Leslie J. Carver
Psychology Department,
University of California,
San Diego, La Jolla,
CA 92093-0109
E-mail: ljcarver@ucsd.edu

Geraldine Dawson
Heracles Panagiotides
Andrew N. Meltzoff
James McPartland
Jonathan Gray
Jeff Munson
Center on Human Development
and Disability, University of Washington,
Seattle, WA 98195

Age-Related Differences in Neural Correlates of Face Recognition During the Toddler and Preschool Years

ABSTRACT: *Research on the development of face recognition in infancy has shown that infants respond to faces as if they are special and recognize familiar faces early in development. Infants also show recognition and differential attachment to familiar people very early in development. We tested the hypothesis that infants' responses to familiar and unfamiliar faces differ at different ages. Specifically, we present data showing age-related changes in infants' brain responses to mother's face versus a stranger's face in children between 18 and 54 months of age. We propose that these changes are based on age-related differences in the perceived salience of the face of the primary caregiver versus strangers.* © *2003 Wiley Periodicals, Inc.* Dev Psychobiol 42: 148–159, 2003.

Keywords: *face recognition; social behavior; attachment; stranger anxiety; event-related potentials*

Interest in relations between brain and behavioral development has grown substantially in recent years. Of special interest is the development of the brain basis of social behavior. Although researchers interested in the role of experience in brain development have proposed that experience can alter brain areas involved in social development (e.g., Greenough, Black, & Wallace, 1987), there are very little data that address this issue. Indeed, we still have little knowledge about the development of brain systems underlying the development of social behavior and cognition.

We describe age-related differences in the neural correlates of face recognition and suggest ways that these differences may be related to changes in social development that arise through the child's interaction with the environment. We examined the neural correlates of the response to the mother's versus a stranger's face throughout the toddler and preschool years. We sought to better understand the development of the recognition of familiar and unfamiliar faces during a period of great developmental change in a number of cognitive and social domains.

Infants have an inherent interest in faces, which may play a pivotal role in the development of relationships with others and in the ability to recognize the emotional states and intentions of others. A substantial body of literature makes it clear that very young infants are able to discriminate familiar from unfamiliar faces. For example, behavioral measures such as looking time and habituation have shown that, from a few days of age, infants prefer to look at a familiar versus an unfamiliar face (e.g., Pascalis & de Schonen, 1994; Pascalis, de Schonen, Morton, Derulle, & Fabre-Grenet, 1995), imitate selected facial movements (Meltzoff & Moore, 1977, 1997), and by 6 weeks of age, differentially imitate familiar versus unfamiliar people (Meltzoff & Moore, 1992, 1998).

Evidence from electrophysiological studies shows that by about 6 months of age infants exhibit differential brain activity to familiar faces versus unfamiliar faces, and that infants' patterns of brain activity can be influenced by

---

Received 8 January 2002; Accepted 18 January 2002
Correspondence to: L. J. Carver
Contract grant sponsor: NICHD
Contract grant numbers: PO1HD34565, and T32HD07391
Contract grant sponsor: NIDCD
Contract grant number: HD22514
DOI 10.1002/dev.10078

how similar the unfamiliar faces are to the familiar ones (de Haan & Nelson, 1997). Although these event-related potential (ERP) studies do not have the spatial resolution to precisely localize the source of brain electrical activity, face-specific components of the ERP as well as face-specific patterns of scalp topography suggest that the specialization of brain areas involved in face processing begins at a very early age. In adult ERP studies, an early negative component, the N170, was larger in response to faces than to other visual stimuli, peaked earlier in response to faces than to other visual stimuli, and was prominent over the right posterior scalp (e.g., Bentin, Allison, Puce, Perez, & McCarthy, 1996). This component likely reflects perceptual aspects of encoding "facedness." de Haan & Nelson (1999) measured ERPs in response to familiar and unfamiliar faces (pictures of the mother's face vs. a stranger's face) or to familiar and unfamiliar objects (pictures of the child's toy vs. an unfamiliar toy). In 6-month-old infants, ERP differences in responses to familiar and unfamiliar faces and objects were found as well as ERP differences to faces versus objects. An early sensory component of the ERP peaked earlier over posterior scalp locations for faces than for objects, suggesting a temporal advantage in processing faces over objects. It is possible that the early positive component observed by de Haan and Nelson is a developmental precursor of the N170, indicating that face-specific ERP components can be differentiated early in development and provide a possible neural correlate of the precocious behavioral responses to faces that have been observed.

Other components of the ERP differentiated familiar from unfamiliar stimuli in studies by de Haan & Nelson (1997, 1999). In these studies, a middle latency negative component (the Nc) was observed. The Nc has been associated with increased attention to salient stimuli (Courchesne, 1978; Nelson, 1994) as well as with recognition memory (de Haan & Nelson, 1997, 1999; Nelson, 1994). de Haan and Nelson (1997, 1999) observed that the Nc component was larger in response to the mother's face than to a stranger's face. This finding suggests that by 6 months of age, infant brain activity discriminates mother from stranger, and that infants may devote more attentional resources to processing the mother's face. The Nc component also was larger in response to the familiar object than to an unfamiliar toy. This finding was in contrast to previous research (e.g., Nelson & Collins, 1991), in which the response to familiar stimuli was smaller than to unfamiliar stimuli. In contrast to the de Haan and Nelson (1997, 1999) study and the present study, the Nelson and Collins study presented infants with "briefly familiarized" rather than truly familiar stimuli. Infants were habituated to pictures, and brain responses to those pictures and new pictures were measured. Thus, at least for 6-month-olds, the Nc component may be larger for familiar stimuli only when those stimuli are well known (e.g., a toy that the child has at home) and have been familiar for a period of months rather than by virtue of a brief familiarization period during laboratory testing.

In addition to differentiating familiar from unfamiliar stimuli, the Nc component was also differentially lateralized depending on the category of stimuli. For face stimuli, the Nc differentiated familiar from unfamiliar stimuli over the right and midline frontal electrodes, but not over left frontal electrodes. For object stimuli, electrodes over the right, midline, and left frontal sites differentiated familiar from unfamiliar stimuli. Thus, the response to faces was right lateralized whereas the response to objects was bilateral in its distribution.

In one study of mother's face recognition described earlier (de Haan & Nelson, 1999), slow wave activity occurring late in the recording epoch also discriminated familiar from unfamiliar stimuli. Positive slow wave (PSW) activity over frontal scalp locations was larger for unfamiliar than for familiar stimuli. The PSW has been associated with memory processes. A larger PSW has been interpreted as evidence that the infant is in the process of encoding the stimulus, but has not yet formed a complete representation (Nelson, 1994). Given that 6-month-olds are able to recognize their mother's face, the increased PSW activity to the stranger may have reflected updating of the memory trace for the unfamiliar stimulus, which was presented repeatedly during the study.

