Mechanisms Underlying the Emergence of Object Representations during Infancy

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Abstract

■ The effects of individual versus category training, using behavioral indices of stimulus discrimination and neural ERPs indices of holistic processing, were examined in infants. Following pretraining assessments at 6 months, infants were sent home with training books of objects for 3 months. One group of infants was trained with six different strollers labeled individually, and another group was trained with the same six strollers labeled at the category level (i.e., "stroller"). Infants returned for posttraining assessments at 9 months. Discrimination of objects was facilitated for infants trained with the individually labeled strollers but was unchanged after training at the category level. Relative to pretraining and to category-level training, individual-level training resulted in increased holistic processing of strollers recorded over occipital brain regions. These results suggest that labeling nonface objects individually, in infancy, facilitates discrimination and leads to the emergence of holistic neural representations not present with category-level labeling. ■

INTRODUCTION

A single glance of a crowded room allows one to recognize familiar and unfamiliar people and objects. During that single glance, one can decide what to attend to, what not to attend to, and how to identify and/or categorize people and objects. With or without awareness, each object or person is placed onto a continuum of importance and relevance. Although controversial, we understand quite a bit about how human adults perceive and recognize faces and objects and how structures in the brain support such processing (Gerlach, 2007; Yovel & Kanwisher, 2004; Haxby et al., 2001; Gauthier et al., 2000; Kanwisher, 2000; Tarr & Gauthier, 2000). We know much less about the development of face and object perception and whether infants view and prioritize the surrounding world in a similar manner as adults. Moreover, the exact nature of the emergence of dedicated neural structures for face and object processing is also not well understood and often debated (Park, Newman, & Polk, 2009; Sugita, 2009; Macchi Cassia, Valenza, Simion, & Leo, 2008; Macchi Cassia, Turati, & Simion, 2004; Gauthier & Nelson, 2001).

In adults, face perception is thought to differ from everyday object perception. First, faces are typically individuated (i.e., every face has an individual-level proper name) and processed at a more subordinate level (Tanaka, 2001). Second, unlike object processing, face processing has been found to rely more heavily on holistic representations (Yin, 1969). It has been argued that differences between objects, and faces arise during development because of differing demands of the environment (Gauthier & Nelson, 2001). However, before the present investigation, there has been no empirical evidence showing that differential learning experiences, in infancy, can lead to distinct neural representations of the same objects.

In adults, expertise with nonface objects leads to similar behavioral and neural response patterns, as found for faces (Rossion & Curran, 2010; Busey & Vanderkolk, 2005; Tanaka & Curran, 2001; Gauthier et al., 2000; Tarr & Gauthier, 2000; Gauthier, Tarr, Anderson, Skudlarski, & Gore, 1999; Tanaka & Taylor, 1991; Diamond & Carey, 1986). Similar to faces, bird experts individuate birds at a more subordinate (species) level compared with nonexperts (Tanaka & Taylor, 1991). In addition, experts perceive objects within their domain of expertise more holistically than objects outside their domain of expertise (Rossion & Curran, 2010; Busey & Vanderkolk, 2005; Gauthier, Curran, Curby, & Collins, 2003; Diamond & Carey, 1986). For example, relative to novices, dog breeders are similarly impaired at recognizing images of dogs and faces when they are presented upside down (Diamond & Carey, 1986). Inversion of stimuli has also been found to disrupt electrophysiological (ERP) indices of face processing (Sagiv & Bentin, 2001; Eimer, 2000; Rossion et al., 2000; Bentin, Allison, Puce, Perez, & McCarthy, 1996) and expert object processing (Busey & Vanderkolk, 2005; Rossion, Gauthier, Goffaux, Tarr, & Crommelinck, 2002). For example, the adult N170 ERP component, recorded over occipital and temporal regions of the scalp, differentiates faces and objects (Carmel & Bentin, 2002) and is enhanced to inverted relative to upright faces as well as objects of expertise (Busey & Vanderkolk, 2005; Rossion et al., 2002). However, the

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adult N170 inversion effect is specific to face categories for which adults have extensive experience and is absent in response to upright and inverted monkey faces (de Haan, Pascalis, & Johnson, 2002) as well as other-race faces (Gajewski, Schlegel, & Stoerig, 2008).

Prior research investigating the acquisition of object expertise in adults suggests that increased expertise is exhibited in those who are trained to discriminate at more specific levels (e.g., they learn to identify exemplars within multiple species of owls; Scott, Shannon, & Nelson, 2006). Neither category (e.g., learning that several species of owls all belong to the "owl" category) nor exposure (passive viewing) training led to an increased ability to tell the difference between individual birds within a species or individual cars within a specific model (Scott, Tanaka, Sheinberg, & Curran, 2006, 2008). Moreover, after training with novel objects at the individual level, adults perceived these trained objects more holistically than after training at the category level (Wong, Palmeri, & Gauthier, 2009).

