Developmental Science (2014), pp 1–11 DOI: 10.1111/desc.12259

PAPER

The lasting effects of process-specific versus stimulus-specific learning during infancy

Hillary Hadley, Charisse B. Pickron and Lisa S. Scott

Department of Psychological and Brain Sciences, University of Massachusetts Amherst, USA

Abstract

The capacity to tell the difference between two faces within an infrequently experienced face group (e.g. other species, other race) declines from 6 to 9 months of age unless infants learn to match these faces with individual-level names. Similarly, the use of individual-level labels can also facilitate differentiation of a group of non-face objects (strollers). This early learning leads to increased neural specialization for previously unfamiliar face or object groups. The current investigation aimed to determine whether early conceptual learning between 6 and 9 months leads to sustained behavioral advantages and neural changes in these same children at 4–6 years of age. Results suggest that relative to a control group of children with no previous training and to children with infant category-level naming experience, children with early individual-level training exhibited faster response times to human faces. Further, individual-level training with a face group – but not an object group – led to more adult-like neural responses for human faces. These results suggest that early individual-level learning results in long-lasting process-specific effects, which benefit categories that continue to be perceived and recognized at the individual level (e.g. human faces).

Research highlights

- Relative to a control group of children with no previous training and to children with infant category-level naming experience, children with early individual-level naming training with faces and objects exhibited faster reaction times to human face stimuli.
- Children with early individual-level naming training with a face group also exhibited more adult-like neural responses to human face stimuli.
- Results suggest that early individual-level experience benefits later processing for frequently experienced face groups and suggest that continued experience is necessary to sustain early stimulus-specific learning benefits.
- These results inform our understanding of the role of early experience on later brain and behavioral abilities in typically developing children and these data highlight the important influence of early infant learning, prior to the onset of formal education, on later developmental abilities.

Introduction

Before 6 months of age, babies readily tell apart faces within both familiar (own race or own species) and unfamiliar (other race or other species) groups (Kelly, Quinn, Slater, Lee, Ge & Pascalis, 2007; Kelly, Liu, Lee, Quinn, Pascalis, Slater & Ge, 2009; Pascalis, de Haan & Nelson, 2002; Vogel, Monesson & Scott, 2012). However, by 9 months of age, infants are better at distinguishing faces within familiar groups. This developmental process, called ‘perceptual narrowing’ or ‘perceptual tuning’, guides concept learning and directs detailed attention towards environmentally relevant categories, such as human faces. As a result, environmentally relevant categories continue to be privileged in both perception and recognition across development and into adulthood (Meissner & Brigham, 2001; Pascalis *et al*., 2002).

Recently, perceptual tuning has been found to be influenced in part by infants’ experience hearing labels matched with images of monkey faces at different levels of abstraction (Pascalis, Scott, Kelly, Shannon, Nicholson, Coleman & Nelson, 2005; Scott & Monesson, 2009). For

Address for correspondence: Lisa S. Scott, University of Massachusetts Amherst, Department of Psychological and Brain Sciences, 413 Tobin Hall/135 Hicks Way, Amherst, MA 01003, USA; e-mail: lscott@psych.umass.edu

example, given approximately 6 hours of training from 6 to 9 months of age, 9-month-olds continued to differentiate unfamiliar monkey faces, while 9-month-olds with no experience exhibited a decline in discrimination ability (Pascalis *et al.*, 2005). Furthermore, when labeling was experimentally manipulated (individual names: 'Boris', 'Fiona'; a category label: 'Monkey', 'Monkey'; or no label at all), only 9-month-olds trained with individual names (from 6 to 9 months of age) continued to differentiate monkey faces (Scott & Monesson, 2009). These findings suggest that early individual-level learning can impact perceptual and conceptual representations, resulting in differential processing of learned categories.

In a related investigation, infants were given analogous training with objects to determine whether object experience and face experience shaped perceptual and conceptual abilities in similar ways (Scott, 2011). Similar to previous work, infants received 3 months of experience (approximately 6 hours total) with six images of strollers paired with either individual labels (e.g. 'Wuggum', 'Zoneep') or a general category label ('Stroller'). Scott (2011) found that although 6-month-olds failed to discriminate strollers prior to training, after training 9-month-olds with individual-level experience, but not category-level experience, demonstrated increased visual discrimination of strollers. In addition, individual-level training, but not category-level training, led to increased holistic processing of strollers as shown by an event-related potential (ERP) inversion effect. These findings suggest that individual-level experience with an object category appears to elicit expert-like perception, similar to what has been found in adult populations when they are trained at the subordinate-level with birds (Scott, Tanaka, Sheinberg & Curran, 2006b) or cars (Scott, Tanaka, Sheinberg & Curran, 2008).

Previous investigations of perceptual expertise in both adults and infants have utilized ERPs in order to further understand the timing and contributing neural mechanisms of the acquisition of expertise (e.g. Scott *et al.*, 2006b, 2008; Scott & Monesson, 2010; Scott, 2011). The adult occipital-temporal N170 ERP component is found to be larger in response to human faces relative to animal faces and non-face objects (Bentin, Allison, Puce, Perez & McCarthy, 1996; Itier & Taylor, 2004), and is also larger in response to stimuli within a personal category of expertise (e.g. dogs for dog experts; birds for bird experts) (Tanaka & Curran, 2001). The N170 has also been found to increase after 2 weeks of bird (Scott *et al.*, 2006b) or car (Scott *et al.*, 2008) expertise training. Finally, the N170 is modulated by inversion, both of faces (Rossion, Delvenne, Debatisse, Goffaux, Bruyer, Crommelinck & Guérit, 1999; Rossion, Gauthier, Tarr, Despland, Bruyer, Linotte & Crommelinck, 2000) and of laboratory-trained objects of expertise (Greebles: Rossion, Gauthier, Goffaux, Tarr & Crommelinck, 2002). These findings suggest that the N170 is in part an index of some aspects of expert holistic processing.

The infant precursors to the adult N170 include the occipital-temporal N290 and P400 components (de Haan, Pascalis & Johnson, 2002; Halit, de Haan & Johnson, 2003; Scott & Monesson, 2010; Scott, Shannon & Nelson, 2006a; Vogel *et al.*, 2012). Previously, it was shown that labeling faces individually led to an N290 and P400 ERP inversion effect which was absent prior to training or after category-level or exposure training (Scott & Monesson, 2010). This inversion effect was similar to what has been reported when adults view upright and inverted human faces, suggesting that early experience individuating faces helps shape the neural mechanisms responsible for face processing. In addition, as described above, experience hearing individual labels matched with distinct exemplars within an object category (strollers) from 6 to 9 months of age led to a similar inversion effect (between the P1 and N290). Thus, as in adults (Tanaka & Curran, 2001; Rossion *et al.*, 2002; Scott *et al.*, 2006b, 2008), learning to individuate objects or faces during infancy leads to neural specialization that can be measured in the ERP waveforms (Scott & Monesson, 2010; Scott, 2011).

