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Differential neural responses to faces paired with labels versus faces paired with noise at 6- and at 9-months

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ABSTRACT

Labeling objects or faces in the first year of life shapes subsequent attention and perception. Three months of hearing individual-level, unique labels for previously unfamiliar faces promotes face differentiation and impacts neural processing during the first year of life. However, it is currently unclear whether verbal labeling influences visual processing of faces *during* label learning and whether these effects differ across the first year of life. The current study examined the impact of individual-level labels versus a non-speech noise on neural responses to monkey faces. Event-related potentials (ERPs) were recorded while infants viewed two species of monkey faces: one paired with labels and one paired with a non-speech noise. At 9 months, neural responses differentiated monkey faces paired with labels relative to those paired with noise during both the first and second halves of the experiment. Nine-month-olds exhibited a faster P1 latency, marginally greater N290 amplitude and reduced P400 amplitude to labeled faces relative to a non-speech noise. However, 6-month-olds' neural responses did not differentiate monkey faces paired with labels from those paired with a non-speech noise until the second half of trials and only showed this effect for P1 latency and N290 amplitude. The results of this study suggest that overall, infants differentiate faces labeled with individual-level labels from those paired with a non-speech noise, however, 6-month-olds require more exposure to the label-face pairings than 9-month-olds.

1. Introduction

Experience hearing individuating labels (i.e., proper names) paired with faces or objects has been shown to impact visual discrimination (Heron-Delaney et al., 2011; Pascalis et al., 2005; Scott, 2011; Scott & Monesson, 2009) and increase perceptual learning, holistic processing (Scott, 2011; Scott & Monesson, 2010), and attention (Pickron, Fava, & Scott, 2017). In order to better understand the impact of experience on the development of face processing, previous studies have used other-species faces to reduce pre-experimental experience confounds (e.g., Pascalis, de Haan, & Nelson, 2002; Pascalis et al., 2005; Scott & Monesson, 2009; Scott & Monesson, 2010). In a pair of investigations, when 6-month-olds were read books with pictures of monkey faces labeled with unique names over a 3-month period, they later differentiated faces within the trained group (Pascalis et al., 2005; Scott & Monesson, 2009). However, when 6-month-olds received training with monkey faces paired with a category label ("monkey"), or with unlabeled faces, infants failed to discriminate monkey faces at 9 months. In this previous work, perceptual narrowing, or the decline in ability to differentiate faces from infrequently experienced groups (for review see Lewkowicz, 2014; Maurer & Werker, 2014; Scott & Fava, 2013; Scott & Monesson, 2009; Scott, Pascalis, & Nelson, 2007; Sugden & Marquis, 2017) was attenuated by naming at the individual-level. These previous results suggest that the specificity of labels (i.e., individual-level, category-level, no label) impacts the development of perceptual representations.

Effects of book training experience on neural responses have also been explored by examining changes in Event-related Potentials (ERP), including the infant P1, N290 and P400 (for review of components, de Haan, Johnson, & Halit, 2003). While both the N290 and P400 components are modulated by tasks that include faces, the N290 is thought to be the morphological precursor to the adult N170, a component associated with face processing and perceptual expertise (Rossion, 2014; Scott, Tanaka, Sheinberg, & Curran, 2006; Scott, Tanaka, Sheinberg, & Curran, 2008). The function of the P400 is less well understood and may in part originate from frontal attention networks (Guy, Zieber, & Richards, 2016). Infants who learned to match monkey faces with individual labels, but not those who learned category-level labels or were provided no labels, exhibited differential N290 and P400 responses to upright and inverted monkey faces (Scott & Monesson,

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2010), a pattern considered to be a marker of expert perceptual (and holistic) processing in adults (Rossion & Curran, 2010).

In addition to these face sensitive components, the P1 has also been examined in studies of attention and perception. The P1 is recorded over occipital and temporal scalp regions and is typically modulated by attention (for review see Hillyard, Vogel, & Luck, 1998) and is sensitive to visual low-level stimulus features (Taylor, 2002) including phase scrambling and color (e.g., Rossion & Caharel, 2011). In adults, the P1 has been reported to be larger in response to faces than objects (e.g., Goffaux, Gauthier, & Rossion, 2003). The P1 has also been found to be sensitive to the orientation of faces in both children and adults (Itier & Taylor, 2004a,b). The infant P1 has been examined in response to object label learning (Scott, 2011). Infants who learned images of strollers paired with individual-level names, over a 3 month period, but not those who received category-level labels, exhibited differential P1 responses to upright and inverted strollers after 3 months of learning. Together with behavioral findings, the presence of differential ERP responses after training suggests that 3 months of individual-level experience with a previously unfamiliar face or object group results in distinct processing of faces and objects learned at the individual-level.

Here it is predicted that labeling impacts early attention, perception, and face processing in a top-down manner. Our prediction is based on a recent hypothesis suggesting that word learning between 6 and 9 months of age acts as a top-down influence and impacts visual perception of faces (Hadley, Rost, Fava, & Scott, 2014). As infants learn to associate words with visual referents, they begin to build conceptual representations, which in turn influence visual processing above and beyond the contributions of bottom-up stimulus features. Measuring ERPs allows for investigating early stages of attention and visual processing in order to determine whether hearing verbal labels impacts attention and perception in 6- and 9-month-old infants.

Previous reports lend support to this hypothesis (Gliga, Volein, & Csibra, 2010; Plunkett, Hu, & Cohen, 2008). For example, in 10-month-olds, labels override perceptually-based categories in a novelty preference task (Plunkett et al., 2008). Further, at the neural level, brief experience hearing an experimenter label a toy with a specific noun (e.g., "blicket") has been found to enhance visual processing of objects at 12 months of age (Gliga et al., 2010). Relatedly, Friedrich and Friederici (2008), Friedrich and Friederici (2011) reported that when novel objects were consistently paired with the same label across multiple presentations, 6- and 14-month-olds exhibited an increased N400 ERP response during the second half trials, suggesting that infants form semantic representations of object-word pairs over time. Interestingly, 14-month-olds, but not 6-month-olds, also exhibited increased ERP responses for a component related to word meaning (N200-500) during the first half of trials (Friedrich & Friederici, 2008). This additional learning response in the first half of trials suggests that although younger infants form associations for word-object pairs after relatively brief experience, they require more exposure than their older counterparts.