Training effects have also been investigated in infants using faces (Scott & Monesson, 2009, 2010; Pascalis et al., 2005). Infants who were trained with six individually labeled monkey faces over a 3-month period maintained the ability to discriminate monkey faces. However, infants who learned these same six faces categorically (i.e., all faces were labeled "monkey") or were simply exposed to these faces (i.e., faces were not labeled) showed a decline in the ability to discriminate monkey faces (Scott & Monesson, 2009). Labeling faces individually also led to an occipital-temporal ERP inversion effect, similar to what is found in adults, that was not present before training and was not present after category or exposure training (Scott & Monesson, 2010). These results suggest that experience with individually labeled faces, from 6 to 9 months of age, can critically shape the perceptual representation that is responsible for later recognition and discrimination of faces.

However, little is presently known about how individual-level learning shapes object perception during infancy and whether individual-level experience with objects leads to face-like cortical representations. Much of the early developmental literature focuses on determining whether infants can represent objects as solid and connected items that behave in predicable ways (e.g., Baillargeon, 1993; Spelke & Van de Walle, 1993; Wynn, 1992). Beyond knowing that infants can represent objects, we also know that by 6–7 months of age infants categorize visual objects at the global, basic, and subordinate levels (Quinn & Tanaka, 2007; Mareschal & Quinn, 2001). Finally, infants as young as 3 months of age have been found to link spoken words with object categories (Ferry, Hespos, & Waxman, 2010) and by the end of the first year of life infants use linguistic labels to guide object individuation (Xu, Cote, & Baker, 2005).

These early categorization abilities have led researchers to hypothesize that the development of face and object representations in infancy might be akin to the acquisition of perceptual expertise in adults (Scott & Monesson, 2009, 2010; Quinn & Tanaka, 2007). The present investigation goes beyond the existence of representations and determining whether infants can categorize and shows the emergence of experience-specific representations with training. Moreover, results from the present study provide fundamental insights into the mechanisms mediating the development of the neural systems underlying face and object perception.

Here it was predicted that, unlike learning to categorize objects, learning to individuate objects during the first year of life would lead to specialized processing for those objects—not dissimilar from the acquisition of perceptual expertise in adults. However, it was unclear whether the pattern of change would be similar to what was found when infants were trained with unfamiliar groups of faces (Scott & Monesson, 2009; Pascalis et al., 2005) or whether individual-level object training, unlike face training, results in a fundamentally different developmental trajectory. The ability to tell the difference between two faces within an uncommonly experienced face group (e.g., monkey faces) declines between 6 and 9 months of age (Kelly et al., 2007, 2009; Scott & Monesson, 2009; Pascalis et al., 2005; Pascalis, de Haan, & Nelson, 2002). During this time, face representations appear to be tuned and shaped by socially relevant and frequently encountered faces, relative to less frequently encountered face groups (e.g., monkey faces), a process called "perceptual narrowing" (Scott, Pascalis, & Nelson, 2007). One possibility is that, similar to what was previously found for faces, 3 months of experience with objects labeled at the individual level, but not the category level, would lead to maintenance in the ability to discriminate these objects from 6 to 9 months of age. Alternately, it is possible that 6-month-old infants already treat faces differently from objects and thus, unlike faces, may not show evidence of discrimination of these objects. In this case, individual-level training may increase infants' ability to discriminate these objects between 6 and 9 months of age. It was also hypothesized that, similar to faces (Scott & Monesson, 2010), infants trained with objects labeled at the individual level would exhibit increased holistic processing of the trained objects, as indexed by an ERP inversion effect, relative to infants trained with the same objects with category-level labels.

At 6 months, infants and their families were sent home with a book of stroller images (see Figure 1) and asked to "read" this book to their infants according to a fixed schedule. Strollers were used because, (1) similar to faces, they have three areas of interest (seat, wheels, and handlebars) that vary across exemplars and, (2) although similar to faces in category homogeneity, strollers do not look like faces. Infants were tested longitudinally, at both 6 and 9 months of age and were randomly placed into either an individual-level or a category-level training group. Infants in the individual-level training group were sent home with books in which six images of strollers were labeled at the individual level with nonsense names (i.e., "Wuggum,"

Figure 1. Experimental stimuli. Example photographs of stroller stimuli used for training and pretest and posttest assessments. These images and their corresponding labels were presented within a picture book and used for training.

"Cuggle," "Zoneep," etc.). Infants in the category-level training group were sent home with books in which all six strollers were labeled "Stroller." Each group of infants was trained with the exact same images, only the labels differed. Parents were instructed to only use the provided labels when referring to the images and were given a diary to record their training efforts. After 3 months of training, infants returned to the laboratory for the posttraining assessment.

Before and after the 3-month training period, infants' ability to visually discriminate images of strollers and their neural responses to upright and inverted images of strollers were examined. The visual-paired comparison (VPC) procedure was used to measure infants' discrimination of never-seen-before images of strollers before and after training. The VPC procedure is typically used to index infants' ability to discriminate a recently familiarized stimulus from a new stimulus. Discrimination is inferred if, after a short familiarization period, infants prefer to look at the novel compared with the familiar stimulus for a significantly longer period. Here infants were familiarized and tested with never-seen-before strollers before and after training. After infants completed the VPC task, ERPs were recorded while infants passively viewed images of upright and inverted trained (from the book) and untrained strollers.