There is some evidence that faces are "special," and that the neural substrate for face recognition is established from very early in life (Farah, Rabinowitz, Quinn, & Liu, 2000). A strong nativist version of this would predict that face processing should not substantially change with development, and there should be little developmental change in the neural mechanisms for face processing and recognition.

Nelson (2001) and Gauthier and Nelson (2001) suggested that there is development in the form of increased expertise in face processing. Children at different ages may have differential expertise with different kinds of faces. There is evidence that early in life, infants' preference for facelike stimuli changes. Newborn infants and 2-month-olds, but not infants between these ages, prefer facelike stimuli (Morton & Johnson, 1991), suggesting that there are developmental changes in face processing early in life. One possible explanation for such changes is that they may relate to the development of increased expertise proposed by Gauthier and Nelson.

In the present study, we report results from a cross-sectional study of face recognition in children between 18 and 54 months of age. There are reasons to believe that the relative importance of the mother's and stranger's face may change over this interval for children, and that this may be reflected in different patterns of brain activity. For example, at 6 to 8 months of age, infants are developing specific attachments to their primary caregivers. At this age, infants prefer familiar caretakers and are beginning to display attachment behaviors such as stranger and separation anxiety. Thus, the increased amplitude of the Nc component in response to the mother's face (de Haan & Nelson, 1997, 1999) may be related to the increased salience and importance of the mother in the developing formation of the attachment relationship. Infants at the age tested by de Haan and Nelson (1997, 1999) may be in the process of forming a long-lasting representation of their caretaker's face, and may as a result devote increased attentional and mnemonic resources to the caretaker's face, as evidenced by the larger Nc component of the ERP. Throughout the formation of the attachment relationship, the mother's face likely continues to be an important stimulus. However, by 18 to 24 months of age, toddlers are more likely to approach a stranger (Bretherton, Stolberg, & Kreye, 1981) and generally respond more positively to the presence of a stranger than younger infants (Bohlin & Hagekull, 1993). By 4 years of age, children are engaged in forming relationships with people outside of the caretaking relationship, and are likely to devote more interest and exploratory behavior toward other people other than the primary caregiver, with whom they have a well-established relationship.

In the present study, we utilized an experimental paradigm similar to that used by de Haan & Nelson (1997, 1999), but applied it to a sample of older children between 18 and 54 months of age. In light of the developmental achievements that have occurred by the late preschool period, we hypothesized that although toddlers' brain activity would continue to be different for images of the mother's and stranger's face, the pattern of differentiation evidenced by the ERP would not necessarily be the same as that found in 6-month-olds. Specifically, because of the changing meaning of a stranger's face and the mother's face with development, we hypothesized that there would be age-related differences in ERPs to faces. These age-related differences were expected to reflect which stimulus (i.e., the mother's or the stranger's face) elicited more attention from children, as reflected in the amplitude of the ERP components. In contrast, we did not expect such age-related differences in the ERP to objects.

Furthermore, we had a number of predictions regarding the expected topography of the ERP for the present study. First, based on de Haan & Nelson's (1997, 1999) previous studies with younger infants, we anticipated a middle latency negative component (the Nc) that peaked over frontal central midline scalp locations that was different for the familiar versus unfamiliar stimuli. For faces, the Nc component was expected to be larger in amplitude and peak earlier at frontal and midline central electrodes, and be different for familiar versus unfamiliar faces at anterior midline and temporal electrodes over the right hemisphere. For objects, the Nc component was expected to be different for familiar versus unfamiliar objects at anterior midline electrodes, and temporal electrodes over both the right and left hemispheres.

SUBJECTS AND METHODS

Participants

Participants were three groups ($ns = 14$/group) of full-term, neurologically healthy children between the ages of 18 and 54 months: 1) 18- to 24-month-olds, 2) 24- to 45-month-olds, and 3) 45- to 54 month-olds. Children were screened to ensure typical cognitive functioning using the Mullen Scales of Early Learning (Mullen, 1997). One child was African American, 1 was Asian American, and the remaining children were European American. The children were primarily from middle-class socioeconomic status. An additional 33 children were tested, but were not included in the final sample because they did not provide enough useable ERP data: Twenty-three children did not provide enough artifact-free data for analysis, 9 children did not cooperate with the testing procedure, and equipment failure occurred during testing for 4 children. One additional child was tested, but was not included in the final sample because the screening test indicated below-average cognitive functioning. Of the children included in the final sample, 29 were boys.

Stimuli

Face Stimuli. Mothers' faces were photographed by a color digital camera against a light-gray background. Each mother wore a gray scarf to obscure her neck and clothing neckline. Earrings and other jewelry were removed. Mothers assumed a neutral facial expression. The image of each mother's face was matched with another, dissimilar face selected from mothers of other children who participated in the study.

The experimenter selected the unfamiliar face stimulus so that paired faces were of the same ethnicity, and faces of mothers who wore glasses were paired with faces of other mothers who wore glasses. Otherwise, paired faces were chosen to be dissimilar in terms of hair color, hair style, eye color, face shape, and facial features (e.g., size of nose).

Object Stimuli. Each parent brought the child's favorite toy to the session. The toys did not have faces visible when photographed. Each toy was digitally photographed against a gray background. Since the size of toys varied, images of toys were graphically manipulated so that the perceptual sizes of the stimuli on the monitor on which they were presented were approximately equivalent. Each toy image was matched with another image of a toy selected from toys brought in by other participants.

The choice of the unfamiliar object was made by an experimenter based on the following criteria: Paired objects were from the same category (i.e., both were children's toys). The unfamiliar toy was similar to the participant's toy in shape, color, and size, but had a different function (e.g., if the child's favorite toy was a vehicle, the control toy was chosen to be similar in size shape and color, but was not another vehicle). Each child's parent confirmed that the child was not familiar with the comparison object.

Data Collection. The child sat on the parent's lap in front of a table approximately 75 cm from the video monitor that delivered the stimulus in a sound-attenuated room. A large, trifold screen obscured the back of the monitor and the back part of the room from the child's view. The child's head was measured, and the vertex was marked. An appropriate-size, 64-channel Geodesic sensor net (Electrical Geodesics, Inc.; Tucker, 1993) was placed on the child's head and fitted according to manufacturer's specifications after being dipped into a KCl electrolyte solution. The 64 EEG electrodes covered a wide area on the scalp ranging from nasion to inion and from the right to the left ear arranged uniformly and symmetrically. Impedances were kept below 40 kΩ.