In the present investigation, children who participated in one of two experimentally controlled training studies from 6 to 9 months of age (Scott & Monesson, 2009, 2010; Scott, 2011) returned for a follow-up experiment between 4 and 6 years of age. Children completed a behavioral discrimination and ERP inversion task that included untrained exemplars from within the trained category (monkey faces or strollers), untrained categories (strollers for children trained with monkey faces and monkey faces for children trained with strollers), and human faces.

We predicted that children trained at the individual level would exhibit sustained behavioral and neural changes in response to early experience. However, it was unclear whether these sustained changes would be *stimulus-specific*, *process-specific*, or both. If early individual-level learning resulted in lasting *stimulus-specific* effects we would expect to see faster response times and larger N170 inversion effects for the trained category (monkeys for monkey-trained children and strollers for stroller-trained children) relative to children who experienced category-level training as infants or an untrained control group of children.

If early individual-level learning resulted in lasting *process-specific* effects we would expect to see faster response times and differential N170 inversion effects to stimuli that they continued to learn at the individual level. In this case, human faces. A process-specific effect would be consistent with findings in adults that report that the FFA (Fusiform Face Area) responds to both faces and non-face objects of expertise (e.g. Bilalic, Langner, Ulrich & Grodd, 2011; Gauthier, Skudlarski, Gore & Anderson, 2000; Harley, Pope, Villablanca, Mumford, Suh, Mazziotta, Enzmann & Engel, 2009) as well as reports of N170 suppression effects in response to faces when concurrently processing faces and objects of expertise (Greebles: Rossion, Kung & Tarr, 2004; cars: Rossion, Collins, Goffaux & Curran, 2007). These previous results in adults suggest that faces and objects of expertise share neural resources and support a more general account of specialization for faces as being tuned by experience individuating visually similar objects. In the present investigation, it is possible that in the absence of continued stimulus-specific learning about monkey faces or strollers, the behavioral and neural changes seen at 9 months of age following training will diminish and those neural resources will instead be recruited for individuating human faces. If this is the case, we might expect to see sustained human face advantages for children who learned to match individual-level labels with faces or objects during infancy.

Method

The University of Massachusetts Amherst Institutional Review Board approved all methods and procedures used in this study.

Participants

All parents gave informed consent prior to testing. Seventy-eight 4- to 6-year-old children (Mean age = 4.85 years, range = 4.00–5.58) were recruited (41 males, 37 females). Forty of these children participated in the previous training studies with monkey faces (n = 21) or strollers (n = 19) (Scott & Monesson, 2009, 2010). Participants were randomly assigned to training groups as infants. Fifty-seven percent of the children who completed the infant training studies participated in the present follow-up investigation.[1] Thirty-eight additional children, with no prior training, served as age-matched controls. Behavioral analyses included data from 71 children from the individual-level (n = 17), category-level (n = 21), and control (n = 33) groups. An additional seven children were excluded because their accuracy was less than 50% (n = 4) or for having no correct trials in a condition (n = 3).

Electrophysiological analyses included data from 60 children from the individual-level (n = 16), category-level (n = 18), and control (n = 26) groups. An additional 18 children were excluded because they would not wear the electrode net (n = 5) or did not contribute enough artifact-free trials per condition (n = 13).

Among the children included in analyses, there were no notable differences in family income, parent education, or number of people in the household (Table 1). Children typically came from families with an average of 4.7 people living in the house, an income of $60–70,000 and an average parent education level of some graduate school. No participants had a history of neurological, visual or auditory impairments. Parents of participants were paid $10 and children received a small toy for their participation.

Stimuli and apparatus

Twenty-four digitized color photographs of Barbary macaques (*Macaca sylvanus*), 24 digitized color photographs of black strollers, and 18 digitized color photographs of neutral female Caucasian faces were presented at a visual angle of approximately 13° (Figure 1). The photographs of the Barbary macaques and the strollers were used in previous training studies (Scott & Monesson, 2009, 2010; Scott, 2011). The photographs of neutral female faces were from the NimStim Set of Facial Expressions database (Tottenham, Tanaka, Leon, McCarry, Nurse, Hare, Marcus, Westerlund, Casey & Nelson, 2009). Basic shapes were used as stimuli for the practice trials in the behavioral task.

Procedure

Child participants completed a behavioral match-to-sample task followed by an ERP task with upright and inverted stimuli.

Training procedure

Experimental child participants completed 3 months of face training when they were between 6 and 9 months of age (see Scott & Monesson, 2009; 2010; Scott, 2011, for additional training details). Six-month-olds were randomly assigned one of two training books with six monkey faces or strollers, labeled at the individual (e.g. 'Boris', 'Zoneep') or category level (e.g. 'monkey', 'stroller'). For a period of 3 months, parents were instructed to read/look at the book with their infants

[1] Due to the low sample size, children who completed exposure-level training with monkey faces as infants (Scott & Monesson, 2009) were not included in analyses.

Table 1 *Demographic information on parent income and education for training groups*

		Control	Category	Individual
Income	$15–35,000	3.0%	6.3%	7.1%
	$35–55,000	21.2%	12.5%	35.7%
	$55–75,000	12.1%	6.3%	14.3%
	> $75,000	63.6%	75%	42.9%
	Average income	$65–75,000	$65–75,000	$60–70,000
Education	High school	7.8%	3.0%	12.5%
	Some college/Community college	26.0%	9.4%	18.8%
	4-year college/Some graduate school	26.3%	24.5%	34.4%
	Master's/Doctoral/Professional degree	40.0%	63.3%	34.4%

Note: Demographic information for training groups summarized as percent of responses per demographic bracket for family income and parent education. Parent education is averaged across Parent 1 and Parent 2. The respondents included in this chart are families of infants included in final analyses. One family from the category-level training group declined to respond to the demographic survey and is not included here.