To date, the influence of labeling on neural responses associated with visual perception, attention and face processing has not been investigated prior to the onset of expressive language development. Changes between 6 and 9 months of age are of importance for understanding visual and perceptual development (Scott & Fava, 2013; Scott et al., 2007). The second half of the first year of life may represent an important period during which labels have a lasting influence on the development of visual perceptual and conceptual representations (e.g., Hadley, Pickron, & Scott, 2014). Perceptual narrowing, characterized by a behavioral decline in differentiating faces from unfamiliar groups between 6- and 9-months (e.g., Pascalis et al., 2002; Vogel, Monesson, & Scott, 2012), may be driven by age-related differences in learning to pair individual-level labels with faces or objects. Here, we tested separate groups of 6- and 9-month-olds and examined neural responses associated with individual face-label pairs relative to faces paired with a non-speech noise. Non-speech noises or tones have previously been used to understand the development of concept formation in infants under a year of life (e.g., Ferry, Hespos, & Waxman, 2010). The present investigation aimed to maximize differences across conditions as an initial starting point, and to this end a single non-speech noise comparison condition was used.

Given prior findings suggesting that labeling objects enhances visual perception (Gliga et al., 2010) and influences neural responses (Friedrich & Friederici, 2008; Friedrich & Friederici, 2011), and the recent hypothesis that word learning impacts face processing (Hadley et al., 2014), it was predicted that labeling faces with unique labels would differentially impact neural processing of faces. More specifically, we predicted differential impacts of verbal labels versus noise on ERP indices of visual attention and perception (P1, N290, P400) while infants viewed concurrent presentations of novel monkey faces and labels/noise. Additionally, in order to more closely examine the influence of labels across time, we also analyzed responses during the first versus second half of the task. Following previous findings suggesting young infants need an increased number of label-object trials to form associations (Friedrich & Friederici, 2008; Friedrich & Friederici, 2011), we predicted that 9-month-olds would exhibit differential attention and perceptual processing for faces paired with labels versus noise earlier in the labeling task (first half of trials) relative to 6-month-olds.

2. Materials and methods

2.1. Participants

All parents gave informed consent prior to testing and all work was carried out in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki). Participants were 26 6-month-old (12 males) and 20 9-month-old (11 males) infants. Analyses included data from 14 6-month-olds (mean age = 183.00 days, SD = 8.00 days) and 16 9-month-olds (mean age = 279.88 days, SD = 6.21 days). Twelve 6-month-olds and 4 9-month-olds were excluded from analyses because of excessive noise in the data (6-month-olds: n = 3; 9-month-olds: n = 1), or because one or more conditions had less than 15 artifact-free trials per condition per half of experiment (6-month-olds: n = 9; 9-month-olds: n = 3). The present attrition rates are consistent with previously published infant ERP studies (for review, see DeBoer, Scott, & Nelson, 2007; for meta-analysis, see Stets, Stahl, & Reid, 2012). Parents completed a demographic questionnaire and all infants included in final analyses were identified as White or Caucasian, and 3 infants were also identified as Hispanic or Latino. Infants with a history of neurological, visual or auditory impairments were excluded. Parents of participants were paid $10 and infants received a small toy for their participation.

2.2. Stimuli and apparatus

Visual stimuli consisted of 12 digitized color photographs of Barbary macaques (*Macaca sylvanus*) and 12 digitized color photographs of Tufted capuchins (*Cebus apella*) presented at a visual angle of approximately 13° (Fig. 1). The set of macaque faces was used in a prior infant training study (Scott & Monesson, 2009).

Auditory stimuli consisted of words and a non-speech noise burst (referred to as "noise") that were 610 ms in duration (see Supplementary material for audio stimuli) and recorded/created and processed in Praat (Boersma & Weenink, 2014). Word stimuli included 6 disyllabic words/proper names: "Boris", "Carlos", "Billy", "Harry", "Jamar", "Bobby", spoken by a single female speaker and recorded at a sampling rate of 96000 Hz. To ensure that all word stimuli were the same duration, samples from each word were clipped out until the word was the correct length. Clipped samples were selected primarily from continuants, then vowels, and were chosen on the basis that removing the samples did not change the overall sound of the words. When samples were clipped from vowels, they were taken from the center of