A baseline recording of 130 ms preceded stimulus onset, and the stimulus appeared on the screen for 500 ms. ERP data were recorded for an additional 1,200 ms following stimulus offset. The intertrial interval varied randomly between 500 and 1,200 ms. Details of the timing of events that occurred during trials are shown in Figure 1. Data collection was terminated when the child had attended to 50 of each of the familiar and unfamiliar stimuli or when the child was no longer tolerant of the procedure. An experimenter observed the child through a peephole in the trifold screen and signaled the computer via button press when the child was not attending. Trials on which the child did not attend were removed from the data after data collection.

EEG Recording. The EEG from the 64 channels was registered continuously. The signal was amplified and filtered via a preamplifier system (Electrical Geodesics). The amplification was set at × 1,000 and filtering was done through a 0.1-Hz, high-pass filter and a 100-Hz, elliptical low-pass filter. The conditioned signal was multiplexed and digitized at 250 samples per second via an analog-to-digital converter (PCI-1200; National Instruments) positioned in an Apple Macintosh computer dedicated to data collection. Data were recorded continuously and streamed to the computer's hard disk. A second computer generated the stimuli. The two computers were interfaced via one of their serial ports for precise synchronization. The timing of the stimulus onset and offset was registered together with the physiological record for off-line segmentation of the data. Data were collected using the vertex electrode as a reference, and were re-referenced off-line to an average reference.

Data Editing and Reduction. Data were averaged using the program Averager (Electrical Geodesics, Eugene, OR). Trials that included artifact were excluded from further analysis during averaging. Artifacts were identified as follows: 1) Signals from electrode sites were marked for rejection if signal amplitude exceeded 250 mV or a running average of activity exceeded 150 mV. The use of a running average is similar to a bandpass filter, and rejects both high-frequency noise and low-frequency drift as sources of artifact. This method identified the slope of the activity, and rejected sharp transitions in the data. 2) Trials during which EOG artifact, including eye blinks and movements, occurred also were excluded. EOG artifact was defined as any activity exceeding 150 mVor a deviation in running averages of activity in superior eye channels exceeding 150 mV. 3) Trials that had more than 10 electrode sites not meeting these criteria were not included in the averaging.

Transformations were applied to averaged data to correct for baseline shifts and to digitally filter data (low-pass Butterworth 20 Hz) to reduce environmental noise artifact. In addition, an algorithm that derived values from the neighboring sites by spherical spline interpolation was used to replace electrodes for which more than 25% of trials were rejected by artifact (e.g., Dawson et al., 2002). Participants for whom more than 10 channels required this replacement were excluded from further analyses.

For both the face and object ERPs, components of interest were identified. Based upon previous research (e.g., de Haan & Nelson, 1997, 1999) and upon inspection of the grand-averaged data for each experiment (Figures 2 and 3), the components that were identified were a middle-latency, negative component distributed over frontal electrode sites (the Nc; de Haan & Nelson, 1997, 1999) and a positive component peaking at about

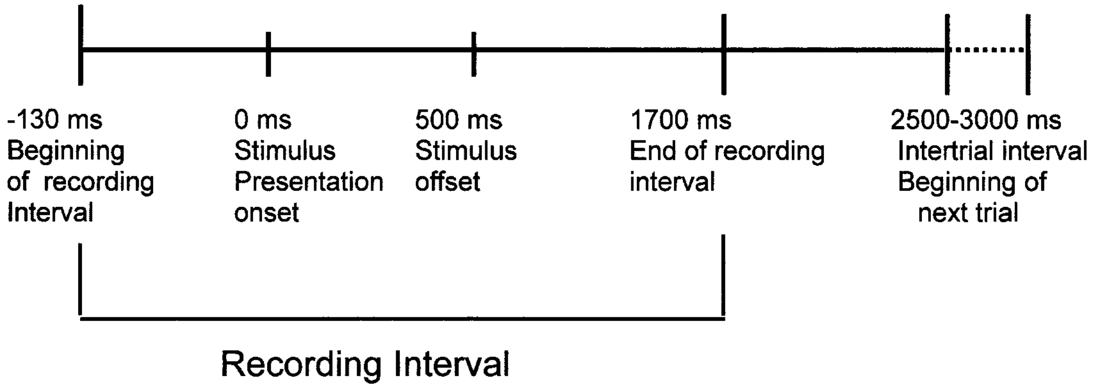

FIGURE 1 Time course of events occurring during ERP recording.

