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## ELECTROPHYSIOLOGICAL CORRELATES OF FACIAL SELF-RECOGNITION IN ADULTS AND CHILDREN

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### **ABSTRACT**

*This study was designed to examine the electrophysiological correlates of facial self-recognition in adults and four-year-old children. Participants passively viewed neutral pictures of their own face, as well as faces of a familiar adult, an unfamiliar adult, and an unfamiliar infant while event-related-potentials (ERPs) were recorded. The results indicate an increase in processing specificity across time in adults but not children. In adults, the vertex positive potential (VPP) seems to be influenced by the emotional saliency of faces, whereas the N200/300 and P300 are differentiating familiar and unfamiliar faces. Additionally, the neural response to the self face compared to all other faces is greatest for the P300 component. In contrast, four-year olds only exhibited differences between familiar and unfamiliar stimuli for the P2 component. Combined, the results of this study indicate processing differences between adults and four-year olds while processing familiar and unfamiliar faces. Furthermore, four-year olds exhibited a more diffuse pattern of electrical activity compared to adults.*

**KEY-WORDS:** *event-related potentials (ERPs), self-recognition, self-perception, face-perception, development*

Face recognition is crucial to a variety of human interactions. From early in infancy through childhood and into adulthood, humans use faces to identify whether someone is familiar, their age, gender or race, emotional information, and intentions (eye-gaze). Many researchers have been particularly interested in the

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development of face recognition because of its importance in everyday life (see Nelson, 2001). Of particular importance is how processing faces of special interest to an individual, such as the face of a parent or a friend, are different from processing unknown or unfamiliar faces.

Only a handful of studies have been conducted to investigate the neural correlates of the development of familiar and unfamiliar face processing. Indeed, most of these studies are limited to the recognition of the mother's face. For example, investigators have utilized electrophysiological techniques to investigate children and infant's neural response to the mother's face. de Haan and Nelson (1997) used event-related-potentials (ERPs) to examine six-month-old infants' ability to recognize their mothers face versus another unfamiliar mothers face. They found that six-month-olds were able to discriminate between their mother and a dissimilar-looking unfamiliar woman as evidenced by different components of the event-related potential (ERP). In addition, research suggests that there may be developmental changes in the relative importance of viewing different faces with different levels of familiarity (such as the mother's face versus strangers' faces). In older children, 18-54 months of age, the specificity of the ERP response to faces changes as a function of age (Carver et al., 2003). Whereas older children show evidence of neural discrimination between familiar and unfamiliar toys, only younger children (18-24 months of age) exhibit ERP differences to familiar and unfamiliar faces (Carver et al., 2003). More specifically, all age groups exhibit a larger negative component (Nc) and P400 to unfamiliar versus familiar toys, but only younger children exhibit neural discrimination between the mother's face and a stranger's face for these components. These findings suggest that the neural correlates of face processing may change across development, and may be related to the emotional salience or significance of the face.

Over and above recognizing the faces of others, recognizing ones own face is often cited as a developmental milestone thought to involve a complex integration of perceptual, cognitive, and social mechanisms. Many theories have included the ability to recognize ones own face as a developmental precursor to adult-like cognitive and social processing (Asendorpf, Warkentin, & Baudonniere, 1996; Gopnik & Meltzoff, 1994; Howe & Courage, 1997). However, awareness of the self has been cited as a developmental process that may begin as early as birth and end as late as adolescence (see Bahrnick, Moss, & Fadil, 1996; Legerstee, Anderson & Schaffer, 1998; Gopnik & Meltzoff, 1994). Despite this wide developmental age range for the development of self-awareness, the majority of research on self-recognition suggests that facial self-recognition begins between 15 and 24 months of age, and self-processing then continues on into adolescence. This suggests that there may be more than one mechanism involved in the development of self-referential processes (Lewis & Brooks-Gunn, 1979; Lewis, 1991). Although the behavioral correlates of self-recognition have been extensively studied across many different ages, the underlying neural substrate involved in the development of self-recognition has not yet been elucidated. Moreover, studies of how self-referential information is represented at a neural level are relatively sparse.

In addition to the fact that facial self-recognition is a powerful cue to which adults would tend to respond, there is an extensive literature on the neural basis of face recognition in general (Damasio, 1985; Farah, Wilson, Drain, & Tanaka, 1998; Rolls, 1992; Mesulam, 1998; Ungerleider, 1995) against which findings pertinent to facial *self*-recognition can be compared. In non-human primates, neurons in the temporal lobe exhibit selective responses to faces (e.g., Desimone, 1991; Perrett, Rolls, & Caan, 1982). In addition, recordings from intracranial electrodes in humans have indicated face-specific response from bilateral regions of the fusiform and inferior temporal gyri (Allison et al., 1994a). Finally, functional magnetic resonance imaging (fMRI) and Positron Emission Tomography (PET) studies have found that the visual presentation of faces activates the fusiform and middle occipito-temporal gyri, the lateral occipital sulcus, and the superior temporal sulcus in the right hemisphere (e.g., Clark et al., 1996; Haxby, Ungerleider, Horwitz, Rapoport, & Grady, 1995; Haxby et al., 1999; Kanwisher, McDermott, & Chun, 1997; McCarthy, Puce, Gore, & Allison, 1997; Paller, Gonsalves, Grabowecky, Bozic & Yamada, 2000; Puce, Allison, Gore, & McCarthy, 1995; Sams, Hietanen, Hari, Ilmoniemi & Lounasmaa, 1997; Sergent, Ohta, & MacDonald, 1992).

Although these studies have found rather consistent areas of activation in response to faces, they do not establish the temporal parameters that coincide with face processing. Event-related potentials (ERPs) have been utilized to investigate the temporal progression of cognitive processes such as face perception. Several studies have postulated the existence of a particular ERP component, negative in polarity, which appears 150-200 ms after stimulus onset in response to facial stimuli (i.e. N170; see Bentin, Allison, Puce, Perez, & McCarthy, 1996; Carmel & Bentin, 2002; Botzel & Grusser, 1989; Jeffreys, 1989; Jeffreys, Tukamachi, & Rockley, 1992). This potential has been attributed to activity in the occipitotemporal and posterior fusiform regions (Allison, McCarthy, Nobre, Puce & Belger, 1994b; Puce, Allison & McCarthy, 1999) and may reflect processes associated with the perceptual analysis of faces (Paller et al., 2000; Eimer, 2000). The VPP (vertex positive potential), or a positive component temporally coincident with the N170, has also been implicated in the perceptual analysis of faces (Bentin et al., 1996; Jeffreys, 1996; Rossion, Joyce, Cottrell, & Tarr, in press). Similar to the N170, the VPP responds more quickly and with greater amplitude to faces compared to objects (Jeffreys & Tukamachi, 1992).

Recently, researchers have begun to look beyond these early face specific components and report a later enhanced negativity between 300 and 500 milliseconds after stimulus onset in response to familiar compared to unfamiliar faces (Eimer, 2000). This negativity was followed by a positive deflection that was also enhanced in response to familiar faces. Eimer concluded that while the N170 is involved in the early perceptual analysis of faces, later components might reflect subsequent processing related to the recognition of these faces.