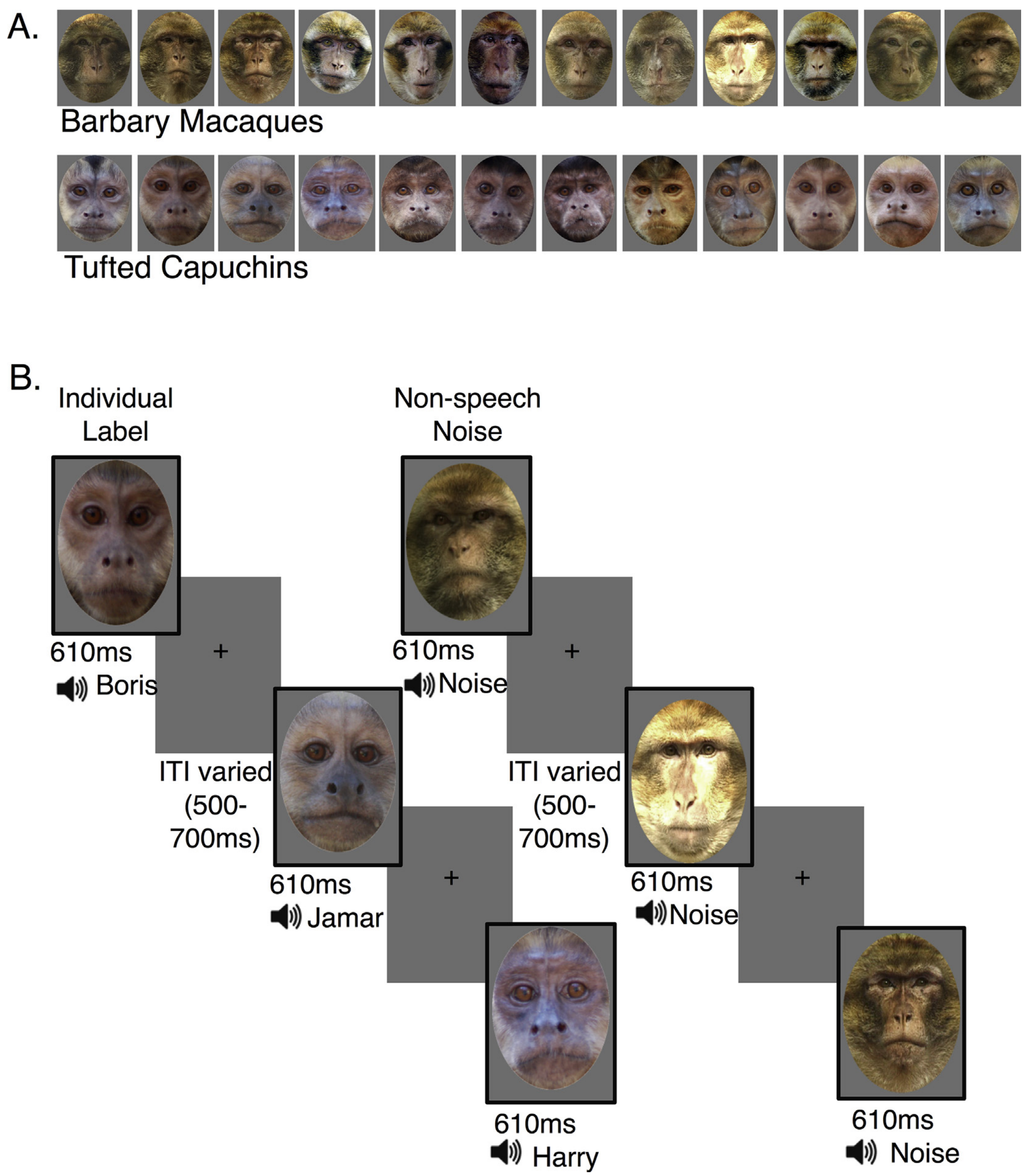

Fig. 1. (A) Stimulus set of monkey faces. Each infant was shown 4 unique faces from each species across blocks. (B) Blocks included 1) individual-level label condition and 2) a non-speech noise condition. Within each block, infants viewed 4 unique faces paired with a label or noise. Faces were repeated up to 15 times throughout the block, in a randomized order with no immediate exemplar repetitions.

the vowel and not from areas in the word where the formants changed. The noise stimulus was a single burst of pink noise filtered with the spectrum of the speech stimuli. This noise was chosen to serve as a perceptually complex sound that does not contain speech-like structural information. Further, a non-speech noise control was chosen instead of a silent baseline to ensure that any label-related effects were not due to a comparison of audiovisual to visual-only information (Balaban & Waxman, 1997). All auditory stimuli were presented with a peak intensity of 60–63 dB SPL (A-weighted).

2.3. Procedure

Infants passively viewed up to 120 trials of monkey faces paired with either unique verbal labels (60 possible trials) or a single non-speech noise burst (60 possible trials) while electrophysiological data (EEG) were recorded. During the session, 6- and 9-month-old infants viewed two sets of a novel face group (monkey faces: Barbary macaques, Tufted capuchins), blocked by species. One set of faces (e.g., Barbary macaques) was matched with individual verbal labels (e.g., “Boris”, “Jamar”), while the other set of faces (e.g., Tufted capuchins) was presented with a non-speech noise (Fig. 1). Infants received approximately equal amounts of experience with the two face groups and viewed trials blocked by sound condition (individual label, noise). In addition, the order of the face groups, exemplars within each face group, and the species assigned to each of the two sound conditions (individual label, noise) were counterbalanced across participants. Consistent with previous label training studies during infancy (Pickron et al., 2017; Scott, 2011; Scott & Monesson, 2009) infants were trained with 4 monkey faces for each species/face group. During each trial, a face and sound (a label or non-speech noise) were presented with the same onset for a duration of 610 ms. Experimenters viewed infants via a live video feed and presented trials when infants were judged to be looking at the screen. Once the experimenter initiated the trial a random 500–700 ms ITI, in which a fixation cross was presented, proceeded the concurrent presentation of the face and the label or sound.

Electrophysiological data were collected using 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 signals were sampled every 2 ms (at a rate of 500 Hz). All electrodes were referenced online to the vertex (Cz). Electrodes were adjusted until impedances were less than 50 kΩ.

2.3.1. ERP processing procedure

Data were processed using NetStation 4.3 (Electrical Geodesics Inc., Eugene, OR). Offline, EEG data were digitally bandpass filtered (FIR filter) at 0.3–30 Hz with a 0.29 Hz rolloff and baseline-corrected with respect to a 100 ms pre-stimulus (onset of the face) baseline. Data were segmented into 1200 ms trials, which included the 100 ms pre-stimulus baseline. A 40 ms offset was applied during trial segmentation to account for the delay in stimuli appearing on the screen (22 ms) and a delay inherent to the anti-aliasing filter associated with the system amplifier (18 ms: Electrical Geodesics, Inc., advisory notice, August 29, 2014). Segmented trials were also visually examined for excessive noise and/or drift. For each segmented trial, channels were automatically rejected if voltage changed by more than 300 μV during the segment. Individual trials were excluded from analyses if they contained more than 12 bad channels (10%). Channels that were marked bad within a trial were replaced using a spherical interpolation algorithm (Srinivasan, Nunez, Tucker, Silberstein, & Cadusch, 1996). Channels that were consistently marked bad (off-scale on more than 70% of trials) were marked bad across the entire recording (6 months: $M = 8.1$ channels, $SD = 6.2$; 9 months: $M = 5.5$ channels, $SD = 5.2$). An average reference was used to minimize noise at the reference site and to accurately estimate scalp topography.

Six-month-olds viewed an average of 118.2 ($SD = 6.4$) trials out of 120 possible trials (Label condition: 58.3 trials; Non-speech noise condition: 59.9 trials). Infants with fewer than 15 artifact-free trials per condition per half, were removed from analyses. Within each condition, 6-month-olds contributed an average of 18 ($SD = 3.8$) out of 30 good/usable trials in the first half and 16 ($SD = 4.4$) out of 30 good/usable trials in the second half of the task. Nine-month-olds viewed an average of 119 ($SD = 1.8$) trials out of 120 possible trials (Label condition: 59.6 trials; Non-speech noise condition: 60 trials). Within each condition, 9-month-olds contributed an average of 19.3 ($SD = 3.7$) out of 30 good/usable trials in the first half and 18.3 ($SD = 3.9$) out of 30 good/usable trials in the second half of the task.

2.4. Analyses

Time windows and electrode groupings were based on previous research (Halit, de Haan, & Johnson, 2003; Scott, 2011; Scott & Monesson, 2010) and visual inspection of the timing of components across individuals and ages. For each component of interest, peak amplitudes were detected and windows were created based on visual inspection of the start and end of each component averaged across participants. Then individual subject averages were inspected to determine whether component peaks fell within the window of interest. Windows were adjusted accordingly in order to include the majority of individual infant component peaks. Infants who did not exhibit one or more discernable peaks, but were not removed for other reasons (i.e., artifacts or noise) remained in the sample for analyses. Mean amplitude and peak latency were analyzed for the occipital-temporal P1, N290, and P400 components. Electrodes over left and right occipital-temporal regions were averaged for analysis (left region consistent with 10–10 locations T5-P7: 58, 59, 64, 65, 69; right region consistent with 10–10 locations T6-P8: 89, 90, 91, 95, 96). For both age groups, mean amplitude of the P1 was measured between 95 and 180 ms after stimulus onset, mean amplitude of the N290 was measured between 215 and 280 ms after stimulus onset, and mean amplitude of the P400 was measured between 340 and 420 ms after stimulus onset.