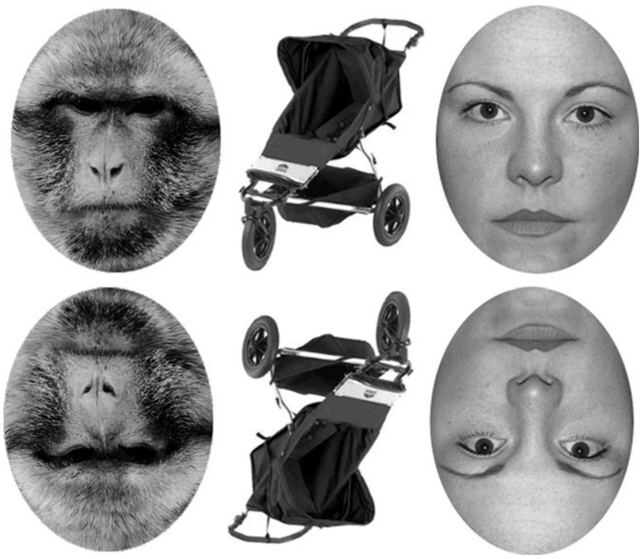


Figure 1 *Examples of Barbary macaque, stroller, and human stimuli used for the behavioral and ERP tasks.*

for 10 minutes a day according to a schedule. This training resulted in approximately 6 hours of training across the 3 months. The books were collected after the training period.

Behavioral procedure

Discrimination was assessed using a match-to-sample paradigm (Lindsay, Jack & Christian, 1991; Sangrigoli & De Schonen, 2004). After three correct practice trials with colored shapes (M = 3.2 trials), children completed three random match-to-sample trials from each of the following four conditions: (1) novel exemplars from within trained category, (2) familiar trained exemplars from within the trained category, (3) exemplars from the untrained category (e.g. strollers for children trained with monkey faces), and (4) human faces. For each trial, children viewed one image for 5 seconds. After a 5-second delay, the familiar image and a novel image from within the same category were presented side-by-side. Children indicated via button press which of the two images was familiar. The number of trials per condition was consistent with what was used for the visual-paired comparison task when the participants were infants (Scott, 2011; Scott & Monesson, 2009).

Electrophysiological procedure

Children passively viewed upright and inverted images of monkey faces, strollers, and human faces. Trials were presented only when children were looking at the screen. Each trial consisted of a 100 ms baseline, a 500 ms stimulus presentation and a 1000–1200 ms randomly varying inter-trial interval. Children completed an average of 209 (SD = 23.6) out of 216 possible trials. The task was completed in the context of a *Finding Nemo* game; children were instructed to press a button when they 'found Nemo' on the screen. ERPs were collected using a 128-channel Geodesic Sensor Net, which was connected to a DC-coupled 128-channel high input impedance amplifier (Net Amps 300 TM, Electrical Geodesics Inc., Eugene, OR). Electrodes were adjusted until impedances were less than 50 kΩ. Amplified signals were low-pass filtered online at 100 Hz and were sampled at 500 Hz. Electrodes were referenced online to the vertex (Cz).

ERP processing procedure

Data were processed using NetStation 4.4.2 (Electrical Geodesics Inc., Eugene, OR). Stimulus-locked ERPs were digitally low-pass filtered at 40 Hz and baseline-corrected with respect to a 100 ms pre-stimulus baseline. Trials were discarded from analyses if they contained more than 12 bad channels (changing more than 160 μV in the entire segment). EEG from individual channels that were consistently bad for a given participant (off-scale on more than 70% of trials) were replaced using a spherical interpolation algorithm (Srinivasan, Nunez, Tucker, Silberstein & Cadusch,1996). Participants contributed an average of 21 (*SD* = 5.6) trials for each of the six conditions and participants with less than 12 artifact-free trials per condition were excluded from analyses (*n* = 13). An average reference was used in order to minimize reference site activity and to accurately estimate scalp topography.

Time windows and electrode groupings were chosen based on previous research (Taylor, Batty & Itier, 2004; Scott *et al.*, 2006a) and visual inspection of the data. Mean amplitude was measured between 116 and 227 ms post-stimulus onset. This window extended from one standard deviation before the peak of the P1 component to one standard deviation after the peak of the N170 component. A peak-to-peak window was chosen to account for condition differences that began at the peak of the P1 and then continued to the N170. For analyses, electrodes from left (64, 65, 66, 69, 70), middle (71, 74, 75, 76, 82), and right (83, 84, 89, 90, 95) occipital temporal regions were grouped and averaged together.

Analyses

Behavioral analyses

Response time and accuracy were measured and averaged for each participant. Only response times from correct trials were analyzed. Trials with a response time greater than 2 *SD*s of the within-training group mean (collapsed across monkey and stroller training) were excluded from analyses. There were no differences in the number of trials per condition across groups or conditions (*Mean number of completed trials* = 2.5, *SD* = 0.6).

There were no significant group differences in response time to trained versus untrained monkey faces or strollers, so responses were averaged to create one 'trained' stimulus condition, collapsing data across monkey-trained and stroller-trained children. Analyses were run to determine whether or not within each condition, the individual-level training group exhibited increased accuracy and faster response times compared to the category-level training group and the no-training control group. Independent *t*-tests were used to compare accuracy and response time between training groups. *P*-values were corrected for multiple comparisons within each group.

Electrophysiological analyses

Waveform differences between the response to objects and faces did not allow for collapsing across groups. Therefore, the mean amplitude of the peak-to-peak P1 to N170 was analyzed separately for children trained with monkey faces and those trained with strollers. In order to investigate condition and region differences between training groups, mean amplitudes were submitted to a $3 \times 3 \times 3$ mixed model MANOVA with factors of training group (individual, category, no-training), condition (human faces, trained, untrained), and region (left, middle, right). For this analysis, data were collapsed across orientation. Difference scores were computed for orientation (response to upright − inverted) within each condition to determine whether an inversion effect was present. Difference scores were submitted to a 3×3 mixed model MANOVA with factors of training group (individual, category, no-training) and region (left, middle, right) for each of the three conditions (human faces, trained, untrained) separately. Due to large morphology and amplitude differences, conditions were analyzed separately. For all analyses, significant interactions were followed up with paired samples and independent samples *t*-tests and *p*-values were Bonferroni corrected.

Results

Behavioral results

Independent *t*-tests indicated that there were no significant overall accuracy differences between training groups (Means (*SE*): Individual: 83.99% (3.46), Category: 87.30% (4.29), Control: 90.07% (2.02)). There were also no significant accuracy differences between training groups in response to human faces, or the trained or untrained category.