Several researchers have recently investigated the neural correlates of explicit facial *self*-recognition in adults. For example, Keenan, Freund, Hamilton,

Ganis, and Pascual-Leone (2000) morphed or merged images of participants' own faces with faces of co-workers. The stimuli were presented as video clips, in which one face (self) was transformed into another (co-worker) and then finally transformed into a famous face. The order of transformation varied. Participants were asked to stop the video clip using either their left or right hand when the face was recognized as either famous, a co-worker, or the self. When participants responded to the self-face with the left hand, an earlier frame was identified than when they responded to the other faces or when they responded using the right hand. Thus, the authors concluded that the right hemisphere could mediate the early attentional processing of the self.

In a subsequent investigation, Keenan, Nelson, O'Connor, and Pascual-Leone (2001) examined a group of patients with epilepsy who underwent the intracarotid amobarbital (WADA) testing prior to neurosurgery. The WADA test involves anaesthetization of one cerebral hemisphere in order to determine cerebral dominance for several cognitive abilities, generally language or recall/recognition memory. While under selective anesthesia of the right or left hemispheres, the patients were shown morphed images of their own faces and those of famous people and told to try to remember each face. After recovery from the procedure, the patients were shown pictures of their own face and pictures of the famous faces. They were instructed to select which face(s) they had been shown (despite the fact that neither face had actually been presented in its entirety). Results indicated that when the left hemisphere had been anaesthetized during stimulus presentation, patients tended to select the self-face as the stimulus that had been shown, suggesting that the right hemisphere is critical for facial self-recognition. The authors extended their study to healthy adults, but instead of using the WADA test, they delivered transcranial magnetic stimulation to the motor cortex of the right or left hemisphere. They measured the evoked responses from the contralateral first dorsal interosseous muscle to determine the amount of activity in each hemisphere during presentation of the morphed pictures. Evoked responses were significantly greater in the right hemisphere when subjects viewed pictures containing elements of their own faces than when they viewed other facial configurations. The authors therefore suggest that the right hemisphere plays a role in self-awareness and higher-order consciousness. Alternatively, a recent investigation by Turk et al. (2002) examined a split-brain patient's (JW) ability to recognize himself and another familiar individual. JW exhibited a left hemisphere bias for processing his own face, while showing a right hemisphere bias when processing other familiar faces.

The frontal cortex has also been implicated in self-referential processing (Craig et al, 1999; Kelly et al., 2002). Craig et al. (1999) used PET to measure neural activation during the encoding and retrieval of trait adjectives related to the self, a well-known public figure, social desirability, and a number of syllables. Results indicate that self-related encoding yields left and right frontal activations. Kelly et al. (2002) extended this work using event-related functional magnetic resonance imaging. In this study participants were imaged while making judgments

about trait adjectives in three different conditions. Participants were asked to determine whether presented adjectives were either self-relevant, other-relevant (famous person), or whether the adjective was presented in upper or lower case letters. Consistent with the above-described study, the results of this study suggest that the medial prefrontal cortex was activated during self-referential processing.

ERPs have also been recorded while healthy adults were presented with and asked to respond to a series of stimuli, including the self-face (Ninomiya, Onitsuka, Chen, Sato, & Tashiro, 1998). In the first of two conditions, adults were presented with a famous face (10% probability), two unfamiliar faces (30% probability) and the self-face (30% probability). In the second condition the self-face was replaced with the presentation of a red square (30% probability). Instructions were to push a button when the target (famous face) stimulus appeared. A positive component, evoked most reliably in oddball tasks, called the P300, was examined at midline scalp leads in response to each stimulus within each condition. The authors found an enhanced P300, maximal at Pz, in response to the target (infrequent) stimulus. However, the evoked response to the self-face was maximal at more anterior sites (Cz). In addition, the latency to the P300 in response to the subject's own face occurred significantly earlier than to the target stimulus. Moreover, the P300 response to the self-face was greater than to the red square. The authors suggest that the P300 in response to the self-face represents a P3a component, typically noted to exhibit a fronto-central distribution, and elicited by salient stimuli under unattended conditions (Donchin et al., 1984; Squires, Squires, & Hillyard, 1975). Similarly, in other studies, autobiographical information has been found to elicit a P300 in the context of an oddball paradigm (Berlad & Pratt, 1996). For instance, Berlad and Pratt investigated the dependence of the amplitude of the P300 on auditory presentation of participant's own names in two experiments. The first experiment was a passive, two-word oddball paradigm with the participant's name as the low probability word. The second task used three words, with two low probability words (one of which was the participant's name). Results indicate a greater amplitude P300 response to the participant's own name compared to both the frequent and infrequent irrelevant words. Additionally, Fischler, Jin, Boaz, Perry and Childers (1987) found that the visual presentation of a subject's family name evoked a larger P300 response compared to irrelevant family names.

Typically, studies of face recognition in adult populations require subjects to make some sort of active explicit response to faces that are familiar versus those that are not (Kapur, Friston, Young, Frith & Frackowiak, 1995; Sergent et al., 1992; Sugiura et al., 2000). For example, subjects might be asked to view a series of facial images and press a button whenever they see a familiar face (Paller et al., 2000). Such studies are valuable in that they provide an index of how information is represented at a conscious level of awareness. However, it could be argued that studies requiring active recognition confound analysis of the visuoperceptual skills necessary to encode the stimulus and recognize that visual stimulus as familiar with sustained attention and motor responding (Sugiura et al., 2000). Active recognition,

in contrast to passive recognition, may require the integration of several cognitive processes.

Based on the above literature, we have taken an inductive approach to the study of facial self-recognition by examining electrophysiological responses to the passive viewing of self versus other familiar and unfamiliar faces in adults and children. The current study consists of two experiments. In the first experiment healthy adults viewed pictures of human faces including their own, a familiar adult, an unfamiliar adult, and an unfamiliar infant while their brain activity was recorded from scalp electrodes. We chose the above stimuli because we wanted to investigate the response to different kinds of familiar and emotionally salient faces. For example, the self-face and a friend's face are both highly familiar faces, but may be perceived very differently. Moreover, a completely unfamiliar picture of an infant may evoke a very different response than the picture of an unfamiliar adult. The infant's face may be seen as high in emotional saliency but low in familiarity.

In the second experiment four-year-old children viewed pictures of themselves, their mother, an unfamiliar female adult, and an unfamiliar four-year-old. Again, although somewhat different from the adult experiment, we chose the above stimuli to represent different levels of familiarity. Both populations passively viewed the stimuli. We choose a passive task for two reasons; first, passive recognition may represent a more direct index of facial processing than active recognition; that is, one that reflects the earliest processing of faces prior to the in-depth processing that is likely involved in making identity judgments or more sophisticated emotion judgments such as "trustworthiness." Second, the use of a passive task will permit us to compare results across different age groups (infants through adults; four-year-olds in this particular study) using a very similar paradigm. To this end we have designed this investigation to answer four main questions about the developmental differences and neural correlates of familiar and unfamiliar face processing in four-year-old children and adults. First, what are the electrophysiological correlates of self-perception in a passive viewing task in these two age groups? Second, how does facial self-perception differ from familiar and unfamiliar face processing in adults and children? Third, what role does emotional saliency play when processing familiar and unfamiliar faces across development? For example, viewing an unfamiliar infant's face is high on emotional saliency and low on familiarity, whereas viewing a friend or mother's face is high on emotional saliency and high on familiarity. Finally, are there topographic differences between the right and left hemisphere and between anterior and posterior regions of the scalp, when processing familiar versus unfamiliar stimuli?