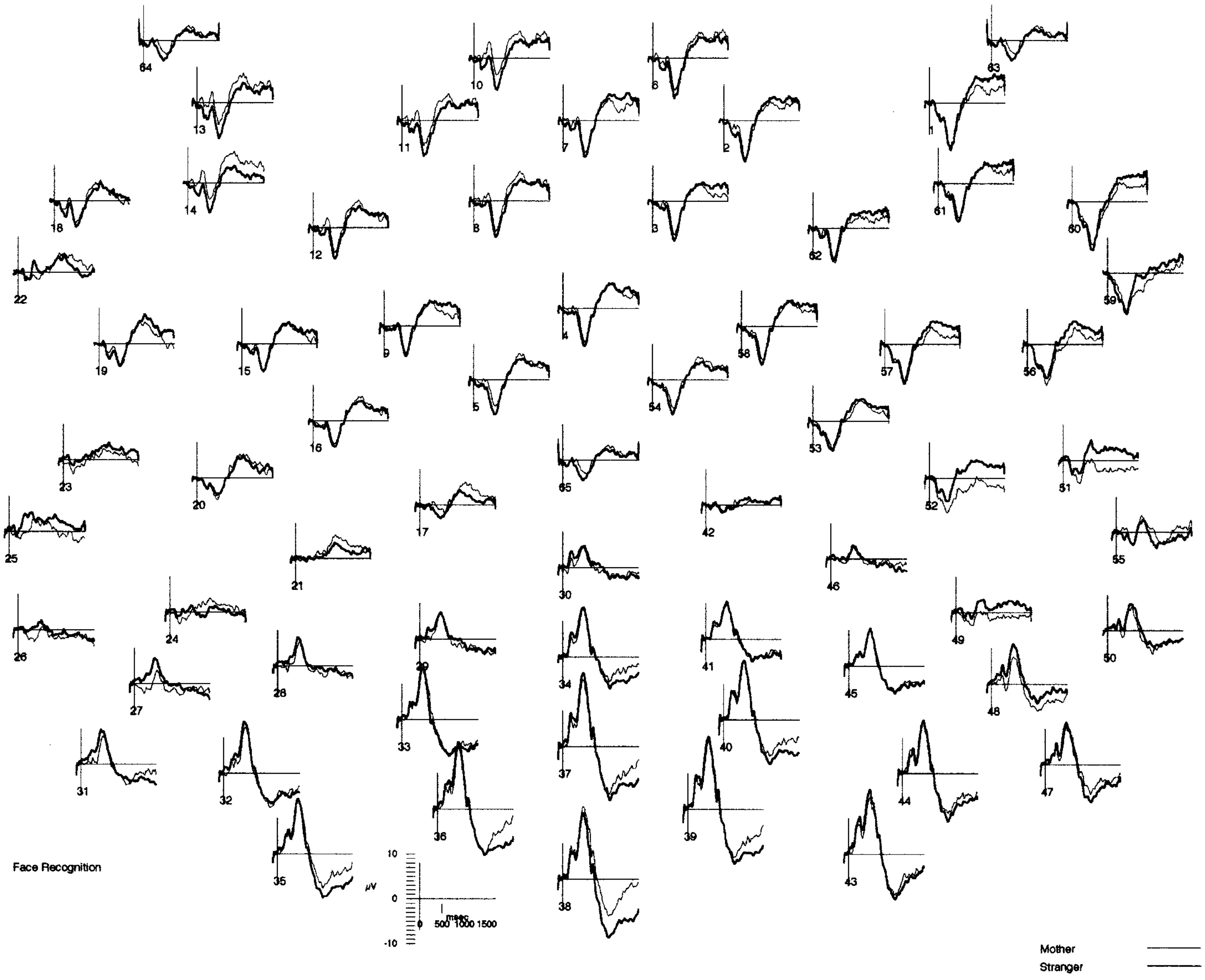

FIGURE 2 Grand mean ERPs to faces.

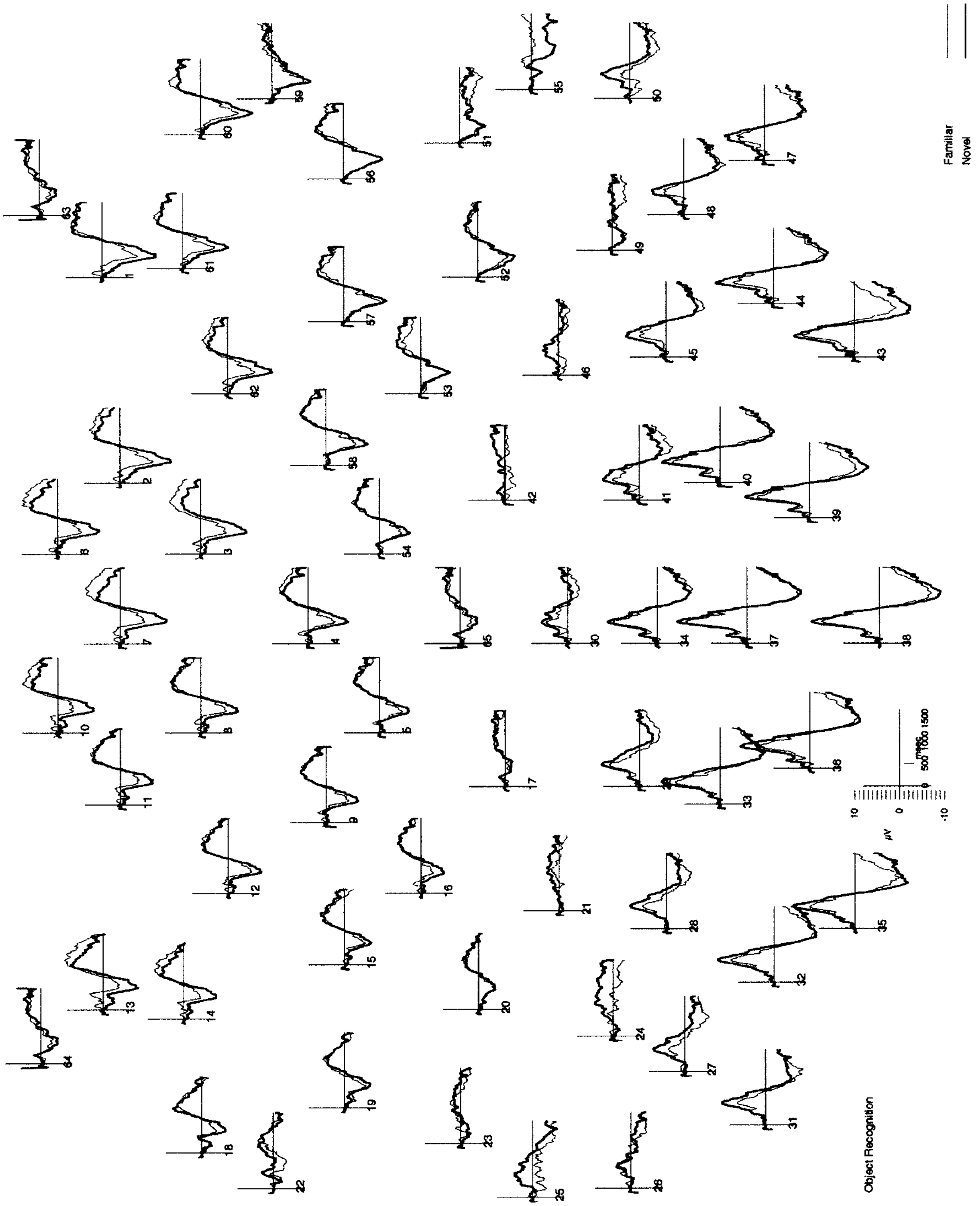

FIGURE 3 Grand mean ERPs to objects.

400 ms over parietal electrode sites (P400). The P400 has been described in past research as a sensory component that may be related to face processing (de Haan & Nelson, 1999). The time interval during which the components of interest occurred for each subject was determined by inspection of the individual average waveforms by the first, third, and fifth authors. Data from several subjects were examined by two observers, who were in agreement about the electrode sites and time intervals at which the components occurred for each instance. The peak amplitude and its latency were extracted for each subject for each component. The time intervals used were 360 to 920 ms for Nc and 380 to 940 ms for P400. The same time intervals were used for both the face and the object studies.