Independent *t*-tests showed significant overall response time differences (collapsed across condition) between training groups. Children in the individual-level training group exhibited faster overall response times compared to children with category-level training ($t(36) = 2.62$, $p = .01$) and with no training ($t(48) = 2.07$, $p = .04$). Children with category-level training and no training did not significantly differ in overall response time. When conditions were analyzed separately, independent *t*-tests revealed that children with individual-level training exhibited significantly faster response times to human faces compared to children with category-level training ($t(36) = 2.80$, $p = .01$) and children with no training ($t(48) = 2.71$, $p = .01$) (Figure 2). The response times between the category-level training and no-training control groups did not significantly differ for human faces. There were also no significant response time differences between training groups in response to the trained or untrained conditions.

Electrophysiological results

P1 to N170 peak-to-peak

Overall amplitude differences across conditions. Although average amplitude analyses for the epoch surrounding the P1 and N170 revealed no significant group differences across conditions or regions for children trained with monkeys or strollers, significant condition differences were present. First, analyses revealed a main effect of condition for children trained with monkeys ($F(2, 23) = 58.92$, $p < .001$, $\eta^2 = .84$) and children trained with strollers ($F(2, 29) = 48.07$, $p < .001$, $\eta^2 = .77$), such that children exhibited the largest amplitude response to human faces, followed by monkey faces, then strollers (Figure 3). Second, analyses showed a main effect of region ($F(2, 29) = 8.39$, $p = .001$, $\eta^2 = .37$) for children in

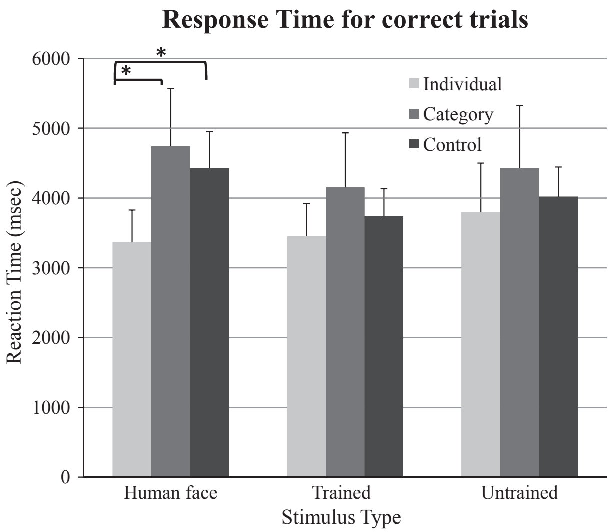


Figure 2 *Response time across training groups for the three stimulus conditions, collapsed across Monkey Face and Stroller training. Error bars represent 95% confidence intervals, calculated for each group and condition separately. Differences that are significant at the p < .01 level are indicated with an asterisk (*). Children trained at the individual level show significantly faster response times to human faces relative to other training groups. Although not significant, children trained at the individual level had faster response times to the trained condition (M = 3451.23, SE = 227.98) relative to children trained at the category level (M = 4152.81, SE = 378.02) and children in the control group condition (M = 3738.64, SE = 190.30).*

the stroller training groups, due to larger amplitude responses recorded over the left versus middle region ($ps = .05$). Finally, analyses revealed an interaction between condition and region for children trained with monkeys ($F(4, 21) = 23.85$, $p < .001$, $\eta^2 = .82$) and strollers ($F(4, 27) = 23.57$, $p < .001$, $\eta^2 = .78$). This interaction was primarily driven by a larger negative amplitude response to human faces relative to monkey faces relative to strollers in both the left and right regions ($ps < .05$) but not the middle region. In the middle region human faces elicited a greater amplitude response than monkey faces and strollers ($ps < .05$) but the amplitude in response to monkey faces did not differ from strollers.

Inversion effect for children with monkey-face training. There were no significant amplitude differences between training groups or across regions in response to the trained (monkey faces) or untrained (strollers) conditions. However, for the human face condition there was a significant main effect of training group ($F(2, 24) = 5.83$, $p < .01$, $\eta^2 = .33$). Follow-up analyses revealed that the children trained at the individual level with monkey faces as infants exhibited the opposite pattern of response from the children trained at the category level during infancy ($p < .05$) and the children without training ($p < .05$). For children trained at the category level during infancy and for the no-training control group, upright human faces elicited a larger negative amplitude than inverted human faces. In contrast, for children who were trained at the individual level as infants, inverted human faces elicited a larger negative amplitude than upright human faces (Figure 4).

Inversion effect for children with stroller training. Analyses revealed a significant interaction between training group and region ($F(4, 60) = 2.66$, $p = .04$) in response to the trained condition (strollers). Although follow-up analyses were not significant after correcting for multiple comparisons, children trained at the individual and category levels appear to exhibit larger negative responses in the left versus middle and right regions. There were no significant amplitude differences across groups in response to the untrained condition (monkey faces) or the human face condition.

Discussion

The current study had two aims: (1) to investigate whether early training produces lasting perceptual and neural advantages years later, and (2) to determine whether these advantages are stimulus-specific, process-specific, or both. In order to answer these questions, the

