2011; Scott & Monesson, 2009, 2010).

The present results suggest that infants use labels to differentially learn about and attend to events in their world. Here we show that infants who were trained with individual-level labels from 6 to 9 months of age learned to individuate these objects and applied this learning to new exemplars within the trained object category. The learning reported here suggests that infants exhibit a profound ability to use labels to build perceptual and conceptual representations to direct attention.

References

Ackles, P. K., & Cook, K. G. (2007). Attention or memory? Effects of familiarity and novelty on the Nc component of event-related brain potentials in six-month-old infants. *International Journal of Neuroscience*, *117*, 837–867. https://doi.org/10.1080/00207450600909970

Althaus, N., & Mareschal, D. (2014). Labels direct infants' attention to commonalities during novel category learning. *PLoS ONE*, *9*, e99670. https://doi.org/10.1371/journal.pone.0099670

Althaus, N., & Plunkett, K. (2016). Categorization in infancy: Labeling induces a persisting focus on commonalities. *Developmental Science*, *19*, 770–780. https://doi.org/10.1111/desc.12358

Althaus, N., & Westermann, G. (2016). Labels constructively shape object categories in 10-month-old infants. *Journal of Experimental Child Psychology*, *151*, 5–17. https://doi.org/10.1016/j.jecp.2015.11.013

Balas, B., Westerlund, A., Hung, K., & Nelson, C. A. I. (2011). Shape, color and the other-race effect in the infant brain. *Developmental Science*, *14*, 892–900. https://doi.org/10.1111/j.1467-7687.2011.01039.x

Baldwin, D. A., & Markman, E. M. (1989). Establishing word-object relations: A first step. *Child Development*, *60*, 381–398. https://doi.org/10.2307/1130984

Baluch, F., & Itti, L. (2011). Mechanisms of top-down attention. *Trends in Neurosciences*, *34*, 210–224. https://doi.org/10.1016/j.tins.2011.02.003

Best, C. A., Robinson, C. W., & Sloutsky, V. M. (2010). The effects of labels on visual attention: An eye tracking study. *Proceedings of the 32nd Annual Conference of the Cognitive Science Society*, *32*, 1846–1851. https://doi.org/10.1006/cogp.1995.1016

Courchesne, E., Ganz, L., & Norcia, A. M. (1981). Event-related brain potentials to human faces in infants. *Child Development*, *52*, 804–811. https://doi.org/10.2307/1129080

Csibra, G., Kushnerenko, E., & Grossmann, T. (2008). Electrophysiological methods of studying infant cognitive development. In C. A. Nelson & M. Luciana (Eds.), *Handbook of developmental cognitive neuroscience* (2nd ed., pp. 247–262). Cambridge, MA: MIT Press.

de Haan, M., Johnson, M. H., & Halit, H. (2003). Development of face-sensitive event-related potentials during infancy: A review. *International Journal of Psychophysiology*, *51*, 45–58. https://doi.org/10.1016/S0167-8760(03)00152-1

de Haan, M., & Nelson, C. A. (1997). Recognition of the mother's face by six-month-old infants: A neurobehavioral study. *Child Development*, *68*, 187–210. https://doi.org/10.1111/1467-8624.ep9706130494

de Haan, M., & Nelson, C. A. (1999). Brain activity differentiates face and object processing in 6-month-old infants. *Developmental Psychology*, *35*, 1113–1121. https://doi.org/10.1037/0012-1649.35.4.1113

Fulkerson, A. L., & Waxman, S. R. (2007). Words (but not tones) facilitate object categorization: Evidence from 6- and 12-month-olds. *Cognition*, *105*, 218–228. https://doi.org/10.1016/j.cognition.2006.09.005

Gelman, S. A., Chesnick, R. J., & Waxman, S. R. (2005). Mother–child conversations about pictures and objects: Referring to categories and individuals. *Child Development*, *76*, 1129–1143. https://doi.org/10.1111/j.1467-8624.2005.00840.x

Gliga, T., Volein, A., & Csibra, G. (2010). Verbal labels modulate perceptual object processing in 1-year-old children. *Journal of Cognitive Neuroscience*, *22*, 2781–2789. https://doi.org/10.1162/jocn.2010.21427

Gredebäck, G., Kaduk, K., Bakker, M., Gottwald, J., Ekberg, T., Elsner, C., . . . Kenward, B. (2015). The neuropsychology of infants' pro-social preferences. *Developmental Cognitive Neuroscience*, *12*, 106–113. https://doi.org/10.1016/j.dcn.2015.01.006

Guy, M. W., Reynolds, G. D., & Zhang, D. (2013). Visual attention to global and local stimulus properties in 6-month-old infants: Individual differences and event-related potentials. *Child Development*, *84*, 1392–1406. https://doi.org/10.1111/cdev.12053