In adults, we expect to see differential processing of faces based on familiarity and emotional salience. Based on prior research, we also expect to see hemispheric and regional differences between familiar and unfamiliar faces. Furthermore, we expect that viewing the self-face will elicit a different neural response than viewing both familiar and unfamiliar faces. In four-year olds we expect to see similar differentiation between familiar and unfamiliar faces, but because the self face may not be as familiar as the mother's face, and four-year

olds likely do not have as much experience (although still able to identify the self), compared to adults, viewing the self face we do not expect to see further discrimination of the self face from other faces. Furthermore, across all conditions we do not expect to see the same degree of electrophysiological activation across the scalp as adults. More specifically, based on a previous report by Passoratti et al., (2003) we expect more diffuse patterns of activation across hemispheres and regions in four-year olds.

## **EXPERIMENT 1**

### **Methods**

#### *Participants*

Adult participants (n=21) were recruited from a group of undergraduate and graduate students in research laboratories in either the Child Psychology or Psychology departments at a University in the Midwest. Two participants were excluded because of eye and/or body movements that resulted in artifacts in the data, and one participant was excluded due to experimenter error. The remaining participants, 11 women and 7 men, were healthy adults (mean age = 24.5 years; SD= 4.3 years) with no histories of uncorrected visual abnormalities, and no histories of neurological or psychiatric problems. Participants were paid five dollars in return for their participation.

#### *Stimuli*

Digitized images of familiar and unfamiliar faces were used as stimuli. The familiar faces were colored images of the participant, and a same age and sex friend of the participant. The unfamiliar faces were those of an unfamiliar, same age and sex adult and an unfamiliar infant (approximately 8-months of age). Participants were asked to identify a same aged/sex friend that they were most familiar with; this person's picture was then used as the familiar stimulus. Pictures of the familiar faces were taken at the time of testing and the unfamiliar faces were taken from an existing database of infant and adult faces. The adult and infant pictures were taken while each was seated in front of a gray screen and wearing a gray scarf around his or her neck. Adult participants were asked to pose a neutral expression, and images were photographed to include only the face. The pictures were captured using an Olympus Camida Digital Camera and then sized using Adobe Photoshop ©. These pictures were used as stimuli during the ERP recording. A total of 160 trials were administered that included the following stimuli: 40 presentations of the self, 40 presentations of the familiar adult, 40 presentations of the unfamiliar adult, and 40 presentations of the unfamiliar infant. Each trial consisted of a 100 ms baseline, a 500 ms stimulus presentation, and a 1200 ms recording after the offset of the stimulus. There was a randomly varying inter-trial-interval of between 500 and 1000 ms between the end of one trial and the start of the next. The faces alternated randomly and each participant saw a different set of faces. Instructions were simply to passively view the images as they

appeared. All participants were monitored via live video to ensure they were attending to the stimuli throughout the task. The experiment was paused when participants were looking away.

#### *Electrophysiological procedure*

Tin recording electrodes sewn into a close-fitting cloth cap were used to record ERP's (Electro-cap International©). ERP's were recorded from 32 scalp sites. However, only leads Cz, Pz, Fz, C3, C4, T3, T4, T5, T6, F3, F4, F7, F8 were used in statistical analyses. After the cap was placed on the head, a small dab of NuPrep© as well as a dab of Electrode Jelly©, was applied under each electrode. A ground electrode was located over the forehead, and two small eye electrodes, located above and below the eye, were used to record vertical eye movements (including blinks). Impedances were accepted if they were less than 5 kOhms. All scalp electrodes were referenced to the scalp electrode Cz and then re-referenced offline to averaged mastoids. EEG data were acquired with a Grass Neuro Acquisition System® with Model 12A5 amplifiers. The gain was set to 50,000 for all scalp leads. The gain for EOG was set at 5,000. A bandpass filter was set to .1 to 30 Hz, and a 60 Hz notch filter was in place. EEG data were sampled at 200 Hz.

#### *ERP data editing, averaging, and analysis*

After the data were collected, they were edited, averaged and analyzed using ERPW, an ERP editing and averaging program developed for use in our laboratory. The EOG data were edited for artifacts using a regression algorithm in this program (Gratton, Coles & Donchin, 1983). Individual trials were excluded from the analysis if they included more than three channels with excessive artifacts arising from body or eye movements. Trials were rejected if EEG responses exceeded +/- 100 microvolts, if EOG showed changes of greater than 100 microvolts within a 50 ms window, or if artifacts were detected in the any of the reference channels (A1, A2, or Cz).

Individual artifact-free trials were combined to form average waveforms for each subject and for each condition (self, familiar adult, unfamiliar adult, and unfamiliar infant). Grand averages were computed for each age group and stimulus type. Participants with fewer than 20 artifact free trials per channel per condition were not included in the grand average. These grand averages were then used to identify the time intervals that reflected components of interest across all leads. Based on prior research, three major components were identified: VPP (or the vertex positive potential), N200/300, and the P300 (see Figures 1 & 2). Different comparisons were used to compare midline leads because these are the leads most typically used in ERP studies. For example, the amplitude of the midline leads is often used to define different components of interest. Additionally, some components (eg. N200/N300) are apparent only at certain leads, and thus only those leads were used in the analyses. Finally, based on our hypotheses and previous research, separate analyses of hemisphere and region were conducted to determine any differences in condition across these regions.

The VPP was present across the majority of recording sites and occurred between 100 and 200 ms. Past research has identified this component as being involved in the processing of facial stimuli. More specifically, the VPP component may be involved in further elaborations or processing of facial stimuli whereby different types of faces may be processed earlier or later than others (Jeffreys, 1989; Jeffreys, Turkamachi & Rockley, 1992; Linkenkaer-Hansen et al., 1998). Furthermore, as mentioned above, Rossion et al. (in press) the VPP may be the dipolar opposite of the more frequently studied N170 component. The maximum positive peak, and the corresponding latency were used for the analysis of the VPP component. A frontally distributed negative component occurring between 200 and 400 ms was also examined. This N200/300 component has been found to be sensitive to visual selection processes and may be involved in the further processing of stimuli after a stimulus has been identified as belonging to a relevant category (Hillyard & Picton, 1987). For the N200/300 component, peak minimum amplitude and its corresponding latencies were analyzed. Finally, the P300 (occurring between 300 and 575 ms) was also examined. Due to the lack of a prominent peak, group measures of average amplitude were analyzed for this component. All measures of amplitude and latency were taken from a pre-stimulus baseline.

To examine the VPP, N200/N300 and P300, three separate MANOVAs were conducted with four levels of condition (self, familiar adult, unfamiliar adult, and unfamiliar infant), and either three levels of lead (Fz, Cz, Pz), two levels of region (frontal (F3, F4, F7, F8); temporal (T3, T4, T5, T6)) or two levels of hemisphere (right (C4, T4, T6, F4, F8); left (C3, T3, T5, F3, F7)). All MANOVAs were conducted using the SPSS for Windows, version 11.0 statistical package. Only significant results will be reported. When appropriate, follow-up analyses of main effects and interactions were conducted using pairwise comparisons adjusted for multiple comparisons using the Bonferroni method.