METHODS

The University of Massachusetts Amherst Institutional Review Board approved all methods and procedures used in this study. All infant participants completed a behavioral visual discrimination task and an upright/inverted perceptual ERP task before and after 3 months of training. Separate (but overlapping) groups of infants contributed to the behavioral and ERP results.

Participants

Parents of all infants gave informed consent before testing. Fifty-one 6-month-old infants were recruited. Of these 51 infants, 38 completed both pretraining and posttraining sessions and were at least 70% compliant with training. Thirteen infants did not return for their 9-month testing session or were not compliant with training. Behavioral analyses included 26 infants (14 boys, 12 girls) randomly assigned to receive either individual-level (n = 12) or category-level (n = 14) training. For behavioral analyses, 12 infants' data were excluded because they exhibited a bias to look only to one side of the computer screen or never fixated on one of the two pictures at either pretraining or posttraining. Electrophysiological analyses included 27 infants (13 boys, 14 girls) randomly assigned to receive individual-level (n = 15) or category-level (n = 12) training. An additional 12 infants were excluded because they did not contribute enough artifact free trials to each condition (n = 9) or their mean amplitude or latency was 1.5 standard deviations away from the mean of all participants for the conditions of interest (n = 3). All infants were born full term and had no visual or neurological abnormalities. Participants were tested at 6 months (mean age = 179.96 days, SD = 9.70) and 9 months (mean age = 271.58 days, SD = 8.17 days) of age. At each session, the families of participants were paid $10 and given a small toy for their participation.

Stimuli and Apparatus

Twelve digitized color photographs of strollers, presented on a dark gray background at a visual angle of approximately 13°, were used as stimuli for the pretest and posttest assessments. Six of these images were used for training and were presented within a picture book (see Figure 1).

Procedure

Behavioral Procedure

Infants' ability to discriminate strollers before and after a 3-month training period was assessed. Infants were tested at 6 and 9 months of age using the VPC procedure. At 6 months, infants were randomly assigned to either the category or the individual training group. Infants were then sent home with the training books for 3 months. At 9 months, infants returned to the laboratory and completed the posttraining VPC task.

The VPC procedure relies on infants' relative interest in novelty and indexes infants' ability to discriminate a recently familiarized stimulus from a new stimulus. Discrimination is inferred if, after the familiarization period, infants look at the novel stimulus for a significantly longer period than the familiar stimulus. Here we familiarized infants to a single stroller for an accumulated looking time of 30 sec and then paired that stroller with a novel stroller for 10 sec (5 sec with the familiar stroller on the right side of the screen and 5 sec with the familiar stroller on the left side of the screen). A digital video camera recorded infant fixations while they completed the VPC task. An experimenter, viewing a live feed of the infant, recorded estimates of infants' looking behaviors using mouse presses. After testing, the videos were slowed to 20% of their normal speed. Two separate observers (interobserver agreement = 85%), blind to the conditions, coded proportion looking to the familiar and novel images. Measures of looking time were averaged across the two 5-sec test trials and then converted into percent fixation for the novel stimuli. Percent novelty preference was computed as the total amount of time looking toward the novel stimulus divided by the total amount of time looking toward the novel and familiar stimulus multiplied by 100. Paired and one-tailed *t* tests were used to determine whether novelty preferences significantly differed across conditions and whether they were greater than chance.

Electrophysiological Procedure

At pretest and posttest, infants passively viewed upright and inverted trained and untrained strollers while seated on their parents' lap. Each image was presented for 500 msec. Half of the images included the six trained strollers (from the book), and the other half of the images were of the six untrained strollers. An experimenter observed infants' gaze direction and only presented trials when infants were attending to the screen. Each trial consisted of a 100-msec baseline, a 500-msec stimulus presentation, and a 1000- to 1500-msec intertrial interval (ITI). During the ITI, infants viewed a blank blue screen with a white fixation cross in the center. Infants completed an average of 130.12 (*SD* = 26.53) trials at pretest and 122.50 (*SD* = 25.09) trials at posttest.

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, Inc., Eugene, OR). Amplified analog voltages (1–100 Hz bandpass) were collected continuously and digitized at 500 Hz. Individual electrodes were adjusted until impedances were less than 50 kΩ.

Postrecording processing was completed using Netstation 4.3 (Electrical Geodesics, Inc., Eugene, OR). EEG was first digitally low-pass filtered at 40 Hz and then segmented and baseline-corrected with respect to a 100-msec 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. Following artifact detection, each trial was visually inspected for noise and rejected if a significant amount of noise or drift was present. Participants with fewer than 15 artifact free trials per condition were excluded from analyses. At pretest (6 months), a mean of 26.02 (*SD* = 5.15) and 28.84 (*SD* = 9.40) trials contributed to each of the four conditions for infants in the individual-level training group and the category-level training group, respectively. At posttest (9 months), a mean of 28.44 (*SD* = 5.76) trials contributed to the average of each condition after individual-level training and a mean of 25.44 (*SD* = 8.63) trials contributed to the average of each condition after category-level training. An average reference was used to minimize the effects of reference site activity and accurately estimate the scalp topography of the measured electrical fields.