To examine the time course of the influence of labels during labeling, responses were compared between the first and second halves of the task. The first half of the learning period consisted of the first 30 trials in each condition block (label, non-speech noise), and the second half of the learning period consisted of the last 30 trials in each condition block.

Difference scores between the Label and Noise conditions were calculated by subtracting the response to the label condition from the response to the non-speech noise condition for each component. Difference scores were then entered into separate 2 × 2 × 2 mixed-measures ANOVAs for each component. Each ANOVA included the between-subjects factor of Age (6 months, 9 months) and within-subjects factors of Half (First, Second) and Region (Left, Right). Significant Half × Age interactions were followed-up with one-sample *t*-tests on the difference score against chance (where a chance difference would be 0) for each age group during both the first and second half of trials.

3. Results

3.1. P1

The P1 component is thought to be a measure of early perception and attention (Hillyard et al., 1998). To determine if labeling impacts early perceptual and attentional processes, we analyzed amplitude and latency differences between label-face pairs and noise-face pairs. Based on previous work reporting P1 changes after 3 months of labeling experience in the first year of life (Scott, 2011), we predicted that labeling would differentially modulate the P1 relative to the noise condition.

Amplitude analyses revealed a Half x Age interaction, $F(1,28) = 6.08$, $p = .020$, $\eta^2 = .18$. Follow-up paired-samples *t*-tests revealed no difference between the difference score in the first versus second half of trials for either 6- or 9-month-olds, both $ps > .089$. One-sample *t*-test against chance revealed no significant difference scores for 6-month-olds, both $ps > .107$. However, in 9-month-old infants, the difference score was marginally greater than chance during the first half

Table 1
Amplitude (microvolts) and Latency (milliseconds) of the P1, N290, and P400 components during the first half of trials, the second half of trials, and over the entire testing period in 6-month-old infants.

	First Half			Second Half			All Trials		
	Label	Noise	Difference	Label	Noise	Difference	Label	Noise	Difference
P1 amplitude	7.46 (5.67)	3.69 (8.42)	−3.77 (8.14)	5.43 (6.83)	6.36 (4.37)	0.93 (7.52)	6.45 (4.45)	5.03 (5.93)	−1.42 (6.21)
P1 latency	153.64 (14.88)	153.23 (18.09)	−0.41 (21.83)	146.34 (17.23)	156.36 (17.21)	**10.01 (13.88)***	149.99 (13.89)	154.79 (16.2)	4.8 (15.47)
N290 amplitude	2.45 (9.62)	1.18 (10.32)	−1.28 (10.14)	−1.10 (6.41)	6.22 (8.32)	**7.32 (7.81)***	0.68 (6.42)	3.7 (7.92)	3.02 (6.69)
N290 latency	266.36 (17.22)	262.5 (21.11)	−3.86 (16.39)	261.49 (18.48)	262.8 (22.95)	1.31 (19.37)	263.92 (16.06)	262.65 (19.76)	−1.27 (14.24)
P400 amplitude	12.04 (8.94)	6.82 (11.01)	−5.22 (7.92)	12.01 (8.86)	14.91 (11.67)	2.90 (8.96)	12.02 (7.81)	10.87 (10.16)	−1.16 (6.52)
P400 latency	388.77 (18.04)	381.36 (17.63)	−7.41 (18.04)	386.66 (17.83)	384.83 (15.29)	−1.83 (19.88)	387.71 (16.17)	383.09 (14.7)	−4.62 (15.74)

Note: Data are reported as mean (standard deviation). Significant differences are marked with an asterisk (*) and bolded.

Table 2
Amplitude (microvolts) and Latency (milliseconds) of the P1, N290, and P400 components during the first half of trials, the second half of trials, and over the entire testing period in 9-month-old infants.

	First Half			Second Half			All Trials		
	Label	Noise	Difference	Label	Noise	Difference	Label	Noise	Difference
P1 amplitude	5.70 (5.65)	8.04 (5.47)	**2.34 (4.54)**‡	6.51 (6.74)	5.86 (5.15)	−0.65 (6.06)	6.10 (5.58)	6.95 (4.83)	0.84 (3.83)
P1 latency	138.80 (17.33)	153.05 (12.37)	**14.25 (16.26)***	140.59 (13.32)	150.97 (13.07)	**10.39 (13.93)***	139.69 (13.37)	152.01 (9.66)	12.32 (12.88)
N290 amplitude	2.90 (7.86)	8.80 (6.83)	**5.90 (8.67)***	1.40 (8.20)	5.69 (6.06)	**4.28 (8.12)**‡	2.15 (7.09)	7.24 (5.15)	5.09 (6.35)
N290 latency	257.58 (15.03)	257.39 (15.51)	−0.19 (18.31)	255.6 (16.88)	252.09 (17.94)	−3.51 (26.93)	256.59 (10.78)	254.74 (13.26)	−1.85 (9.92)
P400 amplitude	15.49 (10.16)	17.84 (11.49)	2.35 (7.53)	14.25 (11.84)	21.02 (7.49)	6.77 (9.94)	14.87 (10.4)	19.43 (8.46)	**4.56 (6.04)***
P400 latency	387.58 (14.01)	381.7 (17.5)	−5.88 (18.25)	385.9 (14.63)	381.59 (14.69)	−4.31 (21.65)	386.74 (12.27)	381.64 (12.9)	−5.09 (15.24)

Note: Data are reported as mean (standard deviation). Significant differences are marked with an asterisk (*) and bolded. Marginally significant differences are marked with a double dagger (‡) and bolded.

of trials $t(15) = 2.06$, $p = .058$, $d = 0.52$, but not the second half $p = .675$, indicating a marginally greater amplitude in the Noise condition than the Label condition during the first half of trials. See Tables 1 and 2 for the means and standard deviations in each condition.

Latency analyses also showed a Half x Age interaction, $F(1,28) = 4.88$, $p = .036$, $\eta^2 = .15$. Follow-up paired-samples *t*-tests revealed a marginally greater difference score in the first than the second half of trials, $t(13) = 2.00$, $p = .067$, $d = 0.53$, for 6-month-olds. There was no difference between the first and second halves in the 9-month-olds, $p = .347$. In the 6-month group, one-sample *t*-tests against chance revealed the difference score was greater than chance during the second half of trials, $t(13) = 2.70$, $p = .018$, $d = 0.72$, but not the first half, $p = .944$, suggesting a faster latency to peak P1 for labeled faces only in the second half of trials (Figs. 2 and 3). However, in the 9 month group, the difference score was greater than chance during both the first half, $t(15) = 3.51$, $p = .003$, $d = 0.88$, and the second half of trials, $t(15) = 2.98$, $p = .009$, $d = 0.75$, suggesting a faster latency to peak P1 for labeled faces across all trials (Figs. 2 and 3).