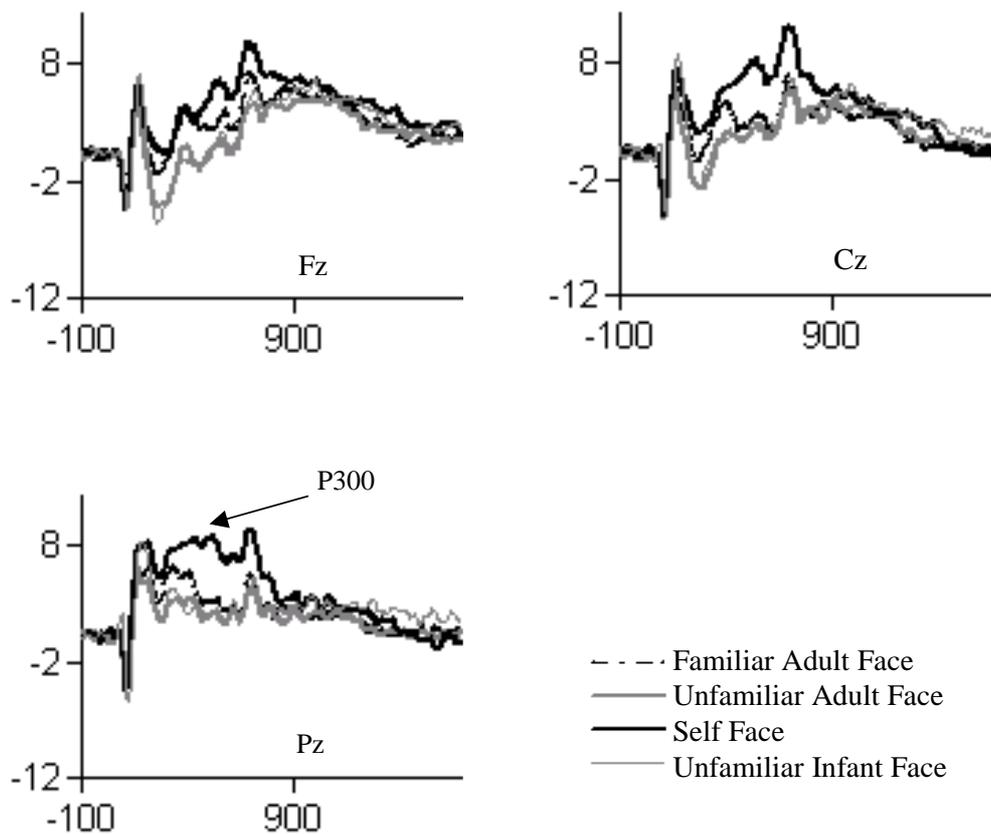
## Results

VPP. Midline analyses of maximum positive amplitude revealed significant differences between conditions ( $F(3, 15) = 7.42, p < .01$ ), no differences between midline leads (electrodes), and a significant interaction between condition and lead ( $F(6, 12) = 3.96, p < .05$ ). Follow-up analyses of the interaction indicate a significantly greater response to the self and unfamiliar infant faces compared to the unfamiliar adult face at electrode Cz. Corresponding latency analyses did not reveal any significant differences.

Analyses of hemispheric differences indicate a significantly longer latency to peak response to the infant compared to the unfamiliar adult face ( $F(3, 15) = 4.86, p < .05$ ). There were however, no differences between hemispheres and no interactions for both amplitude and latency measures.

Analyses of regional differences between the frontal and temporal recording sites indicate no main effect of condition, but a main effect of region

( $F(1, 17)=8.74, p<.01$ ), and a significant interaction between condition and region ( $F(3, 15)=3.79, p<.05$ ), in that there was a greater amplitude response in the frontal region compared to the temporal region to the self ( $t=-3.01, p<.05$ ), familiar adult ( $t=-2.91, p<.05$ ), and unfamiliar infant ( $t=-3.46, p<.05$ ) faces, but not the unfamiliar adult face. The corresponding latency analyses indicate a main effect of condition ( $F(3, 15)=3.42, p<.05$ ), a main effect of region ( $F(1, 17)=10.26, p<.01$ ), but no significant interaction. The follow-up analyses of the main effect of condition revealed no significant differences across conditions. The main effect of region was due to a longer latency to peak at frontal compared to temporal recording sites. (See Figures 1).



**Figure 1.** Event-related potential grand averages of the response to the unfamiliar infant (thin gray), familiar adult (dashed), self (thick black), and familiar adult (thick gray) faces at the midline (Fz, Cz, Pz) electrodes in adults. Each waveform was shifted so that baseline (activity from -100 to 0) was equivalent across different conditions and electrodes.

N200/300. Midline analyses of minimum amplitude revealed significant main effects of condition ( $F(3, 15)= 10.04, p<. 001$ ) and lead ( $F(2, 16)= 19.04, p<.001$ ) and no significant interaction. Follow-up comparisons of the main effect of condition indicate a greater negative amplitude response to both the unfamiliar adult and unfamiliar infant face compared to the self, and familiar adult face. The main effect of lead is due to a greater amplitude response at Fz compared to Cz and Pz, and a greater amplitude response to Cz compared to Pz ( $p$ 's  $< .05$ ). Latency analyses indicate no main effects of condition, or lead, and no significant interaction.

Similar to the VPP, no hemispheric differences were found, but there was a main effect of condition ( $F(3, 15)=15.45, p<.01$ ) in that the amplitude response to the unfamiliar infant face was significantly greater than the response to the self ( $p<.01$ ) and familiar adult faces ( $p<.01$ ). There were no latency differences.

Regional differences between frontal and temporal recording sites, however, were apparent for this component. There was a main effect of condition ( $F(3, 15)=13.55, p<.01$ ), a main effect of region ( $F(1, 17)=16.12, p<.01$ ), and a significant interaction between condition and region ( $F(3, 15)=9.46, p=.01$ ). Follow-up analyses of the interaction reveal a greater amplitude response in the frontal region compared to the temporal region for the familiar adult, unfamiliar adult, and unfamiliar infant (all  $p$ 's  $< .05$ ), but not for the self face (See Figure 3). Furthermore, the amplitude response to the self face was significantly less than the response to the unfamiliar adult and unfamiliar infant ( $p$ 's  $< .05$ ) but not the familiar adult across scalp regions. The corresponding latency analyses revealed no main effect of condition, a main effect of region ( $F(1, 17)=9.18, p<.01$ ), and no significant interactions. The main effect of region was due to a longer latency to peak response in the frontal region.

P300. The apparent lack of a prominent peak across all leads for the P300 component, suggest that average amplitude responses (and not maximum amplitude responses) should be used to evaluate ERP differences across conditions. Midline analyses of average amplitude revealed main effects of condition ( $F(3, 15) = 9.98, p < .001$ ) and lead ( $F(2, 16) = 21.36, p < .001$ ) and no interaction between condition and lead. Follow-up paired comparisons of the main effects of condition indicated a significantly greater average amplitude response to the self face and familiar adult face compared to all other stimuli, and a greater average amplitude response to the self face compared to the familiar adult face (See Figures 2 and 3). An investigation of the main effect of lead indicated a significant increase in average amplitude from Fz to Cz to Pz.