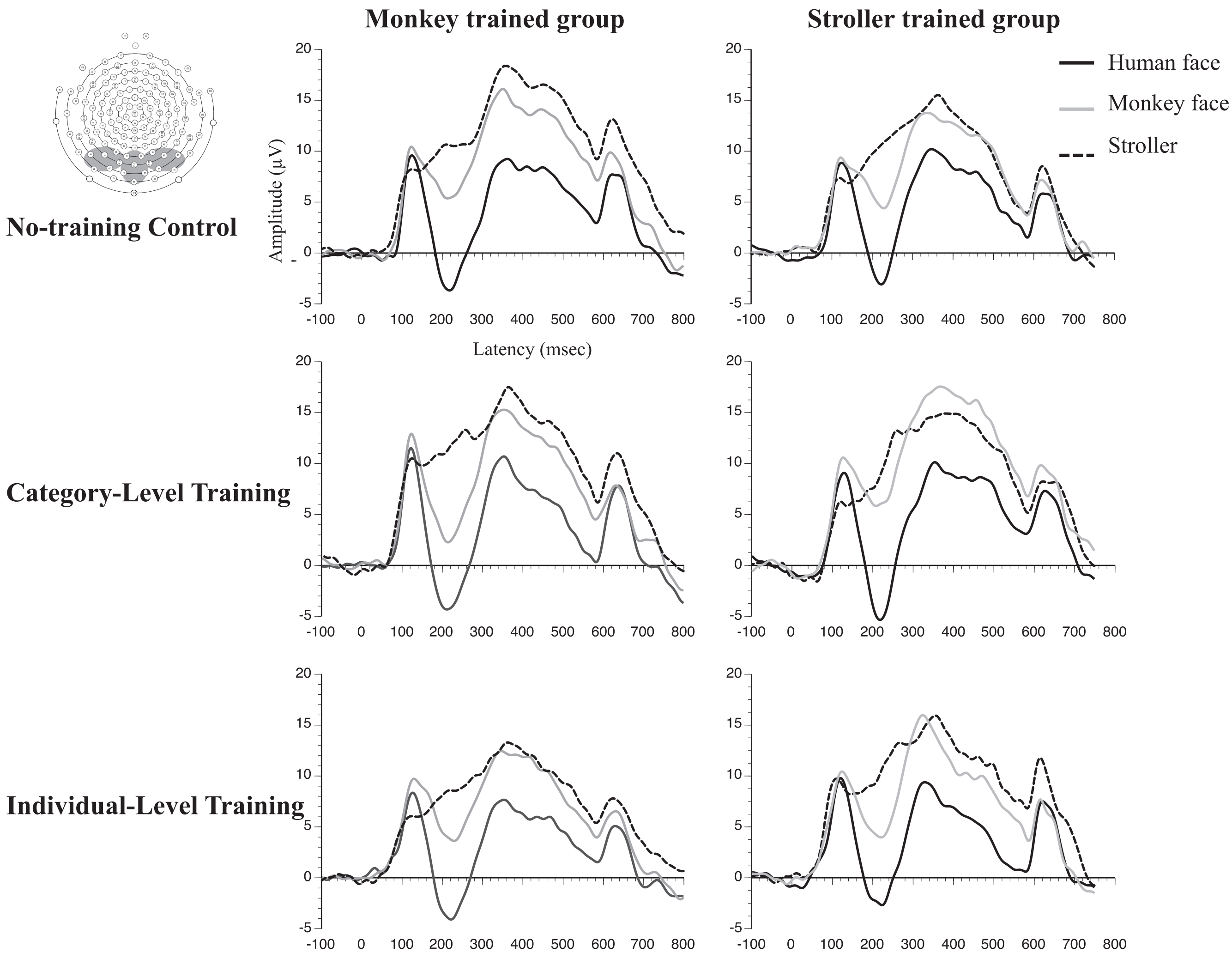


Figure 3 *ERP waveforms in response to human face, monkey face and stroller conditions for children trained with monkey faces (left) and strollers (right). The N170 amplitude is largest in response to human faces, followed by monkey faces, then strollers, for all three groups.*

present study recruited and tested children who had previously participated in face and object training studies as infants (Scott & Monesson, 2009, 2010; Scott, 2011).

Behavioral results reveal that the children who were given experience matching individual-level names with monkey faces or strollers from 6 to 9 months of age exhibited faster responses for human faces. Children who received experience with category-level names as infants and a control group of children without training did not show response time advantages for human faces. The data from the present study provide evidence for the lasting role of early individual-level labeling experience on later face perception and are somewhat consistent with recent investigations examining the lasting effects of early experience on face processing (Macchi Cassia, Kuefner, Picozzi & Vescovo, 2009; de Heering, De Liedekerke, Deboni & Rossion, 2010). Macchi Cassia and colleagues (2009) report that experience with infant faces (growing up with younger siblings) increased adult expertise for infant faces but only when they were re-exposed to infant faces as adults. Similarly, in a recent cross-racial adoption study, early experience with faces of one race resulted in lasting discrimination of that group of faces, even in a new environment where another race was more prominent (de Heering *et al*., 2010).

However, the specific results differ from other studies such that previous investigations (de Heering *et al*., 2010; Macchi Cassia *et al*., 2009) found evidence for stimulus-specific learning benefits related to early experience. In contrast, the current study reveals a transfer of processing advantages from the trained category (monkey faces,