RESULTS

Regression analysis was used to determine whether age was related to the difference between the peak amplitude in response to familiar and unfamiliar stimuli. The difference was defined as the peak response to the unfamiliar stimulus subtracted from the peak response to the familiar stimulus. Thus, for the negative component (Nc), a larger response to the familiar stimulus resulted in a negative score whereas for the positive component (P400) a larger response to the familiar stimulus resulted in a positive score.

When the regression analysis revealed significant relations between variables, it is important to know whether the response to the familiar stimulus, the response to the unfamiliar stimulus, or an interaction between them was correlated with age. Multivariate regression was used to determine which stimulus (i.e., familiar or unfamiliar) was contributing to the significant relation between ERP difference and age. In addition, it also is of interest to confirm that children differentiated familiar from unfamiliar stimuli. Because age-related differences in the relative amplitude to familiar and unfamiliar stimuli were expected for face recognition, repeated measures ANOVA was used to determine at which ages a reliable difference between familiar and unfamiliar events was found. In this way, differences in the response to familiar and unfamiliar stimuli could be detected regardless of the direction of the age-related difference. For object recognition, repeated measures ANOVA was used to detect differences in the amplitude of the ERP components in response to familiar and unfamiliar stimuli since age-related differences in this measure were not expected or found (see *Results*).

ERPs to Faces

Nc Component. The grand average data for face recognition are displayed in Figure 2. The relations between the difference (familiar – unfamiliar ERP amplitude) score and the age of the child for each component at each scalp location are shown in Table 1. Regression analyses were conducted over frontal midline, left-, and right-hemisphere electrode sites. At the midline electrode sites, there was not a significant relation between age and the difference in the response to familiar and unfamiliar faces, $R^2 = .017$, $F(1, 40) = .682$, $p = .42$. At left frontal leads, there was a small but significant relation between the difference in the response to familiar and unfamiliar stimuli and the age of the child, $R^2 = .11$, $F(1, 40) = 5.13$, $p < .05$. At right frontal sites, a significant correlation between age and the difference between the response to familiar and unfamiliar stimuli also was found, $R^2 = .21$, $F(1, 40) = 10.68$, $p < .005$ (Figure 4). Inspection of Figure 5 indicated that the younger children in the sample showed a larger ERP response to the mother's face than to the stranger's face whereas older children showed the opposite pattern.

To examine the nature of the relation between age and amplitude to familiar and unfamiliar stimuli, we conducted multiple regression analyses, predicting amplitude as a function of stimulus type and age, and their interaction. Of particular interest in this model is the interaction term, which tests the degree to which age is differentially related to ERP amplitude for the familiar versus the unfamiliar stimulus. To minimize multicolinearity among the predictors, age was centered around the group mean. For the right hemisphere, the interaction was significant, standard coefficient = .342, $t = 2.39$, $p < .02$. The differential relation observed over the right hemisphere is illustrated in Figure 5. Whereas the response to the mother's face varied with age, there was no such relation for the response to the stranger's face. Figure 5 also suggests that children under the age of about 24 months versus children over the age of about 45 months showed different patterns of brain activity to the familiar and the unfamiliar face. Children under the age of about 24 months showed a greater response to the mother's face than to a stranger's face. Children over the age of about 45 months showed a larger response to the stranger's face than to the mother's face. Children between 24 and 45 months did not show differential Nc amplitude to the two kinds of stimuli.

Repeated measures ANOVAs supported these observations. A 3 (age: 18–24, 24–45, 45–52 months) × 2 (condition: mother, stranger) repeated measures ANOVA was conducted with the amplitude and latency of the Nc response at midline leads as dependent measures. At midline scalp locations, a main effect of group was observed, $F(2, 39) = 6.21$, $p < .005$. The amplitude of the Nc was larger for the young group than for the other groups, Fisher's PLSD, $p < .02$. A main effect of condition also was seen, $F(1, 39) = 4.07$, $p < .05$. The amplitude of the Nc component was larger to the stranger's face than to the mother's face. No effects were seen for the latency of the Nc component.

Table 1. Relations Between Familiar Unfamiliar ERP Amplitude Differences and Age

Component	Scalp Location	Faces (R)	Objects (R)
Nc	Right	.46**	.07
	Left	.34*	.05
	Midline	.13	.24
P400	Right	.29	.03
	Left	.33*	.15
	Midline	.41**	.08

*$p < .05$; **$p < .01$.

At lateral scalp locations, a Condition × Group × Hemisphere interaction was seen, $F(2, 39) = 4.93$, $p < .02$ (Table 2). Follow-up ANOVAs revealed that for the youngest group, a Hemisphere × Condition interaction was observed, $F(1, 11) = 6.45$, $p < .03$. Follow-up paired *t* tests revealed that whereas there was no difference in the amplitude of the Nc in response to mother's and stranger's face over the right hemisphere, $t(11) = .21$, there was a nearly significant difference to the two kinds of stimuli over the left hemisphere, $t(11) = -4.08$, $p = .06$. The response to the mother's face was greater than that to the stranger's face. For the children over 45 months of age, a main effect of condition was seen, $F(1, 11) = 7.39$, $p < .02$. The response to a stranger's face was larger than that to a mother's face. Note that this pattern is opposite that seen in the younger group and in previous research (de Haan & Nelson, 1997, 1999). The children who were intermediate in age showed no effects related to condition at either midline or lateral scalp locations, $ps > .10$. The amplitude of the Nc component for these children was larger on the left than on the right, $F(1, 20) = 11.98$, $p < .005$.

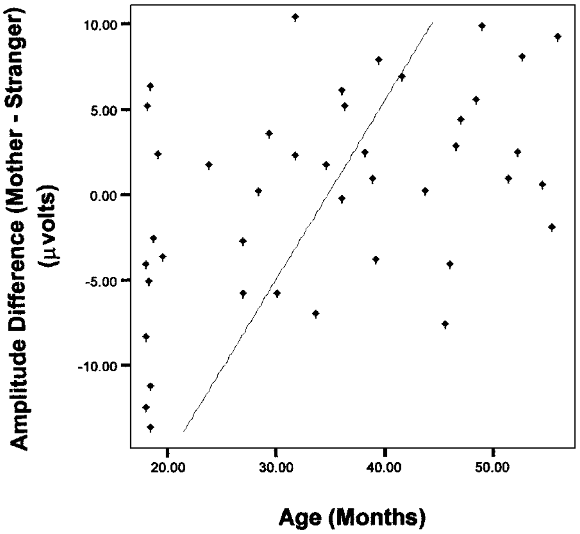

FIGURE 4 The relation between age and the difference in peak amplitude to the mother's face and the stranger's face at right frontal electrode sites for the Nc component. The *x* axis displays the child's age, and the *y* axis displays the difference in peak amplitude between the response to the mother's face and the stranger's face.