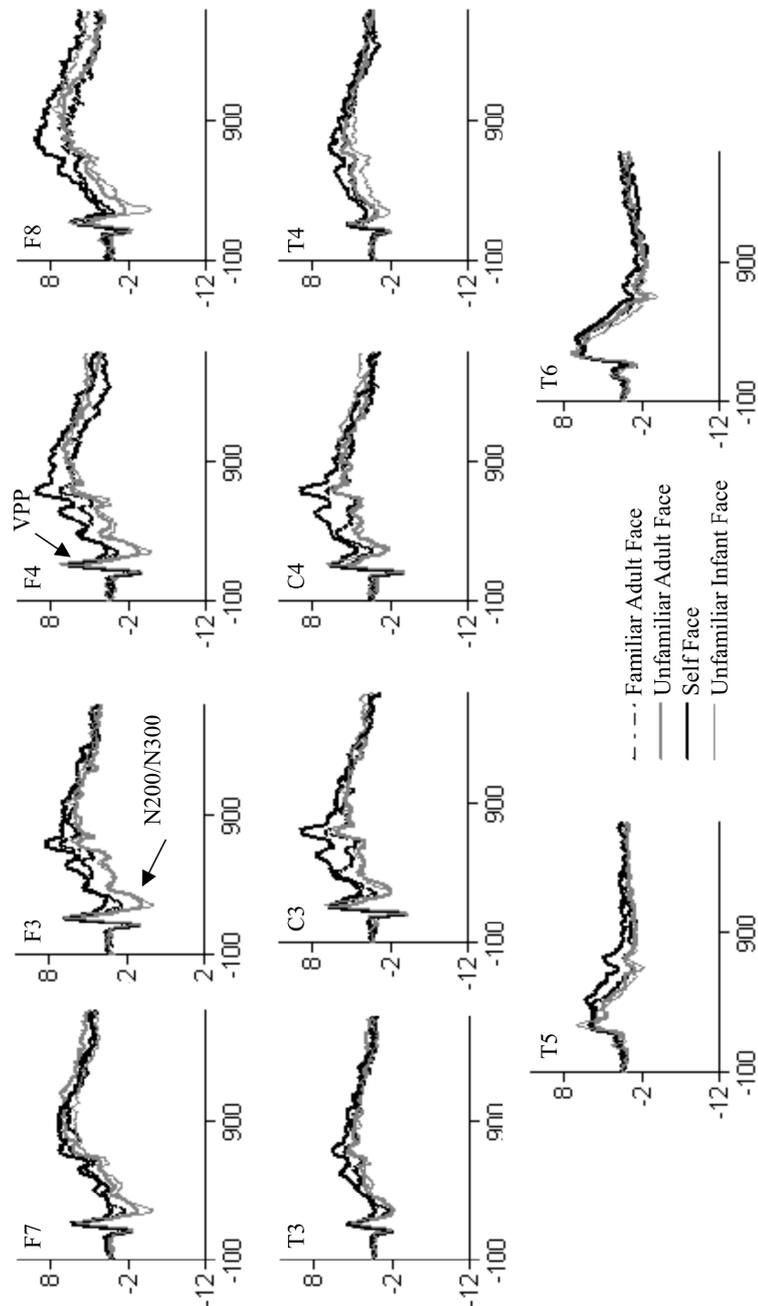
Hemispheric analyses of amplitude differences indicate a main effect of condition ( $F(3, 15)=7.96, p<.01$ ), a main effect of hemisphere ( $F(1, 17)=14.05, p<.01$ ), but no significant interaction. The main effect of condition is due to a greater amplitude response to the self face compared to all other conditions ( $p$ 's $<.05$ ), as well as a greater amplitude response to the familiar adult face compared to all unfamiliar stimuli ( $p$ 's $<.05$ ). The main effect of hemisphere is due to a greater response in the right hemisphere.

**Table 1.** Descriptive Statistics for Midline Amplitude ( $\mu\text{v}$ ) and Latency (ms.) for the VPP, N200/300, and average amplitude for the P300 in adults

		Amplitude M (SD)			Latency M (SD)		
		Fz	Cz	Pz	Fz	Cz	Pz
VPP	Self	7.00 (5.02)	8.33 (5.36)	8.83 (5.02)	167.78 (21.78)	171.44 (13.40)	177.06 (21.03)
	Familiar Adult	6.56 (4.06)	7.44 (4.27)	7.33 (3.11)	166.61 (23.53)	165.28 (22.86)	162.72 (27.83)
	Unfamiliar Adult	5.72 (4.51)	6.06 (4.94)	7.28 (4.40)	164.83 (18.93)	166.72 (19.91)	168.56 (22.45)
	Unfamiliar Infant	7.67 (4.29)	9.17 (4.62)	9.33 (4.14)	176.56 (8.67)	176.78 (10.15)	177.67 (21.24)
N200/300	Self	-2.67 (4.60)	-1.17 (4.40)	2.33 (3.01)	276.78 (47.69)	267.33 (49.70)	268.44 (49.20)
	Familiar Adult	-4.22 (4.53)	-2.5 (5.0)	.56 (3.09)	255.94 (42.43)	261.78 (47.68)	253.72 (47.20)
	Unfamiliar Adult	-5.9 (3.73)	-4.61 (3.85)	-.61 (2.48)	279.56 (42.24)	279.28 (47.23)	271.22 (47.41)
	Unfamiliar Infant	-6.72 (4.21)	-4.17 (4.06)	-.22 (3.72)	277.89 (32.96)	279.00 (32.22)	271.22 (39.75)
P300 (Average Amplitude)	Self	3.67 (3.25)	5.56 (3.91)	7.44 (4.66)			
	Familiar Adult	2.11 (2.78)	2.50 (3.57)	3.89 (2.84)			
	Unfamiliar Adult	-.67 (3.16)	.67 (3.27)	2.22 (3.37)			
	Unfamiliar Infant	-78 (3.35)	1.0 (3.50)	2.22 (2.70)			

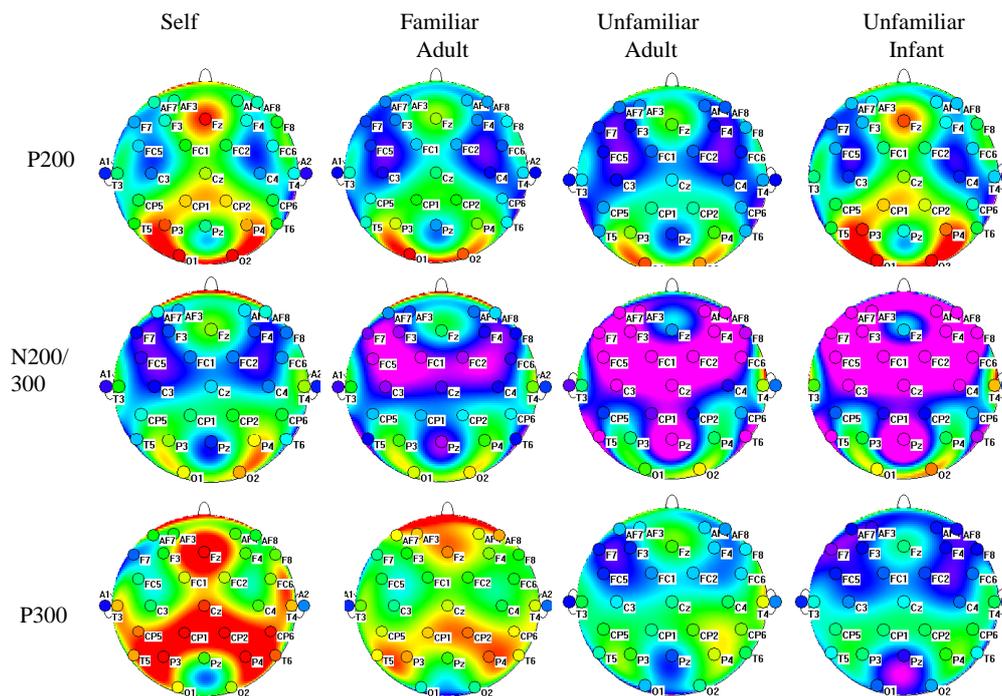
**Table 2.** Means and Standard Deviations of Right, Left, Temporal, and Frontal regions of the scalp in adults. Maximum Amplitude ( $\mu\text{v}$ ) and Latency (ms.) Measures are Reported for the VPP and N200/300, and Average Amplitude measures are reported for the P300.