3.2. N290

The N290 component is thought be the precursor to the adult N170 component, an index face processing and perceptual expertise (Rossion, 2014; Scott et al., 2006; Scott et al., 2008). If labels exert a top-down impact on face processing during development, labels were expected to differentially modulate the N290 relative to noise.

Amplitude analyses revealed a Half x Age interaction, $F(1,28) = 5.81$, $p = .023$, $\eta^2 = .17$. Follow-up paired-samples *t*-tests suggest this interaction is due to a greater N290 difference between

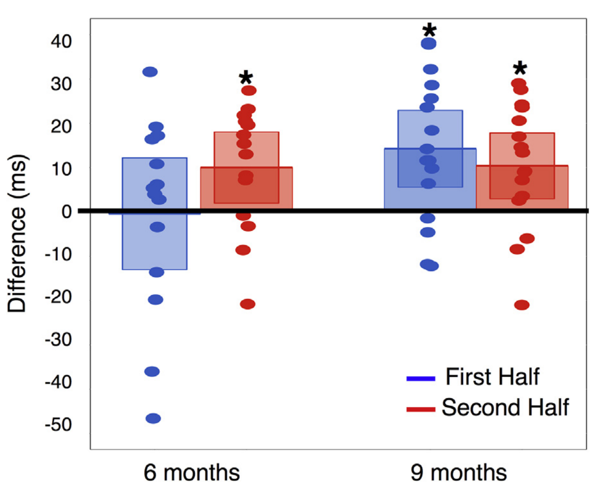

Fig. 2. Differences in P1 latency between conditions at 6 and 9 months during the first and second half of trials. The bar plots include the mean (dark line) and 95% CI (shaded box) as well as individual data points. *Indicates $p < .05$.

label and noise during the second than the first half of trials in the 6-month-olds, $t(13) = 2.65$, $p = .021$, $d = 0.70$, but not the 9-month-olds, $p = .565$. In the 6 month group, one-sample *t*-tests against chance revealed the difference between label and noise was greater than chance during the second half of trials, $t(13) = 3.50$, $p = .004$, $d = 0.94$, but not the first half of trials, $p = .646$. The N290 was greater (more negative) in response to faces paired with labels than faces paired with noise in the second half of trials (Figs. 3 and 4). In the 9 month group, the difference between label and noise was greater than chance during the first half, $t(15) = 2.72$, $p = .016$, $d = 0.68$, and marginally greater than chance during the second half of trials, $t(15) = 2.11$, $p = .052$, $d = 0.53$. This difference was due to a greater N290 in response to faces paired with labels.

Latency analyses of the N290 revealed no significant effects.

3.3. P400

The infant P400 component has previously been found to index both face processing (e.g., de Haan et al., 2003; Halit et al., 2003; Scott & Nelson, 2006; Scott, Shannon, & Nelson, 2006) and sustained attention (Guy et al., 2016). If the P400 indexes later stages of face processing and receives feedback from anterior attention networks, it may develop more slowly than the early P1 and N290 components and learning effects are expected to differ between 6- and 9-month-old infants.

Amplitude analyses revealed a main effect of Half, $F(1,28) = 8.27$, $p = .008$, $\eta^2 = .23$, due to a greater difference between label and noise in the second half ($M = 4.96\,\mu V$, $SD = 9.53$) than the first half of trials ($M = -1.18\,\mu V$, $SD = 8.49$). The differences scores were then collapsed over age. One-sample *t*-tests revealed the difference between label and noise was significantly greater than chance in the second half of trials, $t(29) = 2.85$, $p = .008$, $d = 0.52$, but not the first half, $t(29) = -0.76$, $p = .452$, $d = 0.14$. The amplitudes were greater in the noise condition ($M = 18.17\,\mu V$, $SD = 9.98$) than in the label condition ($M = 13.20\,\mu V$, $SD = 10.44$) in the second half of trials only.

There was also a main effect of Age, $F(1,28) = 6.21$, $p = .019$, $\eta^2 = .18$, due to a greater difference in 9-month-olds than 6-month-olds. The difference scores were then collapsed over Half. One-sample *t*-tests revealed the difference between label and noise was significantly greater than chance in the 9-month-olds, $t(15) = 3.02$, $p = .009$, $d = 0.75$ (Fig. 5), but not the 6-month-olds, $t(13) = -0.66$, $p = .518$, $d = 0.18$. The P400 was greater in response to the noise condition than the label condition in 9-month-olds only. See Tables 1 and 2 for the means and standard deviations in each condition.

P400 Latency analyses revealed no significant effects.

3.4. Results summary

In this investigation, both 6- and 9-month-olds exhibited differential ERP responses to faces paired with labels relative to those paired with a non-speech noise. Both 6- and 9-month-olds exhibited a faster latency