P400. A significant relation between age and the amplitude of the P400 component was found at midline electrode sites, $R^2 = .17$, $F(1, 40) = 8.16$, $p < .01$. This relation is displayed in Figure 6. Over lateral parietal leads, there also was a relation between age and the difference in the response to familiar and unfamiliar stimuli. Over the left parietal hemisphere, the age of the subject was significantly related to the difference between the response to the familiar and the unfamiliar face, $R^2 = .11$, $F(1, 40) = 4.76$, $p < .05$. Over the right parietal hemisphere, the relation between age and difference only approached statistical significance, $R^2 = .09$, $F(1, 40) = 3.56$, $p = .07$.

Multivariate regression did not indicate a significant interaction effect between age and stimulus type over the left hemisphere, standardized coefficient $= -.22$, $t = -1.46$, $p = .15$, or right, standardized coefficient $= -.17$, $t = -1.174$, $p = .24$, scalp locations. Over midline scalp locations, the interaction effect approached significance, standardized coefficient $= -.29$, $t = -1.91$, $p = .06$. As for the Nc component, younger children and older children differentially responded to familiar and unfamiliar stimuli, with younger children showing greater amplitude P400 to the familiar face and older children showing greater amplitude to the stranger's face. Children between 24 and 45 months did not show differential activity to familiar and unfamiliar stimuli.

Over midline scalp locations, repeated measures ANOVA revealed a condition × group interaction, $F(2, 39) = 3.14$, $p = .05$. There was not a significant difference between the response to the mother's and the stranger's face for the two youngest groups (<24 months and between ages 24 and 45 months, $ps > .10$. For the children over 45 months of age, a main effect of condition that approached significance was observed, $F(1, 11) = 4.31$, $p = .06$. The response to the stranger's face was larger than the response to the mother's face.

At lateral scalp locations, a main effect of group was observed, $F(2, 39) = 3.67$, $p < .05$. The amplitude of the youngest group's response was larger than for the middle age group, Fisher's PLSD, $p < .02$, and marginally larger than for the oldest group, Fisher's PLSD, $p = .06$.

ERPs to Toys

Nc Component. Grand average data for the object recognition study are shown in Figure 3. There was no significant relation between age and the difference in

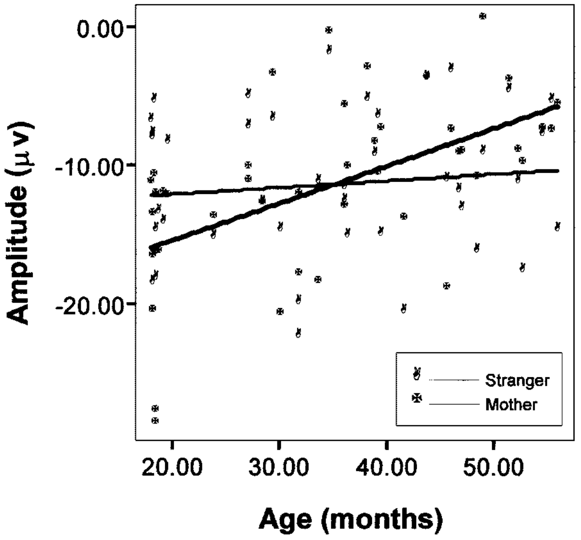

FIGURE 5 Multivariate regression plot showing the relation between age and amplitude to the mother's face and the stranger's face over right frontal electrode sites for the Nc component. The x axis displays the child's age, and the y axis displays the peak amplitude of the Nc component in response to the mother's face (thick line, +) and the stranger's face (thin line, x).

amplitude to familiar and unfamiliar objects at any scalp locations in Experiment 2, $Rs^2 < .05$, $ps > .10$ (Table 1). Descriptive statistics for the object recognition are shown in Table 3.

At midline scalp locations, repeated measures ANOVA for the group of children as a whole revealed a significant main effect of condition, $F(1, 45) = 12.35$, $p < .001$. The amplitude of the Nc was larger in response to the unfamiliar toy than it was to the familiar toy.

At lateral scalp locations, a main effect of hemisphere was observed, $F(1, 45) = 8.98$, $p < .005$. The Nc was larger over the right than the left hemisphere. A main effect of condition also was observed, $F(1, 45) = 9.61$, $p < .005$. The response was larger to the unfamiliar toy than to the familiar toy.

P400 Component. There was no significant relation between age and the difference in amplitude to familiar and unfamiliar objects for the P400 component at any scalp locations in Experiment 2, $Rs^2 < .03$, $ps > .10$.

At midline scalp locations, repeated measures ANOVA revealed no main effect of condition, $F(1, 45) = 1.82$, $p = .18$. At lateral scalp locations, repeated measures ANOVA for the group of children as a whole revealed a significant main effect of condition, $F(1, 45) = 6.65$,

Table 2. Mean Amplitudes of Nc and P400 Components for Each Age Group at Midline, Right, and Left Electrode Sites for the Face-Recognition Study

Component	Age Range (mo)	Mother Mean (SD)	Stranger Mean (SD)	p
Nc				
Midline	18–24	−12.45 (7.08)	−14.13 (5.81)	n.s.
Right	(12)	−10.71 (8.52)	−11.14 (7.22)	n.s.
Left		−16.41 (6.21)	−12.33 (4.67)	.06
P400				
Midline		23.87 (11.63)	20.09 (7.90)	n.s.
Right		23.12 (12.33)	21.38 (6.87)	n.s.
Left		20.26 (12.06)	17.35 (11.14)	n.s.
Nc				
Midline	24–45	−7.95 (4.01)	−8.03 (3.87)	n.s.
Right	(18)	−6.69 (3.64)	−5.94 (3.98)	n.s.
Left		−10.32 (5.60)	−11.28 (5.99)	n.s.
P400				
Midline		13.87 (6.12)	13.23 (6.30)	n.s.
Right		14.57 (7.95)	14.20 (8.31)	n.s.
Left		12.28 (7.94)	13.16 (7.76)	n.s.
Nc				
Midline	45–56	15.45 (6.45)	19.50 (6.73)	.06
Right	(12)	−6.61 (4.98)	−11.01 (2.82)	<.05
Left		−8.33 (4.57)	−10.58 (4.60)	<.05
P400				
Midline		15.45 (6.45)	19.50 (6.73)	.06
Right		13.36 (6.46)	16.49 (5.53)	n.s. (.06)
Left		13.43 (7.50)	16.95 (6.68)	n.s. (.06)