		Amplitude M (SD)		Latency M (SD)		Amplitude M (SD)		Latency M (SD)	
		Right Hemisphere	Left Hemisphere	Right Hemisphere	Left Hemisphere	Frontal Region	Temporal Region	Frontal Region	Temporal Region
VPP	Self	6.05 (3.40)	5.83 (4.11)	167.20 (19.59)	166.78 (13.71)	6.50 (4.17)	4.13 (1.83)	167.69 (17.86)	157.81 (15.40)
	Familiar Adult	5.25 (3.26)	5.29 (2.93)	167.22 (16.43)	163.78 (14.54)	5.72 (3.45)	3.69 (1.25)	166.01 (16.01)	155.87 (17.08)
	Unfamiliar Adult	4.54 (3.22)	5.07 (3.62)	162.45 (21.26)	159.47 (19.67)	5.21 (3.86)	3.84 (1.5)	162.36 (19.51)	150.70 (13.87)
	Unfamiliar Infant	6.25 (3.00)	5.71 (3.36)	174.02 (9.46)	172.68 (10.68)	6.65 (3.77)	3.74 (1.46)	175.13 (10.45)	154.89 (14.34)
N200/300	Self	-1.50 (3.42)	-2.02 (3.12)	260.81 (39.83)	262.54 (41.46)	-2.25 (4.02)	-.48 (1.71)	266.08 (41.76)	244.69 (37.16)
	Familiar Adult	-2.86 (3.74)	-2.97 (3.28)	252.12 (35.63)	252.47 (33.17)	-3.45 (3.54)	-1.06 (1.90)	258.02 (36.71)	239.14 (27.13)
	Unfamiliar Adult	-3.76 (2.78)	-4.37 (2.53)	262.95 (28.51)	264.55 (31.32)	-4.92 (3.10)	-1.43 (1.65)	268.51 (27.69)	247.47 (36.44)
	Unfamiliar Infant	-4.98 (3.51)	-4.72 (2.82)	270.52 (29.85)	260.94 (24.15)	-6.26 (3.48)	-1.70 (1.91)	266.91 (22.03)	249.07 (25.01)
P300 (Average Amplitude)	Self	4.18 (2.57)	2.89 (2.34)			3.15 (2.64)	3.26 (1.92)		
	Familiar Adult	2.69 (2.34)	1.94 (2.53)			2.15 (2.59)	2.13 (1.32)		
	Unfamiliar Adult	1.09 (2.35)	.07 (2.71)			.08 (2.87)	1.66 (1.45)		
	Unfamiliar Infant	.51 (2.48)	.00 (2.95)			-.38 (2.81)	.94 (1.62)		



**Figure 2.** Event-related potential grand averages of the response to the unfamiliar infant (thin gray), familiar adult (dashed), self (thick black), and familiar adult (thick gray) faces for both the anterior-posterior regions, and left-right hemispheres in adults. Components of interest are marked and labeled with arrows. Each waveform was shifted so that baseline (activity from -100 to 0) was equivalent across different conditions and electrodes.

The analyses of regional amplitude differences across temporal and frontal recording locations indicate a main effect of condition ( $F(3, 15)=6.92, p<.01$ ), no main effect of region, and a significant interaction between condition and region ( $F(3, 15)=4.95, p<.01$ ). Follow-up analyses indicate that the response to the self face is significantly greater than the response to all other faces in the temporal region ( $p$ 's<.05) and that the response to the self face is significantly greater than the unfamiliar adult and unfamiliar infant, but not the familiar adult in the frontal region ( $p$ 's<.05).



**Figure 3.** Topographic head plots using a spherical spline interpolation of the ERP response to the self, familiar adult, unfamiliar adult, and unfamiliar infant for the P200, N200/300, and P300 in adults.

## Discussion

This experiment was designed to answer several questions about the neural correlates of self-referential face processing in adults. Our approach was to have adults passively view images of themselves, a same aged/sex familiar and unfamiliar adult, and an unfamiliar 8-month old infant while ERPs were recorded. We utilized a passive viewing paradigm in this study to probe the basic process of face and self-perception in the absence of other cognitive demands. Additionally,

the use of passive tasks in adults will provide a useful comparison to developmental (see Experiment 2) and clinical populations (DeBoer, Scott, & Nelson, in press). We then explored the influence of these different types of stimuli on several ERP components. Results indicate a general increase in brain processing specificity of faces over time in adults.

Although the N170 is typically used to investigate the electrophysiological correlates of face processing, several investigators have noted that using a mastoid reference eliminates the specificity of the N170 response and may bias analyses of this component (Carmel & Bentin, 2002; Rossion et al., in press). When a mastoid reference is used, it has been suggested that one looks at the vertex positive potential (VPP), occurring at approximately the same latency as the N170 (Rossion et al., in press). The VPP is a positive component, typically occurring between 100-200 ms that is involved in the processing of facial stimuli (Jeffreys, 1989; Jeffreys, Turkamachi & Rockley, 1992; Linkenkaer-Hansen et al., 1998). This component is found in a variety of facial recognition tasks. The latency of this early positive component has been found to vary based on changes in face type, such as the inversion of the face, reversing the contrast polarity of photographic images, and selectively removing particular facial features (Jeffreys, 1989).

In the current study, the adult VPP was significantly greater in amplitude in response to the self, familiar adult and unfamiliar infant compared to the response to the unfamiliar adult in the frontal compared to temporal scalp regions. Similar effects were found at the vertex (Cz), in that the self and unfamiliar infant faces elicited a greater amplitude response than the unfamiliar adult. All of the faces presented in this study, except the unfamiliar adult face, carry some level of emotional or affective significance, and thus, for this component, these faces seem to be processed differently than the unfamiliar adult face (which presumably carries no affective or emotional significance) in the frontal region and at the vertex. This finding is consistent with recent data suggesting that the affective characteristics of faces may play an important role in the structural encoding and perception of faces (Pizzagalli et al., 2002; Eimer & Holmes, 2002). Eimer and Holmes (2002) report a frontally mediated positive response to fearful faces around 120 msec after stimulus onset. Furthermore, early ERP components (~112 ms; ~160 ms) are modulated by affective face information such as liked versus disliked versus neutral faces (Pizzagalli et al., 2002). Combined, the data presented in the current study and findings described above suggest that affect processing and emotional saliency may play an important role in the early processing of faces.

Both the N200/300 and the P300 showed effects indicating sensitivity to familiar and unfamiliar faces. For the N200/300 unfamiliar faces elicited a greater negative response than familiar faces. Differential processing of the self face, compared to all other stimuli, was also apparent in both frontal and temporal regions. Studies of face recognition have reported a negative component occurring approximately 200-400 ms after stimulus onset that is modulated by unknown and known faces (Debruille, Pineda & Renault, 1996; Eimer, 2000; Bentin & Deouell, 2000) and semantically matching versus non-matching facial stimuli (Barrett &

Rugg, 1989). The current study found a negative potential occurring approximately 200 to 300 ms after stimulus onset that differentiated familiar and unfamiliar stimuli. Bentin and Deouell (2000) report a greater negative potential (N400) in frontal and central scalp regions in response to faces of familiar celebrities and politicians compared to unfamiliar faces. The results of the current study support previous research indicating a frontally mediated negative component modulated by the familiarity of a stimulus, but unlike previous reports (Eimer, 2000), the current study found greater negativity to unfamiliar faces compared to familiar faces. However, the latency of the component reported here is much earlier than the component Eimer reports. Additionally, one major difference between the current study and previous reports is that we used “personally” familiar stimuli rather than “publicly” familiar faces such as celebrities or politicians. Although the pattern of results for this component seems to be dependent on familiarity and not personal relevance, future investigations may want to control the influence of different kinds/levels of familiarity on the N200/300 component.