Guy, M. W., Zieber, N., & Richards, J. E. (2016). The cortical development of specialized face processing in infancy. *Child Development*, *87*, 1581–1600. https://doi.org/10.1111/cdev.12543

Hadley, H., Pickron, C. B., & Scott, L. S. (2015). The lasting effects of process-specific versus stimulus-specific learning during infancy. *Developmental Science*, *18*, 842–852. https://doi.org/10.1111/desc.12259

Hadley, H., Rost, G. C., Fava, E., & Scott, L. S. (2014). A mechanistic approach to cross-domain perceptual narrowing in first year of life. *Brain Sciences*, *4*, 613–634. https://doi.org/10.3390/brainsci4040613

Havy, M., & Waxman, S. R. (2016). Naming influences 9-month-olds' identification of discrete categories along a perceptual continuum. *Cognition*, *156*, 41–51. https://doi.org/10.1016/j.cognition.2016.07.011

Hoehl, S. (2015). How do neural responses to eyes contribute to face-sensitive ERP components in young infants? A rapid repetition study. *Brain and Cognition*, *95*, 1–6. https://doi.org/10.1016/j.bandc.2015.01.010

Hurley, K. B., Kovack-Lesh, K. A., & Oakes, L. M. (2010). The influence of pets on infants' processing of cat and dog images. *Infant Behavior and Development*, *33*, 619–628. https://doi.org/10.1016/j.infbeh.2010.07.015

Kopp, F., & Lindenberger, U. (2011). Effects of joint attention on long-term memory in 9-month-old infants: An event-related potentials study. *Developmental Science*, *14*, 660–672. https://doi.org/10.1111/j.1467-7687.2010.01010.x

Kovack-Lesh, K. A., McMurray, B., & Oakes, L. M. (2014). Four-month-old infants' visual investigation of cats and dogs: Relations with pet experience and attentional strategy. *Developmental Psychology*, *50*, 402–413. https://doi.org/10.1037/a0033195

Nelson, C. A., & Monk, C. S. (2001). The use of event-related potentials in the study of cognitive development. In C. A. Nelson & M. Luciana (Ed.), *Handbook of developmental cognitive neuroscience* (pp. 125–136). Cambridge, MA: MIT Press.

Pascalis, O., Scott, L. S., Kelly, D. J., Shannon, R. W., Nicholson, E., Coleman, M., & Nelson, C. A. (2005). Plasticity of face processing in infancy. *Proceedings of the National Academy of Sciences of the United States of America*, *102*, 5297–5300. https://doi.org/10.1073/pnas.0406627102

Peltola, M. J., Leppänen, J. M., Mäki, S., & Hietanen, J. K. (2009). Emergence of enhanced attention to fearful faces between 5 and 7 months of age. *Social Cognitive and Affective Neuroscience*, *4*, 134–142. https://doi.org/10.1093/scan/nsn046

Reid, V. M., Striano, T., Kaufman, J., & Johnson, M. H. (2004). Eye gaze cueing facilitates neural processing of objects in 4-month-old infants. *NeuroReport*, *15*, 2553–2555. https://doi.org/10.1097/00001756-200411150-00025

Reynolds, G. D. (2015). Infant visual attention and object recognition. *Behavioural Brain Research*, *285*, 34–43. https://doi.org/10.1016/j.bbr.2015.01.015

Reynolds, G. D., Courage, M. L., & Richards, J. E. (2010). Infant attention and visual preferences: Converging evidence from behavior, event-related potentials, and cortical source localization. *Developmental Psychology*, *46*, 886–904. https://doi.org/10.1037/a0019670

Reynolds, G. D., & Richards, J. E. (2005). Familiarization, attention, and recognition memory in infancy: An event-related potential and cortical source localization study. *Developmental Psychology*, *41*, 598–615. https://doi.org/10.1037/0012-1649.41.4.598

Richards, J. E. (2003). Attention affects the recognition of briefly presented visual stimuli in infants: An ERP study. *Developmental Science*, *6*, 312–328. https://doi.org/10.1111/1467-7687.00287

Richards, J. E., Reynolds, G. D., & Courage, M. L. (2010). The neural bases of infant attention. *Current Directions in Psychological Science*, *19*, 41–46. https://doi.org/10.1177/0963721409360003

Samuelson, L. K., & Smith, L. B. (1999). Early noun vocabularies: Do ontology, category structure and syntax correspond? *Cognition*, *73*, 1–33. https://doi.org/10.1016/S0010-0277(99)00034-7