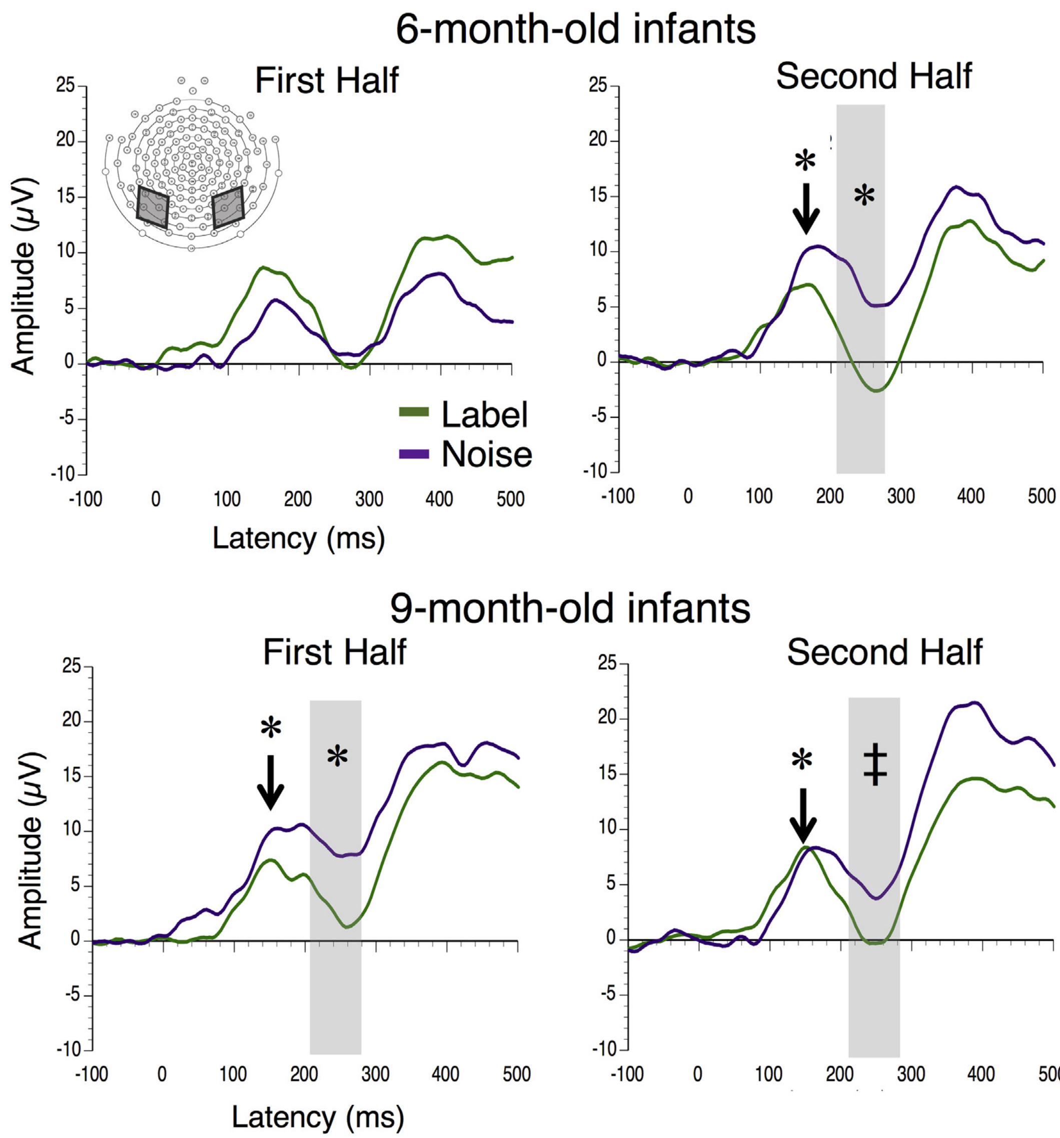

Fig. 3. Waveforms of ERP responses for 6- and 9-month-olds for the first and second halves of the training period, collapsed across hemispheres. The responses in both the label and noise conditions are shown. Significant P1 latency differences are marked with an arrow and an asterisk and significant N290 amplitude differences are marked with a box and asterisk. [*]Indicates $p < .05$, [‡]indicates $p = .05$.

to peak P1 and a larger N290 amplitude in response to faces paired with verbal labels relative to those paired with a non-speech noise. At 6 months of age, these differences were only present during the second half of trials. At 9 months of age, P1 differences were present across all trials (first and second half) and significant N290 differences were present during the first half of trials. Additionally, 9-month-olds exhibited greater P400 amplitude across both the first and second half of trials in response to faces paired with a non-speech noise than faces paired with verbal labels. Results are summarized in Tables 1 and 2.

4. Discussion

The current study aimed to determine the extent to which brain responses that support attention and perception during a face-labeling task differ at 6- versus 9-months of age and whether neural processing is differentially modulated by individual-level verbal labels versus a single non-speech noise. Using a within-subjects design, separate groups of 6- and 9-month-old infants were presented with both unique verbal labels and a single non-speech noise paired with two species of unfamiliar monkey-faces while ERPs were recorded.

A single non-speech noise was used as a comparison to individual-level verbal labels. The goal was to maximize the contrast between the speech labels and comparison condition and so a single non-speech noise was used. This controlled comparison serves as an important first step in demonstrating the influence of individual-level labels on face processing and the results can be used as a comparison for future work. For example, future research should compare responses to individual versus category speech labels to discern the importance of *unique* labels. Recent research suggest that unique labels/names play a particularly important role in supporting learning within a book reading context from 6- to 9-months of age (e.g., Pickron et al., 2017). The current research supports this previous finding and suggest that both 6- and 9-month-old infants differentiate faces paired with labels from those paired with a non-speech noise. Additionally, future studies could use multiple, unique, non-speech noise exemplars to determine if making the noise condition more similar to the label condition results in differential processing. Due to the use of a non-speech control condition, it is possible that the differential responses between the label and non-speech noise conditions were driven by perceptual properties of speech versus non-speech sounds. However, our investigation focused on responses typically found to index early visual attention and perception and so any differences found for these visual components suggest that