The classic P300 component has been found anywhere between 300 and 900 ms after stimulus onset (Donchin, McCarthy, Kutas, & Ritter, 1983). This component has been found to relate to a variety of psychological circumstances related to information processing (Donchin, et al., 1983; Donchin & Coles, 1988; Ruchkin, Sutton & Teuting, 1975; Sutton & Ruchkin, 1984), including the cognitive evaluation of stimulus significance (Hillyard & Picton, 1987) and the probability and relevance of the stimulus (Squires, Donchin, Herning & McCarthy, 1977). Ninomiya and colleagues (1998) reported greater P3 amplitudes in response to the self-face compared to other non-target faces. The authors concluded that one’s own face may have emotional or personal relevance, which modulates the amplitude of the P3 response. In the current study, the P300 component continues to differentiate familiar from unfamiliar stimuli, but, consistent with Ninomiya et al.’s report, the self-face consistently elicits a greater amplitude response than the familiar adult face. Furthermore, the amplitude response to the familiar adult face, although significantly smaller than the response to the self, is also greater than the amplitude response to the unfamiliar adult and infant faces. Consistent with Keenan et al. (2000; 2001) the current study found a greater amplitude response in the right hemisphere compared to the left hemisphere across all conditions. Therefore, the results of this study do not support preferential processing of the self-face in one hemisphere or the other compared to other familiar or unfamiliar faces. These results suggest that face processing, including self-referential processing may occur preferentially in the right compared to the left hemisphere. Finally, regional comparisons between the frontal and temporal scalp electrodes suggest that in the temporal region, the self face is eliciting a greater amplitude response compared to all other faces. However, the response in the frontal region seems to only differentiate familiar from unfamiliar faces, the response to the self face is not different from the familiar face. This suggests that processing familiar faces, including the self-face, may be mediated by more anterior or frontal structures, and that the temporal region may have an additional role in perceiving

the self face. Ninomiya and colleagues found an overall greater P300 response at more central and anterior scalp locations. In the current study, the overall amplitude of the P300 was greatest at posterior scalp locations, but the processing of familiar faces tended to also have a greater amplitude response in the anterior regions compared to the unfamiliar faces. The differences between the current study and Ninomiya's investigation could be due to several factors. First, this may simply be due to the increased number of recording electrodes used in the current study. Second, the current study did not evoke a prominently peaked P300. This lack of a peaked P300 may be due to the design of the task. Both the passive nature of this task and the equal probability of stimuli may have influenced the amplitude response of the P300 component.

The greater amplitude response to the self-face compared to all other faces, and the familiar adult face compared to unfamiliar faces may correlate with degree of personal-relevance; more personally relevant stimuli evoke greater amplitude responses. The P300 component could also represent the binding of emotional salience with contextual (situational) cues. This binding process may serve to link the emotional salience of the faces (self and/or familiar face) with the visual perception of the stimuli. The findings reported here are also consistent with studies that have investigated the neural correlates of autobiographical information; such as hearing one's own voice or reading one's own family name (Kircher et al., 2000; Fink et al., 1996; Fischler, et al., 1987). For example, Kirscher and colleagues (2000) used fMRI to study the correlates of self versus non-self judgments in a series of experiments. In the first two experiments morphed images of the participant or their partner alternated with an image of an unfamiliar face. In the last experiment, participants made decisions about psychological trait adjectives previously categorized as describing themselves. Results indicate activation of the left fusiform gyrus in response to self-referential processing (regardless of task), and left insula activation in response to the familiar face condition. Together with the results from the current study, this implies that the responses to the self-face may be mediated by a more extended neural circuitry than the responses to familiar and unfamiliar faces.

The results reported here indicate that the ERP response to familiar and unfamiliar faces increases in processing specificity of stimuli across time. The task used in the current study allowed us to investigate the electrophysiological correlates of passive self- and other-recognition. Other studies have used active discrimination tasks (e.g. Keenan et al., 2000; 2001; Ninomiya et al., 1998; Paller et al., 2000) to determine the neural correlates of self-processing. These active tasks may require additional cognitive processing, above and beyond the passive viewing of faces, which could possibly confound the results (Sugiura et al., 2000). The results reported here can, therefore, be viewed as reflecting electrophysiological correlates of more rudimentary aspects of self-recognition. In addition, the task used in this study can be applied without alteration to the study of developmental, geriatric, and clinical populations. It must be acknowledged that the use of a passive-viewing paradigm brings with it the risk that subjects may not

remain on task. To ensure that all participants paid attention to the stimuli we monitored them by live video. Additionally, the presence of clearly defined ERP components that discriminate among the various stimuli would argue against this concern. Moreover, as stated at the outset, if our ultimate goal is to examine the *development* of facial self recognition, then in order to test very young children it may be necessary to utilize a passive task, as children under approximately 5-6 years have a difficult time performing tasks in which button presses and vigilant attention are simultaneously required (for discussion, see Nelson & Nugent, 1990, in which 4 year old children were tested with a passive paradigm).

The second experiment in this study was designed to follow-up the above adult ERP study to see whether four-year olds children have the same processing specificity as was reported in the adult population. We chose to study four-year olds, because we expected that they would show behavioral evidence of self-recognition. Using the classic rouge test, past research indicates that when a dab of rouge is placed on a child's face, children between 15 and 24 months of age can verbally or physically indicate that they recognize that something is on their face (Lewis & Brooks-Gunn, 1979; Lewis, 1991). Based on these findings, four-year-old children should be well beyond the age when they first demonstrated this skill. Thus, the current investigation provides an electrophysiological comparison for future investigations with younger and possibly older children. Based on the above findings, as well as past research using electrophysiological techniques with infants, it is hypothesized that viewing both the self and the mother's face will elicit a differential response than the unfamiliar faces. Additionally, it is hypothesized that similar to the adult findings, the topographic distribution of the neural response will differ across conditions, in that the self and mother's faces be more frontally distributed compared to the unfamiliar faces. Finally, we hypothesize that similar to adults, four-year olds should exhibit differential processing to the self face compared to all other stimuli.

## EXPERIMENT 2

### Methods

#### *Participants*

Participants were recruited from a volunteer database consisting of parents who had expressed an interest in child developmental research. All participants were typically developing four-year-old children (n=19), with no histories of neurological or uncorrected visual abnormalities. The group of four-year-olds consisted of 10 girls and 9 boys (Mean age = 4 years 14 days (SD= 7.1 days)). An additional 11 children were tested, but their data were excluded because of eye and/or body movements that resulted in artifacts in the data (n=5), unwillingness to complete the study (n=5), and equipment failure (n=1). Children were given a toy in exchange for their participation.

### *Stimuli*

The stimuli were color images of four different faces. Stimuli were presented for 160 trials consisting of: 40 presentations of the mothers' face (familiar), 40 presentations of the child's own face (presumed to be familiar), 40 presentations of a unfamiliar female face, and 40 presentations of an unfamiliar (same sexed) four-year-olds' face. The methods for taking the pictures were the same as in Experiment 1.