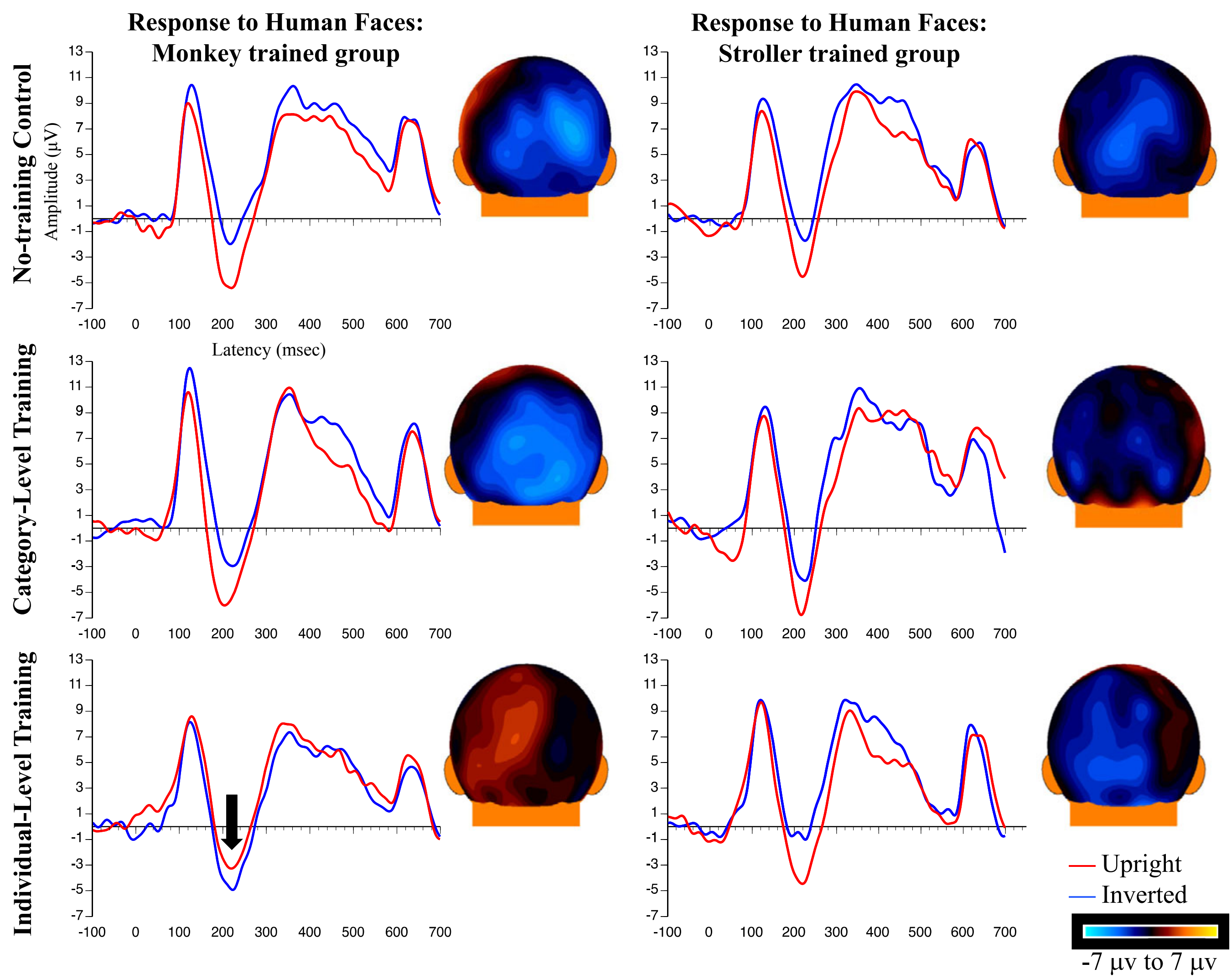


Figure 4 *ERP waveforms and topography of N170 amplitude differences between upright and inverted human faces for children trained with monkey faces (left) and strollers (right). Children trained with individually labeled monkey faces show a different pattern of N170 response relative to other groups, a pattern difference not apparent following stroller training.*

strollers) to a more relevant category (human faces) following training between 6 and 9 months of age. This disparity is likely related to method and design differences across investigations. In the current study, experience in infancy was experimentally manipulated and experience with the trained category (monkey faces, strollers) did not continue past 9 months of age. In the previous studies (de Heering *et al.*, 2010; Macchi Cassia *et al.*, 2009), early experience was not experimentally controlled and was more interactive and dynamic in nature. In addition, the current study did not re-expose children to the trained category of monkey faces or strollers prior to testing. It is possible that, similar to what was reported by Macchi Cassia *et al.* (2009), a period of re-exposure to monkey faces or strollers would lead to stimulus-specific benefits for the trained conditions in children.

In the present study, although not significant, infants with individual-level labeling experience exhibited numerically faster response times to the trained category (monkey faces or strollers) relative to children trained with category-level labels as infants and children with no prior training. This numerical difference, combined with results from previous work (de Heering *et al.*, 2010, Macchi Cassia *et al.*, 2009), suggests that the lasting benefits of early stimulus-specific learning cannot currently be ruled out. Future work designed to further disentangle stimulus-specific and process-specific learning during infancy and into childhood will lead to a better understanding of the extent to which stimulus-specific learning effects are maintained across development.

In addition to behavioral effects, the electrophysiological results also support a process-specific explanation for learning benefits following individual-level experience. However, these benefits were seen following experience with monkey faces, and not following experience with strollers. Specifically, individual-level training with monkey faces led to an adult-like ERP inversion effect in response to human faces. While all training groups exhibited differences between upright and inverted human faces, the individual-level training group displayed the opposite pattern compared to the category-level training and no-training control groups (see Figure 4). Children trained at the individual level with monkey faces exhibited a greater amplitude response to inverted compared to upright faces – comparable to the typical adult N170 inversion effect (Rossion *et al*., 1999, 2000). These results suggest that children with a history of supplementary individual-level experience as infants show more adult-like N170 responses to human faces.

In contrast, children trained at the individual level with an object category (strollers) did not show a differential ERP inversion effect for human faces relative to other training groups. We interpret the difference in the response time and ERP findings to suggest that although individual-level experience with any type of stimulus category may result in process-specific response time benefits, experience only results in adult-like inversion effects if the trained stimulus is perceptually similar. We hypothesize that this discrepant pattern of results is due to task differences, as our neural measure indexes holistic processing, and the match-to-sample task indexes discrimination/recognition. If task differences are accounting for these patterns it is likely the case that the holistic processing effects reported here are specific to faces or face-like stimuli whereas the response time effects are more general and can be applied to a wide range of stimuli. The discrepancy between the response time and holistic processing effects leads to several future research directions. For example, how would children perform on a behavioral task designed to assess holistic processing following early experience with faces or objects? Are there differences between learning faces versus objects at the individual level that lead to generalized advantages for human faces following face, but not object, experience?

Previous adult training studies have shown that individual-level experience can lead to both stimulus-specific and process-specific learning. Adults trained to recognize birds at the subordinate level (i.e. species) showed expert recognition of trained species and also exhibited a transfer of expertise to untrained species within the same family (Scott *et al*., 2006b; Tanaka, Curran & Sheinberg, 2005). Process-specific learning in adults did appear to have limits, as expertise did not extend to novel bird families (e.g. no transfer from owls to wading birds). Although we did not find evidence of lasting stimulus-specific learning in the present study, as infants these children exhibited stimulus-specific benefits (behavioral discrimination and an ERP inversion effect in response to the trained category [monkey faces or strollers]) immediately following training (Scott & Monesson, 2009, 2010; Scott, 2011). In addition, the pre- and post-training tests conducted when these children were infants did not include a human face condition. More controlled training and the inclusion of a human face control condition in infants may allow us to understand whether or not individual-level training advantages for human faces were observed immediately after training. Based on results from both infants and adults, it is possible that stimulus-specific effects are more immediate while process-specific effects are long lasting (i.e. of the order of years).

The results presented here suggest that process-specific learning during the period of 6 to 9 months of age shows particularly strong and lasting benefits. Indeed, this period has been hypothesized to constitute a 'sensitive period' during which specialized cortical regions are formed or enhanced in response to environmental experience (Lewkowicz & Ghazanfar, 2009; Scott, Pascalis & Nelson, 2007). Although previous reports suggest a stimulus-specific sensitive period, the present results suggest that process-specific learning effects may also account for long-lasting benefits. Future work needs to determine whether the period from 6 to 9 months actually constitutes a sensitive period or whether training at any age will result in immediate or long-lasting benefits. It is also unclear what aspect of our individual-level training protocol was particularly important or whether training changed parent–child interactions surrounding labeling.

In sum, infants learn from parents' labeling at a very early age. Talking to babies, and providing labels and names for things in their world, can help them make connections between what they see and what they hear. In essence, this labeling helps them recognize people and objects and helps them decide how detailed their understanding of the object or face needs to be. The results of the present study suggest that early learning in infancy is, in part, process-specific in nature and learning benefits can be seen in children as much as 4 to 5 years later.