Mean amplitude was measured for the P100, N290, and P400 components. Peak amplitudes were detected for each component of interest, and windows were created based on visual inspection of the start and end of each component across participants. The P100 was measured within 130–150 msec after stimulus onset, the N290 was measured within 150–280 msec after stimulus onset, and the P400 was measured within 300–500 msec after stimulus onset. Electrodes over the occipital regions of the left hemisphere, middle, and right hemisphere were averaged for analysis (right hemisphere: 90, 95, 99, 89, 94 [directly posterior to T6]; middle: 70, 75, 83, 74, 82 [corresponding to O1, O2, and Oz]; left hemisphere: 65, 64, 63, 69, 68 [directly posterior to T5]).

Initial analyses revealed no hemisphere differences, and effects concentrated over the middle region (electrodes 70, 75, 83, 74, 82; corresponding to the 10/20 locations O1, O2, and Oz). Thus, all analyses reported here used averaged electrodes over the middle region and means were submitted to separate 2 × 2 × 2 MANOVAs for amplitude and latency for each of the two training conditions, including two levels of test (pretraining at 6 months; posttraining at 9 months), two levels of orientation (upright; inverted), and two levels of training (trained strollers; untrained strollers). Follow-up analyses of significant interactions were conducted using paired sample *t* tests.

Training Procedure

After the pretest, participants in the individual-training group were sent home with books in which six images of strollers were labeled at the individual level with nonsense names (e.g., "Nosep," "Wuggum"). Participants in the category-training group were sent home with books in which the same six images of strollers were labeled at the category level (i.e., all were labeled "stroller"). For each group (individual, category), there were two different training books, counterbalanced across participants, containing six different strollers. The training books were randomly assigned within each group, so half of the infants were trained with one set of six strollers and the other half were trained with another set of six strollers. The six strollers not present in the training book served as untrained images at both pretest and posttest.

After the pretest assessment, parents were given a diary and training schedule with instructions to read the book for 10 min with their infant everyday 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. Parents were instructed to only use the provided labels when referring to the images but that they could elaborate or tell whatever stories they liked when reading the books to their infants. Parents were given a diary to record their training efforts and were considered compliant with the training if they followed the schedule for at least 75% of the time.

RESULTS

VPC Results

After a 30-sec familiarization period, visual fixation time was measured in response to two 5-sec side-by-side presentations of the familiarized stroller and a novel stroller. Fixation duration to the novel stimulus was averaged across the two 5-sec test trials and then converted into percent fixation for the novel stimuli. Data were first analyzed using one-tailed t tests that compared the percent fixation toward the novel stimulus with chance (50%). At 6 months, before training, novelty preferences were not found for either the individual (M = 51.2%, SE = 3.7%, $t(11) = .32$, $p = .76$) or category (M = 48.4%, SE = 3.2%, $t(13) = -.48$, $p = .63$) training groups (see Figure 2). However, after 3 months of training, infants with individuation training increased their ability to discriminate strollers and exhibited a significant novelty preference (M = 64.7%, SE = 3.5%, $t(11) = 4.18$, $p = .01$). No preference was found after the equivalent category-level training (48.9%, SE = 3.0%, $t(13) = -.372$, $p = .72$; see Figure 2).

Within each training group, planned paired t tests were also conducted to determine whether the percent looking toward the novel stimulus was maintained from pretraining to posttraining. The results of these analyses revealed a significant increase in percent novelty preference after individual training ($t(11) = -2.40$, $p = .04$) and no change in percent novelty preference after category training ($t(13) = -.12$, $p = .91$). Furthermore, the novelty preference after individual-level training was significantly greater than the novelty preference after category-level training ($t(11) = 2.79$, $p = .02$). This group difference was not present before training ($t(11) = .23$, $p = .83$). These results suggest that experience individuating, but not categorizing, multiple exemplars of strollers from 6 to 9 months of age increases infants' ability to discriminate among strollers. Moreover, it appears that learning to individuate multiple exemplars at more specific levels led strollers to be treated differently from everyday categories of objects. This finding is consistent with previous adult work on the acquisition of perceptual expertise with nonface visual categories (Scott et al., 2008; Scott, Tanaka, et al., 2006).

Electrophysiological Results

P1

For the P1 amplitude, analyses of infants trained at the individual level revealed a significant interaction between pretest/posttest and whether the stroller was upright or inverted $F(1, 11) = 11.89$, $p = .05$, $\eta^2 = 52$). A follow-up examination of this interaction revealed a marginally greater amplitude recorded in response to viewing upright relative to inverted strollers before training ($t(11) = 1.99$, $p = .07$). However, individual-level training reversed this response, and a significantly greater P1 amplitude was found for inverted relative to upright strollers after training ($t(11) = -2.58$, $p = .03$). Analyses of infants in the category training group showed a significantly greater amplitude response to the upright relative to the inverted strollers ($F(1, 13) = 7.55$, $p = .02$, $\eta^2 = .37$; see Figures 3 and 4). However, unlike infants trained at the individual level, category training did not reverse the direction of the inversion effect.