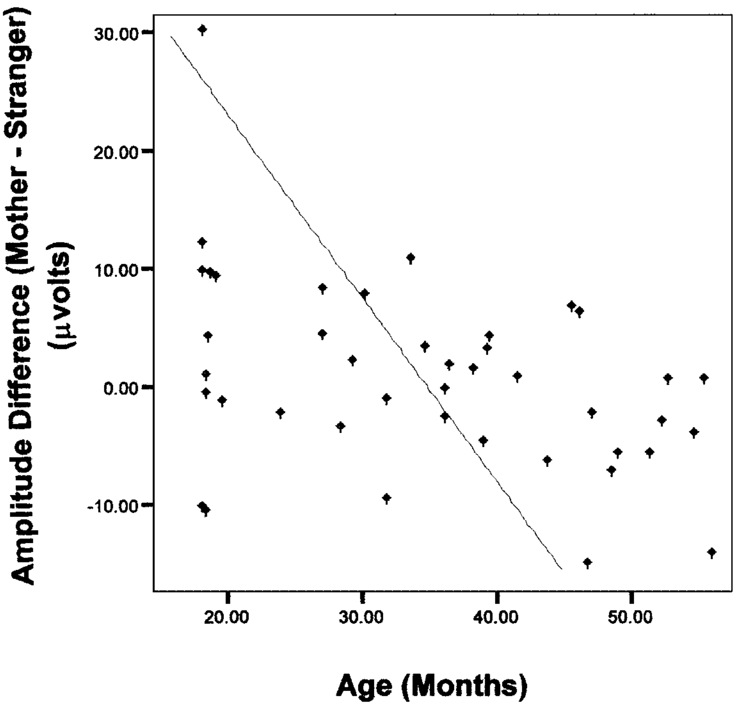

FIGURE 6 The relation between age and the difference in peak amplitude to the mother's face and the stranger's face at midline electrode sites for the P400 Component The *x* axis displays the child's age, and the *y* axis displays the difference in peak amplitude between the response to the mother's face and the stranger's face.

$p < .02$. The amplitude of the P400 was larger in response to the unfamiliar toy than it was to the familiar toy.

DISCUSSION

This study was designed to test the hypothesis that the neural correlates of face recognition vary as a function of the age of the child during early childhood. The results indicate that responses to familiar versus unfamiliar faces, but not familiar versus unfamiliar objects, are related to the child's age. Children of all ages showed differential responses to familiar versus unfamiliar objects, with larger amplitude Nc and P400 components to the unfamiliar toy than to the familiar toy.

In contrast, children's responses to familiar and unfamiliar faces varied as a function of the age of the child. The youngest children, between 18 and 24 months of age, showed greater ERP responses to the mother's face than to a stranger's face. This finding is consistent with those of de Haan & Nelson (1997, 1999), who found that 6-month-olds produced greater amplitude Nc responses to a mother's face than to a stranger's face.

In contrast to these young infants, however, the oldest children (between 45 and 54 months of age) showed greater responses to a stranger's face than a mother's. Children between 24 and 45 months of age did not show differential brain activity in response to a mother's and a stranger's faces, suggesting that this may be a transitional point in development. The Nc component has been attributed both to attentional processes and memory (de Haan & Nelson, 1997, 1999; Nelson, 1994). The age-related differences may therefore reflect developmental changes in the way children are devoting attentional resources to a mother's versus a stranger's face. Clearly, children do not cease to recognize or find salient their

Table 3. Mean Amplitudes of Nc and P400 Components at Midline, Right, and Left Electrode Sites for the Face-Recognition Study

Component	Familiar	Unfamiliar	*p*
Nc			
Midline	−9.09 (4.70)	−11.72 (6.16)	<.001
Right	−10.72 (5.21)	−13.10 (6.40)	<.005
Left	−7.84 (6.27)	−9.76 (6.44)	<.005
P400			
Midline	15.29 (8.49)	16.79 (8.38)	n.s.
Right	14.54 (7.92)	16.62 (9.27)	<.02
Left	14.16 (7.59)	17.04 (9.00)	<.02

mother's face between the second and fourth years of life. Rather, we suggest that at the earliest ages we tested and younger, including the 6-month-olds tested by de Haan & Nelson (1997, 1999), infants are devoting the bulk of attentional resources to learning about, recognizing, and understanding the face of the primary caregiver. In contrast, by 4 years of age, most children have a firmly established relationship with and representation of their caregiver and are relatively more interested in learning about other people. Between these ages, we suggest that children are in transition between devoting more attentional resources to a mother's face and a stranger's face.

Consistent with this hypothesis, Doyle, Bellugi, Kronenberg, and Graham (2002) recently measured sociability toward strangers in typically developing children, children with Down Syndrome, and children with Williams Syndrome in these age ranges. Of interest for the data we present here, typically developing children between the ages of 4 and 6 years were far more sociable than either 6- to 8-year-olds or 1- to 3-year-olds. These data suggest not only that 4-year-olds are likely more interested in learning about new people than younger children, as we suggest, but that they are perhaps even more sociable with strangers than older children.

Brain development in a number of systems is dependent on input from experience. For example, in the visual system, the development of ocular dominance columns and normal binocular vision requires visual input (Hubel, Wiesel, & LeVay, 1977). Further, normal development in the visual system requires synaptic activity in cortical circuits in the visual system (Katz & Shatz, 1996). It is likely that other systems are constructed by strengthening of connections through activity that occurs in response to experience. From the perspective of developmental theory, brain systems would be expected to change as children progress through developmental stages and tasks.

In the area of attachment, infants progress through stages in which their attachment becomes increasingly specific to a primary caregiver (Cassidy & Shaver, 1999). Infants begin to exhibit behaviors that suggest that they are beginning to form specific relationships with the primary caregiver at in the second half-year of life. Between 6 and 24 months, infants are upset at separation and seek proximity to the primary caregiver, especially after separation. In contrast, at 36 months of age, children are less distressed at brief separation and are tolerant of separation in the presence of friendly adults. By 48 months, children can separate easily from the primary caregiver provided they are prepared for separation through a plan or discussion with the primary caregiver (Marvin & Britner, 1999). It can be expected, from a developmental perspective, that the brain systems involved in social behaviors would change in conjunction with the formation of the attachment relationships. For example, the primary caregiver plays an increasingly important role in the life of the child as the relationship between the infant and mother progresses. If social–emotional behavioral changes can be related to brain functioning, the changing role of the mother should be apparent in developmental changes in neural correlates of cognitive and social responses to the primary caregiver.