Acknowledgements

Funding for this research was awarded to LSS by a National Science Foundation CAREER Award (BCS-1056805). The authors would like to thank members of the Brain, Cognition and Development Lab (UMASS) for relevant discussion, C. Desjardins, E. Fava, C. Flegenheimer, K. Leis, S. McCormick, and M. Moore for research assistance and N. Hathaway for technical assistance.

References

Bentin, S., Allison, T., Puce, A., Perez, E., & McCarthy, G. (1996). Electrophysiological studies of face perception in humans. *Journal of Cognitive Neuroscience*, **8** (6), 551–565. doi:10.1162/jocn.1996.8.6.551

Bilalic, M., Langner, R., Ulrich, R., & Grodd, W. (2011). Many faces of expertise: fusiform face area in chess experts and novices. *Journal of Cognitive Neuroscience*, **31** (28), 10206–10214.

de Haan, M., Pascalis, O., & Johnson, M.H. (2002). Specialization of neural mechanisms underlying face recognition in human infants. *Journal of Cognitive Neuroscience*, **14** (2), 199–209. doi:10.1162/089892902317236849

de Heering, A., De Liedekerke, C., Deboni, M., & Rossion, B. (2010). The role of experience during childhood in shaping the other-race effect. *Developmental Science*, **13** (1), 181–187.

Gauthier, I., Skudlarski, P., Gore, J.C., & Anderson, A.W. (2000). Expertise for cars and birds recruits brain areas involved in face recognition. *Nature Neuroscience*, **3** (2), 191–197.

Halit, H., de Haan, M., & Johnson, M.H. (2003). Cortical specialisation for face processing: face-sensitive event-related potential components in 3- and 12-month-old infants. *NeuroImage*, **19** (3), 1180–1193. doi:10.1016/S1053-8119(03)00076-4

Harley, E.M., Pope, W.B., Villablanca, J.P., Mumford, J., Suh, R., Mazziotta, J.C., Enzmann, D., & Engel, S.A. (2009). Engagement of fusiform cortex and disengagement of lateral occipital cortex in the acquisition of radiological expertise. *Cerebral Cortex*, **19** (11), 2746–2754.

Itier, R.J., & Taylor, M.J. (2004). N170 or N1? Spatiotemporal differences between object and face processing using ERPs. *Cerebral Cortex*, **14** (2), 132–142. doi:10.1093/cercor/bhg111

Kelly, D.J., Liu, S., Lee, K., Quinn, P.C., Pascalis, O., Slater, A.M., & Ge, L. (2009). Development of the other-race effect during infancy: evidence toward universality? *Journal of Experimental Child Psychology*, **104** (1), 105–114.

Kelly, D.J., Quinn, P.C., Slater, A.M., Lee, K., Ge, L., & Pascalis, O. (2007). The other-race effect develops during infancy: evidence of perceptual narrowing. *Psychological Science*, **18** (12), 1084–1089. doi:10.1111/j.1467-9280.2007.02029.x

Lewkowicz, D.J., & Ghazanfar, A.A. (2009). The emergence of multisensory systems through perceptual narrowing. *Trends in Cognitive Sciences*, **13** (11), 470–478. doi:10.1016/j.tics.2009.08.004

Lindsay, D.S., Jack, P.C., & Christian, M.A. (1991). Other-race face perception. *Journal of Applied Psychology*, **76** (4), 587–589. doi:10.1037//0021-9010.76.4.587

Macchi Cassia, V., Kuefner, D., Picozzi, M., & Vescovo, E. (2009). Early experience predicts later plasticity for face processing: evidence for the reactivation of dormant effects. *Psychological Science*, **20** (7), 853–859.

Meissner, C.A., & Brigham, J.C. (2001). Thirty years of investigating the own-race bias in memory for faces: a meta-analytic review. *Psychology, Public Policy, and Law*, **7** (1), 3–35.

Pascalis, O., de Haan, M., & Nelson, C.A. (2002). Is face processing species-specific during the first year of life? *Science*, **296** (5571), 1321–1323. doi:10.1126/science.1070223

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** (14), 5297–5300. doi:10.1073/pnas.0406627102

Rossion, B., Collins, D., Goffaux, V., & Curran, T. (2007). Long-term expertise with artificial objects increases visual competition with early face categorization processes. *Journal of Cognitive Neuroscience*, **19** (3), 543–555.

Rossion, B., Delvenne, J.F., Debatisse, D., Goffaux, V., Bruyer, R., Crommelinck, M., & Guérit, J.M. (1999). Spatio-temporal localization of the face inversion effect: an event-related potentials study. *Biological Psychology*, **50** (3), 173–189.

Rossion, B., Gauthier, I., Goffaux, V., Tarr, M.J., & Crommelinck, M. (2002). Expertise training with novel objects leads to left-lateralized face-like electrophysiological responses. *Psychological Science*, **13** (3), 250–257.

Rossion, B., Gauthier, I., Tarr, M.J., Despland, P., Bruyer, R., Linotte, S., & Crommelinck, M. (2000). The N170 occipito-temporal component is delayed and enhanced to inverted faces but not to inverted objects: an electrophysiological account of face-specific processes in the human brain. *NeuroReport*, **11** (1), 69–74.

Rossion, B., Kung, C.C., & Tarr, M.J. (2004). Visual expertise with nonface objects leads to competition with the early perceptual processing of faces in the human occipitotemporal cortex. *Proceedings of the National Academy of Sciences of the United States of America*, **101** (40), 14521–14526.

Sangrigoli, S., & De Schonen, S. (2004). Effect of visual experience on face processing: a developmental study of inversion and non-native effects. *Developmental Science*, **7** (1), 74–87.

Scott, L.S. (2011). Mechanisms underlying the emergence of object representations during infancy. *Journal of Cognitive Neuroscience*, **23** (10), 2935–2944.

Scott, L.S., & Monesson, A. (2009). The origin of biases in face perception. *Psychological Science*, **20** (6), 676–680. doi:10.1111/j.1467-9280.2009.02348.x

Scott, L.S., & Monesson, A. (2010). Experience-dependent neural specialization during infancy. *Neuropsychologia*, **48** (6), 1857–1861. doi:10.1016/j.neuropsychologia.2010.02.008

Scott, L.S., Pascalis, O., & Nelson, C.A. (2007). A domain-general theory of the development of perceptual discrimination. *Psychological Science*, **16** (4), 197–201.