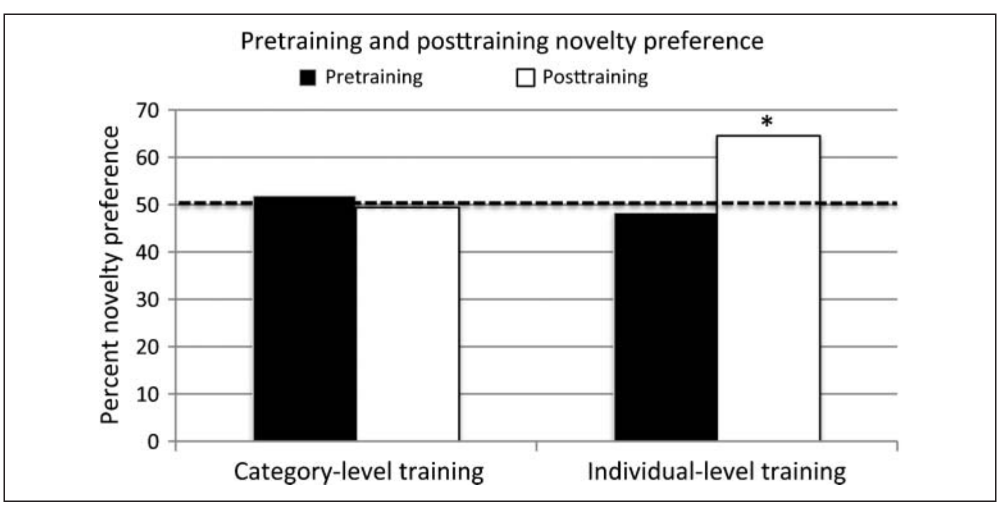

Figure 2. Behavioral results. Mean percentage of time spent looking toward the novel stimuli before and after 3 months of individual or category training with strollers.