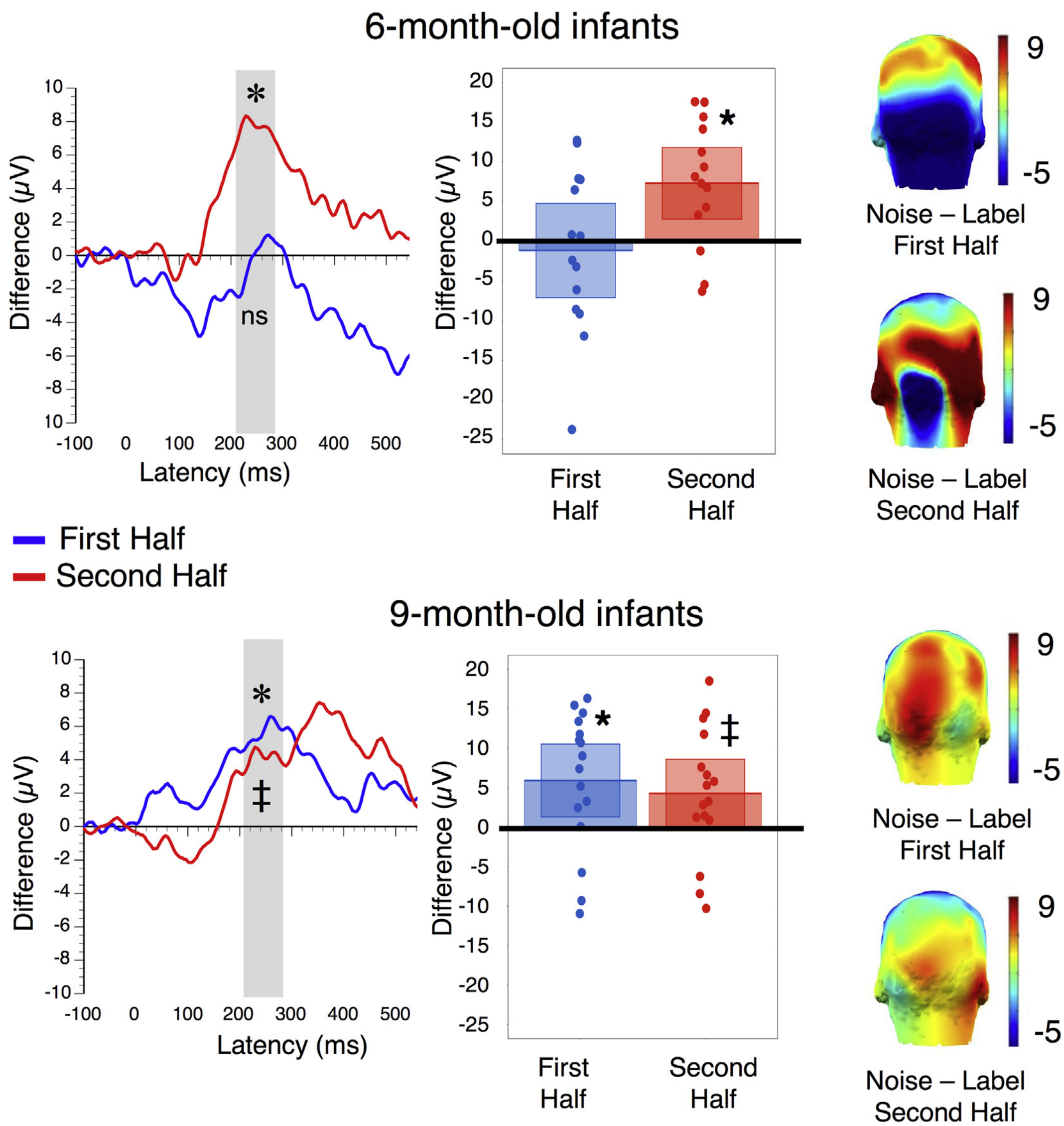

Fig. 4. Difference in amplitude of N290 responses for 6- and 9-month-olds. (Left) The first and second halves of the learning period collapsed across hemispheres. Waveform plot show the difference in responses to label and non-speech noise conditions which were calculated by subtracting the response to the label condition from the response to the non-speech noise condition. The time window is marked with a shaded box. (Middle) Bar graphs show differences between conditions. The bar plots include the mean (dark line) and 95% CI (shaded box) as well as individual data points. (Right) Head plots display the difference in amplitude response between the label and non-speech noise conditions during the N290 window. Larger values represent a larger amplitude difference between conditions. [*]Indicates $p < .05$, [‡]indicates $p = .05$.

the label and/or noise conditions impacted visual processing.

The results of the current study suggest that while both 6- and 9-month-olds' ERP responses to faces are differentially impacted by labels versus noise, 6-month-old infants require more exposure for this differentiation to occur. At 9 months, labels have an effect early in the first half of trials as indexed by P1 latency and N290 amplitude differences. These same differences are not present in 6-month-old infants until the second half of trials. Differential amplitude between face-label and face-noise conditions is sustained throughout the task in 9-month-olds. Finally, N290 differentiation is sustained for the P400 component, throughout the task, in 9-month-olds but not 6-month-olds.

Both 6- and 9-month-old infants exhibited a faster latency to peak P1 amplitude for the label versus non-speech noise condition (Figs. 2 and 3), suggesting that hearing a verbal label facilitates very early attention and perceptual processing of visual stimuli. This faster processing of labeled faces was apparent in both the first and second halves of trials at 9 months of age. In contrast, 6-month-olds only exhibited differences in P1 latency between sound conditions during the second half of trials. The label-related P1 modulation is consistent with a recent finding in adults (Maier, Glage, Hohlfeld, & Abdel Rahman, 2014) as well as a previous results in infants (Scott, 2011). Adults exhibited a larger P1 amplitude in response to recently learned labeled objects indicating that category labels influenced early visual processing (Maier et al., 2014). Similarly, Scott (2011) reported that 9-month-olds exhibited a differential P1 amplitude response to objects after 3 months of experience matching individual-level labels with objects. Together with the current findings, these results indicate that labels influence early visual attention and perceptual processing not only after multiple months of experience, but also *during* the label-learning process and as early as the P1 component (95–180 ms after stimulus onset).

Both 6- and 9-month-old infants exhibited a larger face-related ERP component (N290) in response to monkey faces paired with individual labels relative to those paired with a non-speech noise. However, this effect was not present until the second half of trials for 6-month-olds (Figs. 3 and 4). This result is consistent with previous work that reports 12-month-olds exhibit enhanced visual perception of objects that have