Sarter, M., Givens, B., & Bruno, J. P. (2001). The cognitive neuroscience of sustained attention: Where top-down meets bottom-up. *Brain Research Reviews*, *35*, 146–160. https://doi.org/10.1016/S0165-0173(01)00044-3

Scott, L. S. (2011). Mechanisms underlying the emergence of object representations during infancy. *Journal of Cognitive Neuroscience*, *23*, 2935–2944. https://doi.org/10.1162/jocn_a_00019

Scott, L. S., & Monesson, A. (2009). The origin of biases in face perception. *Psychological Science*, *20*, 676–680. https://doi.org/10.1111/j.1467-9280.2009.02348.x

Scott, L. S., & Monesson, A. (2010). Experience-dependent neural specialization during infancy. *Neuropsychologia*, *48*, 1857–1861. https://doi.org/10.1016/j.neuropsychologia.2010.02.008

Smith, L. B., Jones, S. S., Landau, B., Gershkoff-Stowe, L., & Samuelson, L. (2002). Object name learning provides on-the-job training for attention. *Psychological Science*, *13*, 13–19. https://doi.org/10.1111/1467-9280.00403

Srinivasan, R., Nunez, P. L., Tucker, D. M., Silberstein, R. B., Cadusch, P. J., & Peter, J. (1996). Spatial sampling and filtering of EEG with spline Laplacians to estimate cortical potentials. *Brain Topography*, *8*, 355–366. https://doi.org/10.1007/bf01186911

Stampe, D. M. (1993). Heuristic filtering and reliable calibration methods for video-based pupil-tracking systems. *Behavior Research Methods, Instruments, & Computers*, *25*, 137–142. https://doi.org/10.3758/BF03204486

Stets, M., Stahl, D., & Reid, V. M. (2012). A meta-analysis investigating factors underlying attrition rates in infant ERP studies. *Developmental Neuropsychology*, *37*, 226–252. https://doi.org/10.1080/87565641.2012.654867

Vitevitch, M. S., & Luce, P. A. (2004). A web-based interface to calculate phonotactic probability for words and nonwords in English. *Behavior Research Methods, Instruments, & Computers*, *36*, 481–487. https://doi.org/10.3758/BF03195594

Waxman, S. R., & Braun, I. (2005). Consistent (but not variable) names as invitations to form object categories: New evidence from 12-month-old infants. *Cognition*, *95*, https://doi.org/10.1016/j.cognition.2004.09.003

Waxman, S. R., & Markow, D. B. (1995). Words as invitations to form categories: Evidence from 12- to 13-month-old infants. *Cognitive Psychology*, *29*, 257–302. https://doi.org/10.1006/cogp.1995.1016

Supporting Information

Additional supporting information may be found in the online version of this article at the publisher's website: Data and stimuli for this study are freely available at: https://nyu.databrary.org/volume/546.

Figure S1. Computer-Generated Novel Objects That Were Included in the Study

Table S1. Eye Tracking: Average Dwell Time at 6 and 9 Months Between Training Groups

Table S2. Event-Related Potential (ERP): Average Negative Central (Nc) Amplitude to Frequently and Infrequently Presented Objects at 6 and 9 Months Between Training Groups

Table S3. Eye Tracking: Three-Factor Multivariate Analysis of Variance (MANOVA) for Changes in Dwell Time Between Training Groups

Table S4. Eye Tracking: Follow-Up Paired *t* Tests for Age × Training Interaction

Table S5. Eye Tracking: Two-Factor Multivariate Analysis of Variance (MANOVA) for Dwell Time Differences Between Training Groups at 9 Months

Table S6. Event-Related Potential (ERP): Four-Factor Multivariate Analysis of Variance (MANOVA) for Training, Region, Age, and Object-Related Negative Central (Nc) Amplitude Changes

Table S7. Event-Related Potential (ERP): Follow-Up Paired *t* Test for Negative Central (Nc) Amplitude Interaction of Object Frequency × Training

Table S8. Event-Related Potential (ERP): Follow-Up Paired *t* Tests for Negative Central (Nc) Amplitude Four-Way Interaction: Training × Infant Age × Region × Object Frequency

Table S9. Event-Related Potential (ERP): 9-Month-Old Three-Factor Multivariate Analysis of Variance (MANOVA) Negative Central (Nc) Amplitude Differences Between Training Groups, Object Frequency, and Region

Table S10. Event-Related Potential (ERP): 9-Month-Old Negative Central (Nc) Amplitude Differences Follow-Up Paired *t* Tests for Two-Way Interaction Object Frequency × Training

Table S11. Event-Related Potential (ERP): 9-Month-Old Follow-Up Paired *t* Tests Negative Central (Nc) Amplitude Differences Three-Way Interaction of Object × Region × Training