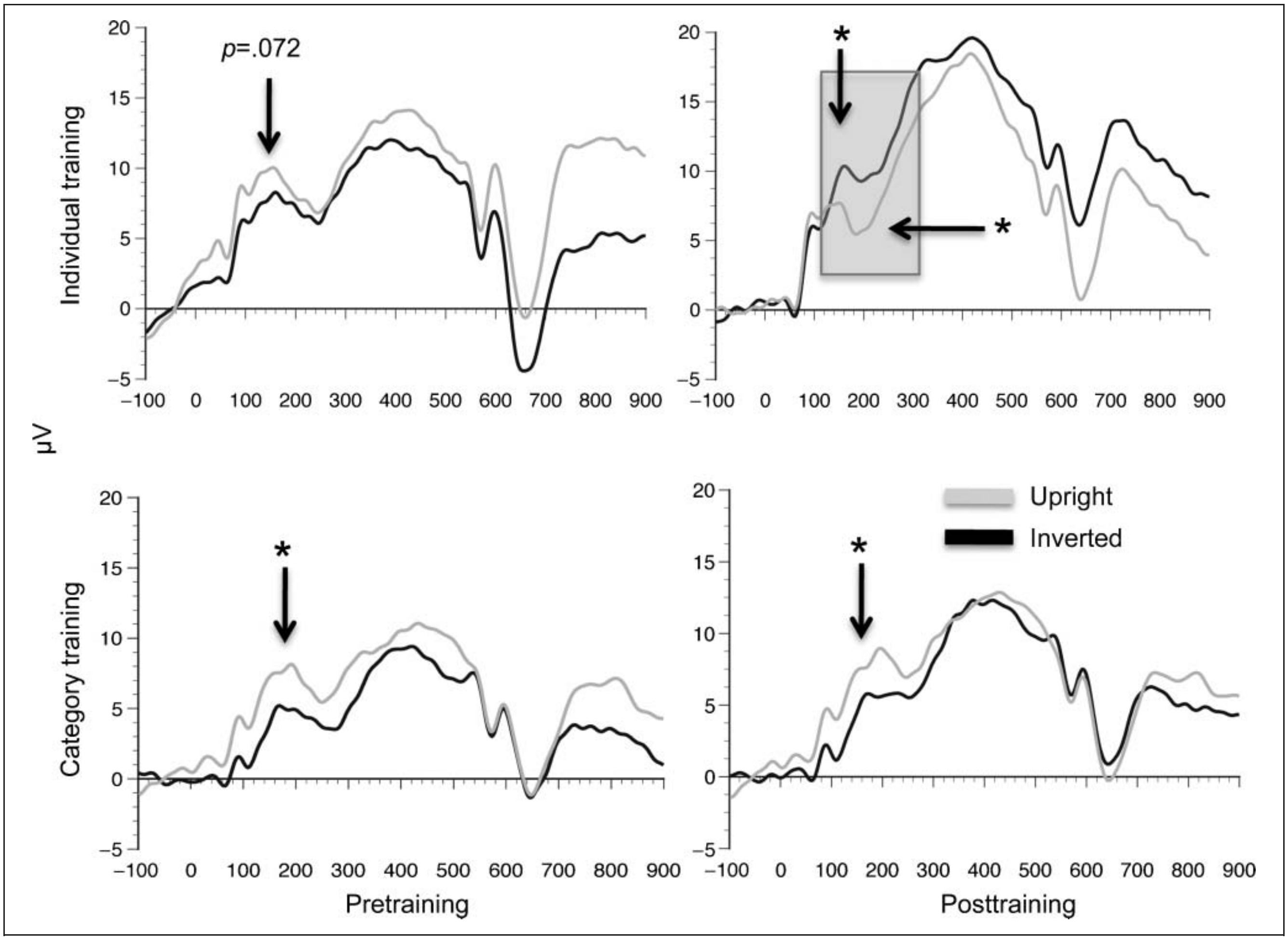

Figure 3. ERP waveforms. ERP responses averaged across the middle occipital region in response to upright and inverted trained and untrained strollers. P1 mean amplitude was greater for upright relative to inverted strollers before training and after category-level training (significant effects indicated by arrows and asterisks). This pattern was reversed and continued to the N290 after individual-level training.

For infants trained at the individual level, analyses of the peak P1 latency revealed a significant main effect of orientation ($F(1, 11) = 6.67$, $p = .03$, $\eta^2 = .38$) because of a longer latency response to inverted compared with upright strollers. No other significant main effects or interactions were found for infants trained at the individual level or for infants trained at the category level.

For infants in both the individual-level and category-level training groups analyses of the peak N290 latency revealed a significant main effect of test (individual level: $F(1, 11) = 10.76$, $p = .01$, $\eta^2 = .50$; category level: $F(1, 13) = 5.20$, $p = .04$, $\eta^2 = .30$) because of a longer latency response at pretest (6 months of age) relative to posttest (9 months of age).

N290

For the N290 amplitude, analyses of infants trained at the individual level revealed a significant interaction between pretest/posttest and whether the stroller was upright or inverted ($F(1, 11) = 4.63$, $p = .05$, $\eta^2 = .30$). Similar to the P1, this interaction was because of a greater negative amplitude, recorded in response to viewing upright relative to inverted strollers after individual-level training ($t(11) = -2.48$, $p = .03$; see Figures 3 and 4). There were no significant N290 amplitude differences before training or after category-level training.

P400

For infants trained at the individual level, no significant amplitude or latency differences were found. However, infants trained at the category level exhibited significantly greater amplitude P400 response posttraining relative to pretraining ($F(1, 13) = 6.96$, $p = .02$, $\eta^2 = .35$) and a significant interaction between the orientation of the stroller and whether the images were trained versus untrained ($F(1, 13) = 4.90$, $p = .05$, $\eta^2 = .27$). A follow-up of this interaction revealed that untrained inverted strollers elicited a marginally larger P400 than trained inverted strollers ($t(13) = -2.09$, $p = .06$). This difference was not present for upright strollers or after individual-level training.

Latency analyses of infants in the category-training group also revealed a significant interaction between the orientation of the stroller and whether the images were trained versus untrained ($F(1, 13) = 6.37$, $p = .03$, $\eta^2 = .33$). A follow-up examination of this interaction revealed a significantly longer latency to peak response for upright trained strollers relative to upright untrained strollers ($t(13) = 2.43$, $p = .03$) and a marginally longer latency to peak to inverted relative to upright untrained strollers ($t(13) = -2.10$, $p = .06$).

DISCUSSION

The present investigation examined whether infants form experience-specific object representations during the first year of life. The goal of this research was to take what we know about the acquisition of expertise in adults and determine whether training during infancy leads to similar increases in the ability to differentiate among trained exemplars and in holistic processing of trained objects. Relative to training with strollers labeled at the category level, training with strollers labeled at the individual level led to an increased ability to discriminate strollers and increased holistic representations, as indexed by the ERP inversion effect. These results inform our understanding of the nature of the development of face and object processing and are consistent with acquisition of object perceptual expertise in adults.