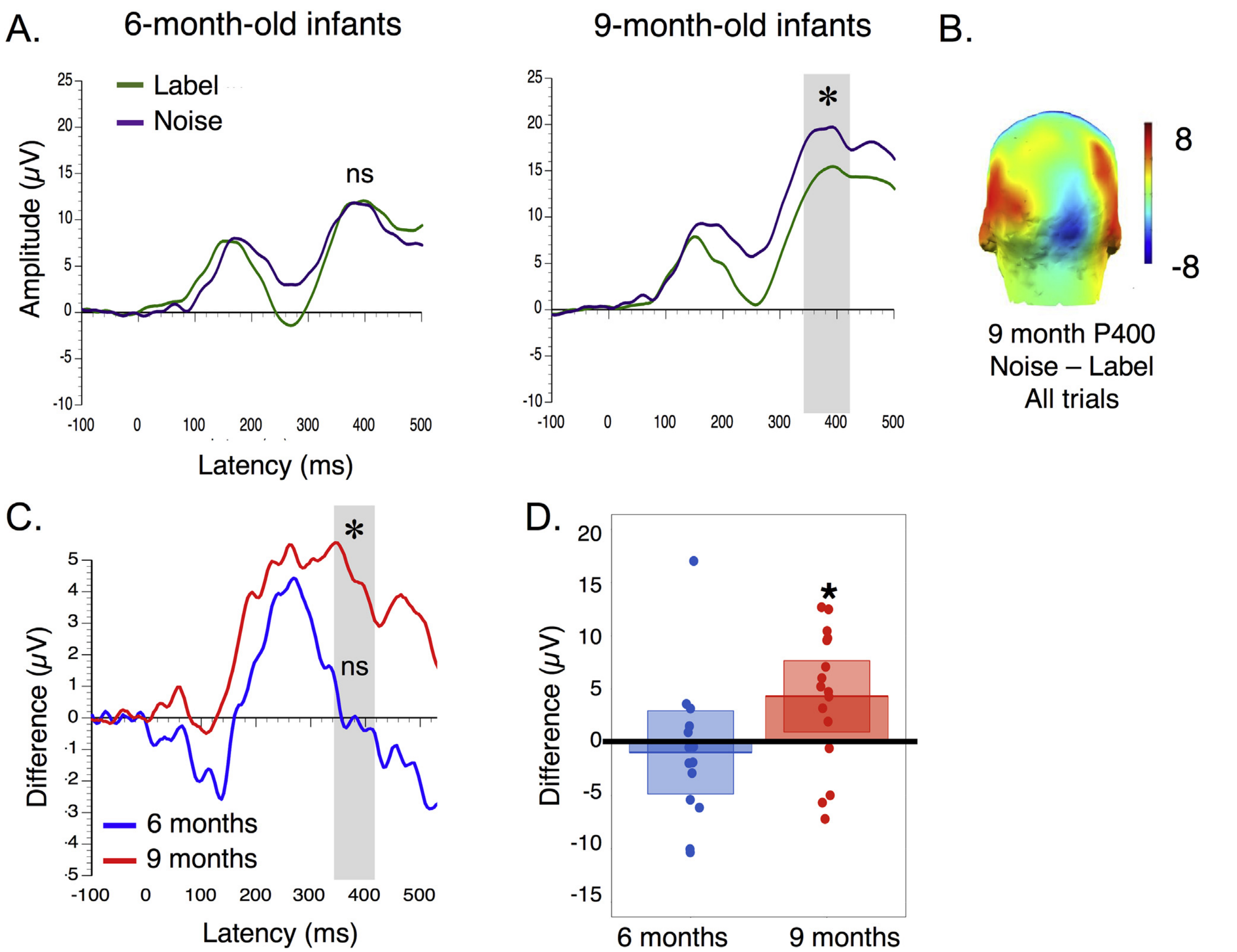

Fig. 5. Difference in amplitude of P400 responses for 6- and 9-month-olds for all trials, collapsed across hemisphere. (A) Waveform plots show the response to the label and non-speech noise conditions in 6- and 9-month-olds infants. The time window is marked with a shaded box. (B) Head plot displays the difference in amplitude response between the label and non-speech noise conditions during the P400 window for the 9-month-olds. Larger values represent a larger amplitude difference between conditions. (C) Waveform plot show the difference in responses to label and non-speech noise conditions which were calculated by subtracting the response to the label condition from the response to the non-speech noise condition. (D) Bar graphs show differences between conditions. The bar plots include the mean (dark line) and 95% CI (shaded box) as well as individual data points. *Indicates $p < .05$.

been explicitly labeled (e.g. "Blicket") compared to a generic reference (e.g., "it") (Gliga et al., 2010). The current study suggests that labels impact visual perception earlier than 12 months of age, but also suggest that younger infants may require more learning relative to their older counterparts. Finally, labels may influence multiple stages of processing, including attention and early visual perception, face and object perception, and later sustained attention as indexed by different ERP components.

Nine-month-olds exhibited both a larger N290 amplitude as well as a differential P400 amplitude in response to faces paired with labels versus those paired with a non-speech noise. In contrast to 6-month-olds, 9-month-olds exhibited a differential P400 response across the entire learning period (Fig. 5). Recently, source analyses of the P400 component suggest that anterior brain regions associated with attention contribute to a sustained P400 response in infants (Guy et al., 2016). Consistent with this previous finding, we suggest that the differential P400, reported here, reflects a combination of engagement of both posterior based perceptual systems and anterior-based sustained attention systems. More specifically, we hypothesize that differential processing for the P400 at 9 months is a result of feedback from anterior sustained attention networks and suggested increased connectivity between anterior attentional and posterior perceptual systems.

Relatedly, language development and increased language experience may also impact the neural systems recruited during this task. Specifically, with additional language experience, learning labels for faces or objects may result in increased feedback to cortical regions involved in visual processing from cortical regions involved in attention and language processing. This hypothesis is supported by dynamic causal modeling of ERP responses in adults that suggest late-occurring components (i.e., after 200 ms) are best explained by models including forward and backward connections (Garrido, Kilner, Kiebel, & Friston, 2007). Although speculative, we suggest that the P400 component may be the result of both forward and backward neural connections.

In a previous ERP study that taught 6-month-olds to associate a novel word with a novel object (Friedrich & Friederici, 2011), the authors reported that infants did not show differential responses between consistent and rotating word-object pair conditions in the first half of training but did show differences in the second half of training. The results reported here are consistent with this finding such that 6-month-olds did not show differential responses to the label versus non-speech noise condition until the second half of training. These findings suggest that 6-month-olds may need additional trials in order to exhibit differential neural responses, recorded over occipital temporal regions, to the label versus the noise.

The current results indicate that labels influenced early stages of visual processing at 6 months of age – as indexed by the P1 and N290 components – and influenced both early and later stages of visual processing at 9 months – as indexed by the P1, N290 and P400 components. It is currently unclear what the differential P400 response seen at 9 months, but not 6 months, reflects. It is possible that 9-month-olds' additional experience with word learning and referential labeling influences the impact of labeling on visual processing. However, it is also possible that the differential P400 response seen at 9, but not 6 months, may simply reflect a quantitative difference associated with changes in rates of encoding. That is, if 6-month-olds were given additional label-face training trials, they may eventually also show a differential P400 response to faces paired with labels compared to those paired with non-speech noise. Moreover, the use of the unfamiliar monkey faces may also impact processing of face-label versus face-noise pairs. It is possible that face familiarity impacts processing and that differences between 6- and 9-month olds would not be present when tested with highly familiar stimuli, like parent faces or own-race female faces. Future work is necessary to determine whether the differences seen between 6- and 9-month-old infants are primarily due to differences in language development, in the amount of experience needed to encode a label and face/object association, or due to differential brain connectivity.

Finally, in the present study, some of our analyses were under powered. Although consistent with other recent infant ERP studies (Guy et al., 2016; Pickron et al., 2017) a larger sample size may impact the results of the current study.

4.1. Conclusions

In conclusion, the present study provides initial evidence that unique verbal labels influence infants' visual processing of faces *during* a period of face labeling. Face-sensitive neural responses, over occipital-temporal scalp regions, differentiate faces paired with verbal individual-level names from faces paired with a single non-speech noise. Two clear differences emerge between 6 and 9 months of age. First, younger infants exhibit face-label and face-noise differentiation for ERP components related to early attention and perceptual processing (P1, N290) while older infants exhibit differential effects across these components as well as the later P400, which has been previously implicated in both face processing and sustained attention. Second, 6-month-olds only exhibit differential effects during the second half of trials, while 9-month-olds exhibit effects during both the first and second halves of trials. The label-related effects at both ages suggest that infants as young as 6 months of age use labels to orient attention and shape visual perception. However, the more complex processing seen at 9 months, including sustained differentiation of conditions for the P400 component, indicates that the way in which verbal labels influence face processing changes across development and may involve a complex interaction of posterior perceptual and anterior attentional neural networks.

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Author Contributions

H. Hadley and L. Scott designed the study. H. Hadley collected and processed data and completed initial analyses. R. Barry-Anwar completed revised analyses and created figures and tables. R. Barry-Anwar, H. Hadley and L. Scott all contributed to writing and revising the manuscript.

Appendix A. Supplementary data

Supplementary analyses associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.visres.2018.03.002. Data associated with this manuscript can be found at: https://nyu.databrary.org/volume/608.

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