Scott, L.S., Shannon, R.W., & Nelson, C.A. (2006b). Neural correlates of human and monkey face processing in 9-month-old infants. *Infancy*, **10** (2), 171–186. doi:10.1207/s15327078in1002_4

Scott, L.S., Tanaka, J.W., Sheinberg, D.L., & Curran, T. (2006a). A reevaluation of the electrophysiological correlates of expert object processing. *Journal of Cognitive Neuroscience*, **18** (9), 1453–65. doi:10.1162/jocn.2006.18.9.1453

Scott, L.S., Tanaka, J.W., Sheinberg, D.L., & Curran, T. (2008). The role of category learning in the acquisition and retention of perceptual expertise: a behavioral and neurophysiological study. *Brain Research*, **1210**, 204–215.

Srinivasan, R., Nunez, P.L., Tucker, D.M., Silberstein, R.B., & Cadusch, P.J. (1996). Spatial sampling and filtering of EEG with spline Laplacians to estimate cortical potentials. *Brain Topography*, **8** (4), 355–366.

Tanaka, J.W., & Curran, T. (2001). A neural basis for expert object recognition. *Psychological Science*, **12** (1), 43–47.

Tanaka, J.W., Curran, T., & Sheinberg, D.L. (2005). The training and transfer of real-world perceptual expertise. *Psychological Science*, **16** (2), 145–151.

Taylor, M.J., Batty, M., & Itier, R.J. (2004). The faces of development: a review of early face processing over childhood. *Journal of Cognitive Neuroscience*, **16** (8), 1426–1442.

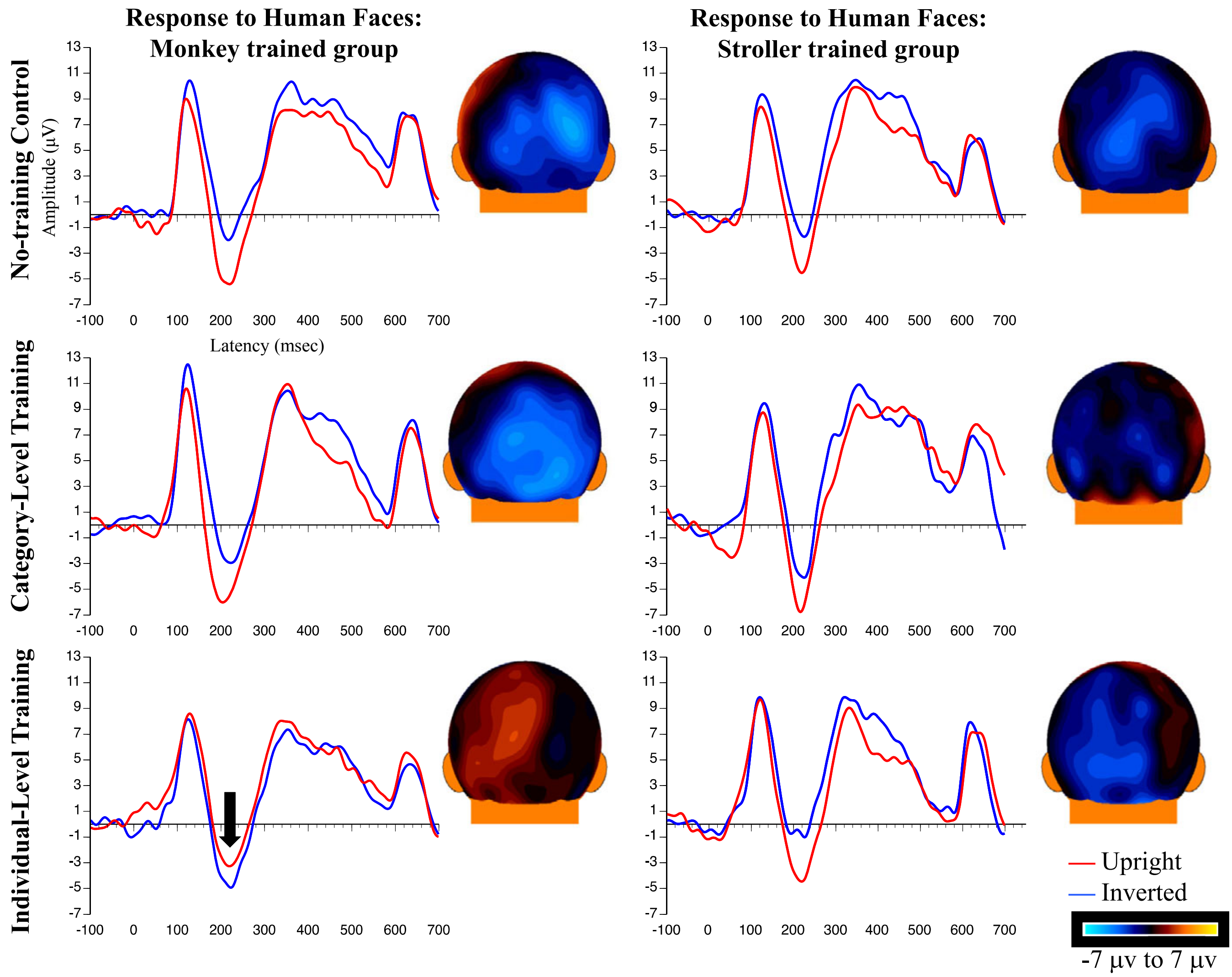
Tottenham, N., Tanaka, J.W., Leon, A.C., McCarry, T., Nurse, M., Hare, T.A., Marcus, D.J., Westerlund, A., Casey, B.J., & Nelson, C. (2009). The NimStim set of facial expressions: judgments from untrained research participants. *Psychiatry Research*, **168** (3), 242–249.

Vogel, M., Monesson, A., & Scott, L.S. (2012). Building biases in infancy: the influence of race on face and voice emotion matching. *Developmental Science*, **15** (3), 359–372. doi:10.1111/j.1467-7687.2012.01138.x

Received: 21 June 2013
Accepted: 27 August 2014

Graphical Abstract

The contents of this page will be used as part of the graphical abstract of html only. It will not be published as part of main article.



This study aimed to determine whether conceptual learning between 6 and 9 months leads to sustained behavioral advantages and neural changes in childhood. Here, children who received individual-level training with monkey faces (all monkey faces were individually named) from 6-9 months of age, showed an adult-like Event-related potential (ERP) inversion effect for human faces relative to children with no training, or who were trained with strollers or were trained at the category level with monkey faces.