Before training, 6-month-old infants did not show evidence of discrimination of strollers. This finding is inconsistent with several investigations finding that 6-month-olds readily discriminate faces of multiple (but not all) races (Kelly et al., 2009) and species (Scott & Monesson, 2009; Pascalis et al., 2002, 2005). This early ability to discriminate unfamiliar face groups declines between 6 and 9 months of age (Kelly et al., 2007, 2009; Scott & Monesson, 2009; Pascalis et al., 2002, 2005). This process of perceptual tuning or narrowing has previously been described as domain-general process that also occurs for phonemic perception, intersensory perception, conceptual understanding of word meaning, and the discrimination of musical rhythms (for a review, see Lewkowicz & Ghazanfar, 2009; Scott et al., 2007). On the basis of these previous perceptual narrowing findings across multiple domains, the same pattern of decline in ability to discriminate was expected for strollers unless trained at the individual level. However, 6-month-olds showed no evidence of discrimination among exemplars of strollers, suggesting that the process of visual perceptual

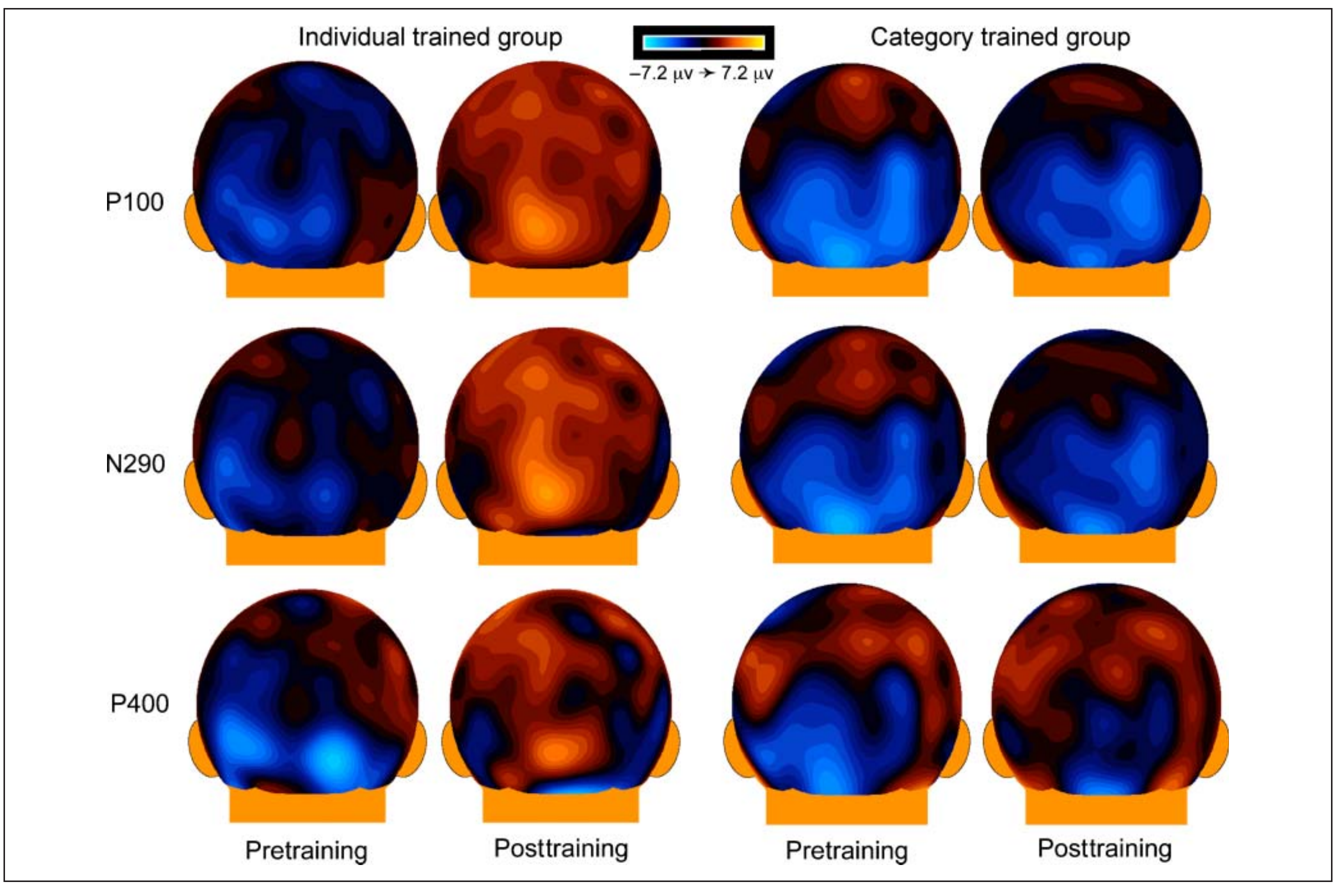

Figure 4. Topographic distribution of the amplitude difference between inverted and upright strollers (inverted–upright) after individual-level training, including P1 (130–190 msec), N290 (150–280 msec), and P400 (300–500 msec) components.

narrowing, from 6 to 9 months of age, may be specific to faces. Three hypotheses remain to be tested to better understand this finding. First, it is likely that 6-month-old infants have had previous experience with strollers and have already learned to categorize and not individuate them. Testing training effects with a novel class of artificial objects will help determine the role of previous experience in object training. Second, it is possible that infants younger than 6 months will show evidence of discrimination of non-face objects, such as strollers, and that perceptual narrowing does occur; it just occurs earlier for objects than for faces. Finally, visual perceptual narrowing may be restricted to stimuli with more information in the upper half of the stimulus relative to the lower half. Recently, it has been suggested that early infant preferences for faces may be because of a more general bias of the visual system to preferentially attend to stimuli (like faces) that contain more information in the upper visual half (Macchi Cassia et al., 2004). It is possible that the existence of these early domain-general visual biases helps the visual system prioritize stimuli that are important to discriminate. Then, as infants learn more about their social environment, they decline in the ability to distinguish among people within unfamiliar groups. Testing these hypotheses require (1) examining training effects with a novel class of objects, (2) training infants before 6 months of age, and (3) training with object categories that do not look like faces but still have more information in the upper, relative to the lower, visual half.