The present results provide support for the view that face processing changes with increased expertise for faces. The developmental trajectory of the electrophysiological response to faces in the present study parallels developmental changes in the significance of different kinds of faces for children. During the months when the primary attachment relationship is being forged, infants and toddlers can be thought of as forming expertise for a specific face — that of the primary caregiver — as the person with whom the child is forming a special bond. After the establishment of this relationship, children can be thought of as more general "face experts," and can devote additional resources to learning about other faces.

It is important to note that in the present study only the response to the mother's face varied with age. Thus, it is not the case that younger toddlers are disinterested in strangers' faces. Instead, it appears that children of all ages attend equally to strangers, but that younger children devote an especially large amount of attention to their mother's face as well. This finding is consistent with the well-established finding that infants and young children are very interested in faces in general from a very early age (Goren, Sarty, & Wu, 1975).

Overall, our results suggest that face processing is a developmental phenomenon. The neural correlates of face recognition vary with children's age, and the degree of attentional resources they devote to processing faces may differ depending on the significance of the face during a particular point in development. Future studies should examine these age-related changes longitudinally, and with consideration for the social and cognitive tasks with which the child is engaged.

NOTES

This research was funded by a program project grant from the National Institute of Health and Human Development and the National Institute on Deafness and Communication Disorders (P01 HD34565), which is part of the National Institutes Health Collaborative Program of Excellence in Autism. The Murdock Trust provide funds for purchase of the system for recording electroencephalographic activity. We gratefully acknowledge the parents and their children who participated in this study, and the assistance of the Diagnostic and Statistical Cores of the University of Washington Autism Program Project. Charles Nelson was helpful as a consultant in the design and implementation of the study.

REFERENCES

Bentin, S., Allison, T., Puce, A., Perez, E., & McCarthy, G. (1996). Electrophysiological studies of face perception in humans. Journal of Cognitive Neuroscience, 8, 551–565.

Bohlin, G., & Hagekull, B. (1993). Stranger wariness and sociability in the early years. Infant Behavior and Development, 16, 53–67.

Bretherton, I., Stolberg, U., & Kreye, M. (1981). Engaging strangers in proximal interaction: Infants' social initiative. Developmental Psychology, 17, 746–755.

Cassidy, J., & Shaver, P. R. (1999). Handbook of attachment: Theory, research, and clinical applications. New York: Guilford Press.

Courchesne, E. (1978). Neurophysiological correlates of cognitive development: Changes in long-latency event-related potentials from childhood to adulthood. Electroencephalography and Clinical Neurophysiology, 45, 468–482.

Dawson, G., Carver, L. J., Meltzoff, A. N., Panagiotides, H., McPartland, J., & Webb, S. J. (2002). Neural correlates of face and object recognition in young children with autism, developmental delay, and typical development. Child Development, 73, 700–717.

de Haan, M., & Nelson, C. A. (1997). Recognition of the mother's face by 6-month-old infants. A neurobehavioral study. Child Development, 68, 187–210.

de Haan, M., & Nelson, C. A. (1999). Brain activity differentiates face and object processing in 6-month-old infants. Developmental Psychology, 35, 1113–1121.

Doyle, T. F., Bellugi, U., Korenberg, J., & Graham J. (2002). Everybody in the world is my friend: Hypersociability in young children with Williams Syndrome. San Diego: University of California San Diego Technical Report. (submitted)

Farah, M. J., Rabinowitz, C., Quinn, G. E., & Liu, G. T. (2000). Early commitment of neural substrates for face recognition. Cognitive Neuropsychology, 17, 117–123.

Gauthier, I., & Nelson, C. A. (2001). The development of face expertise. Current Opinions in Neurobiology, 11, 219–224.

Goren, C., Sarty, M., & Wu, P. (1975). Visual following and pattern discrimination of facelike stimuli by newborn infants. Pediatrics, 56, 544–549.

Greenough, W. T., Black, J. E., & Wallace, C. S. (1987). Experience and brain development. Child Development, 58, 539–559.

Hubel, D. H., Wiesel, T. N., & LeVay, S. (1977). Plasticity of ocular dominance columns in monkey striate cortex. Philosophical Transactions of the Royal Society of London B Biological Science, 278, 377–409.

Katz, L. D., & Shatz, C. J. (1996). Synaptic activity and the construction of cortical circuits. Science, 274, 1133–1138.

Marvin, R. S., & Britner, P. A. (1999). Normative development: The ontogeny of attachment. In J. Cassidy & R. Shaver (Eds.), Handbook of attachment: Theory, research, and clinical applications (pp. 44–67). New York: Guilford Press.

Meltzoff, A. N., & Moore, M. K. (1977). Imitation of facial and manual gestures by human neonates. Science, 198, 75–78.

Meltzoff, A. N., & Moore, M. K. (1992). Early imitation within a functional framework: The importance of person identity, movement, and development. Infant Behavior and Development, 15, 479–505.

Meltzoff, A. N., & Moore, M. K. (1997). Explaining facial imitation: A theoretical model. Early Development and Parenting, 6, 179–192.

Meltzoff, A. N., & Moore, M. K. (1998). Object representation, identity, and the paradox of early permanence: Steps toward a new framework. Infant Behavior and Development, 21, 201–235.

Morton, J., & Johnson, M. H. (1991). CONSPEC and CONLERN: A two-process theory of infant face recognition. Psychological Review, 2, 164–181.

Mullen, E. M. (1997). Mullen Scales of Early Learning. Los Angeles: Western Psychological Services.

Nelson, C. A. (1994). Neural correlates of recognition memory in the first postnatal year. In G. Dawson & K. W. Fisher (Eds.), Human behavior and the developing brain (pp. 269–313). New York: Guilford Press.

Nelson, C. A. (2001). The development and neural bases of face recognition. Infant and Child Development, 10, 3–18.

Nelson, C. A., & Collins, P. (1991). Event-related potential and looking-time analysis of infants' responses to familiar and unfamiliar events: Implications for visual recognition memory. Developmental Psychology, 27, 50–58.

Pascalis, O., & de Schonen, S. (1994). Recognition memory in 3- to 4-day-old human infants. NeuroReport, 5, 1721–1724.

Pascalis, O., de Schonen, S., Morton, J., Derulle, C., & Fabre-Grenet, M. (1995). Mother's face recognition in neonates: A replication and an extension. Infant Behavior and Development, 18, 79–85.