Here we found that infants who learned six strollers labeled at the individual level showed discrimination of untrained strollers. However, infants who learned six strollers labeled "stroller" showed no evidence of discrimination. Labeling strollers at the individual level appears to facilitate later discrimination of two previously unseen strollers. This increased discrimination is comparable to what has been found after training at the subordinate or individual levels in adults (Wong et al., 2009; Scott et al., 2008; Scott, Tanaka, et al., 2006). These results suggest that, despite the many qualitative differences between infants and adults, object learning in infants and adults is very similar.

Faces are typically perceived as a single holistic unit, whereas objects are perceived in a piecemeal fashion and are easily broken down into separable parts. Although holistic processing is multifaceted (Maurer, Grand, & Mondloch, 2002), one of the most robust markers of holistic face processing in adults is the face inversion effect (Rossion & Curran, 2010; Yin, 1969). The inversion effect is associated with neural activity in regions of the occipital and temporal cortices, including the fusiform face area and the occipital face area (Yovel & Kanwisher, 2005). In adults, the N170, recorded over occipital and temporal regions of the scalp, differentiates faces and objects (Carmel & Bentin, 2002) and is larger in response to inverted relative to upright faces and objects of expertise (Gajewski et al., 2008; de Haan et al., 2002).

Previous developmental ERP studies have found both the N290 and the P400 components to index infant face-processing abilities (Scott & Monesson, 2010; Scott & Nelson, 2006; Scott, Tanaka, et al., 2006; de Haan et al., 2002; de Haan & Nelson, 1999). Moreover, individual-level learning, during the first year of life, was found to be necessary for face-specific neural specialization and the emergence of the face inversion effect in infancy (Scott & Monesson, 2010). Similar to the present investigation, Scott and Monesson recorded ERPs in response to upright and inverted monkey faces before (at 6 months) and after (at 9 months) infants completed 3 months of training with six monkey faces labeled at either the individual level (i.e., "Boris," "Fiona"), the category level (i.e., all faces labeled "Monkey"), or without labels (Scott & Monesson, 2010). A greater amplitude N290 and P400 response to inverted relative to upright faces was found after individual level, but not category level or exposure training. This same pattern of results was found in the present investigation after individual-level training with strollers. However, here both amplitude and latency differences between upright and inverted stimuli were found beginning at the P1 component (peaking around 170 msec and recorded over occipital brain regions) and continuing to the N290 component and, although not significantly, the P400 component (see Figures 3 and 4). The timing and location of the P1 component is of interest because it peaks around the same latency and over similar brain regions as the adult N170 component. In addition, unlike previous findings, the P1 differentiates upright and inverted strollers before training. Notably, this pattern of differentiation reverses after training at the individual level but not the category level (see Figures 3 and 4). This reversal is evidence of an expertise effect and suggests that after individuation training infants are both showing increased evidence of behavioral differentiation and forming holistic representations of trained objects. It is currently difficult to determine why the P1 exhibits inversion effects before training without following up experiments. However, it is possible that object categories that have a canonical orientation (such as strollers, cars, or houses) elicit larger inversion effects than object classes that lack a canonical orientation.

It is important to point out that infants trained with category labels exhibit differential processing of trained and untrained, upright and inverted strollers. Untrained inverted strollers elicit a marginally larger amplitude P400 than trained inverted strollers and the P400 to upright untrained stroller peaked significant faster than to upright trained strollers. Finally, the P400 peaked marginally faster to upright versus inverted untrained strollers (but not to trained strollers). However, it is difficult to interpret these findings because although they appear to be driven by the posttraining results, there is not a significant difference between posttraining and pretraining, suggesting a lack of power. This familiarity effect was not found after training with individual-level labels and suggests that category training may lead infants to emphasize familiarity relative to individual-level training.

The results from the present investigation suggest that experience individuating objects, via labeling, from 6 to

9 months of age critically shapes the perceptual representation that is responsible for later recognition and discrimination of objects. Typically, inversion impairments are diminished or absent during object perception; however, perceptual expertise with a class of objects (e.g., cars, fingerprints, and dogs) increases the inversion effect in adults (Rossion & Curran, 2010; Busey & Vanderkolk, 2005; Diamond & Carey, 1986). Here, for the first time, object expertise is shown in infants using two separate measures, suggesting that infants learn about objects in a very similar manner as adults.

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