### *Electrophysiological procedure*

The methods for the recording preparation (including electrode cap placement, mastoid and eye electrode placement, etc.) were the same as in Experiment 1 unless otherwise noted. ERP's were recorded from 13 scalp sites (Cz, Pz, Fz, C3, C4, T3, T4, T5, T6, F3, F4, F7, F8) using the 10/20 system (Jasper, 1958). Impedances were accepted if they were less than 10 kOhms. The participants were seated in a small chair while they passively viewed the stimuli. Instructions were simply to watch the images as they appeared. All children were monitored by live video to ensure they remained on task.

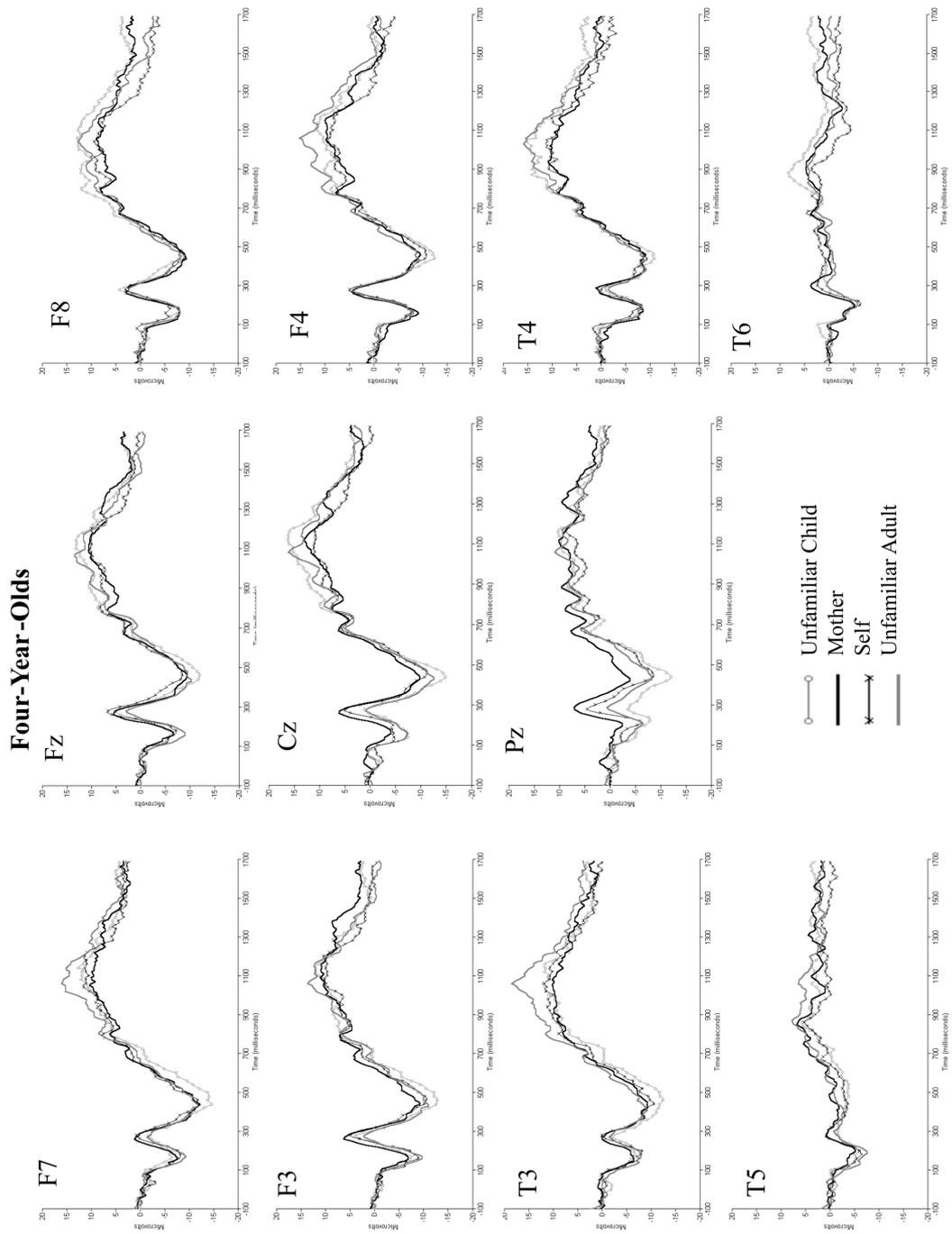
All scalp electrodes were referenced to the scalp electrode Cz and then re-referenced offline to averaged mastoids. EEG data were acquired with Grass Neuro Acquisition System® with Model 12A5 amplifiers, with gains set to 20,000. The gain for EOG was set at 5, 000. A bandpass filter was set to .1 and 30 Hz and a 60 Hz notch filter was in place. The sampling rate was 100 Hz.

### *Behavioral procedure*

Following the ERP task, each child completed a behavioral test of self-recognition. This included putting a dab of rouge on each participant's nose and placing the child in front of a mirror (Lewis & Brooks-Gunn, 1979). The dab of rouge was covertly placed on the nose while the experimenter was removing the electrode cap and cleaning the child's face. A mirror was then placed in front of the child and asked if "everything was all cleaned up?" Behavioral self-recognition was inferred if, within three minutes of being placed in front of the mirror, the child indicated by touch or speech that there was something on his or her nose.

### *ERP Data editing, averaging, and analysis*

ERP data editing, averaging, and analysis for Experiment 2 was the same as in Experiment 1 unless otherwise noted. Individual trials were excluded from the analysis if they included more than two electrode leads with excessive artifacts arising from body or eye movements. Trials were rejected if responses exceeded +/- 250 microvolts, if electrooculogram (EOG) showed changes of greater than 100 microvolts within a 50ms window, or if artifacts were detected in the any of the reference channels (A1, A2, or Cz). Individual artifact-free trials were combined to form average waveforms for each subject and each condition (self, unfamiliar adult, unfamiliar child and mother). Grand average waveforms were computed for each of the conditions. Participants with fewer than 10 artifact free



**Figure 4.** Event-related potential grand averages of the response to the self, unfamiliar adult, and unfamiliar infant at the midline (Fz, Cz, Pz), frontal (F3, F4, F7, F8), and temporal (T3, T4, T5, T6) leads in four-year-olds. Each waveform was shifted so that baseline (activity from -100 to 0) was equivalent across different conditions and electrodes.

trials per channel per condition were not included in the grand average. These grand averages were then used to identify the time intervals that reflected components of interest.

Three major time intervals or epochs were identified based on visual inspection of the topographical maps and morphological characteristics of the grand average and individual waveforms (See Figure 4). The first waveform of interest was a positive component, occurring between 230-320 ms, referred to from now on as the P2. In this epoch maximum amplitude and the corresponding latency were analyzed. The second epoch, referred to as the N2, represented a negative component occurring between 320-600 ms. In this component minimum amplitude and latency were analyzed. The final epoch represented the positive slow wave (PSW), occurring between 600-1230 ms. In this epoch, the area under the wave form was used in the analysis. Statistical analyses and follow-up comparisons were conducted in the same manner as in Experiment 1.

## Results

P2. Amplitude analyses at the midline leads revealed a main effect of condition ( $F(3, 16)=6.06, p<.01$ ), no main effect of lead, and a significant interaction between condition and lead ( $F(6, 13)=3.56, p<.05$ ). Follow-up comparisons revealed that the amplitude response to the mother's face was significantly greater than the amplitude response to the unfamiliar adult and unfamiliar four-year old, but was not significantly different from the self-face at Cz (See Figure 5). There were no latency differences.

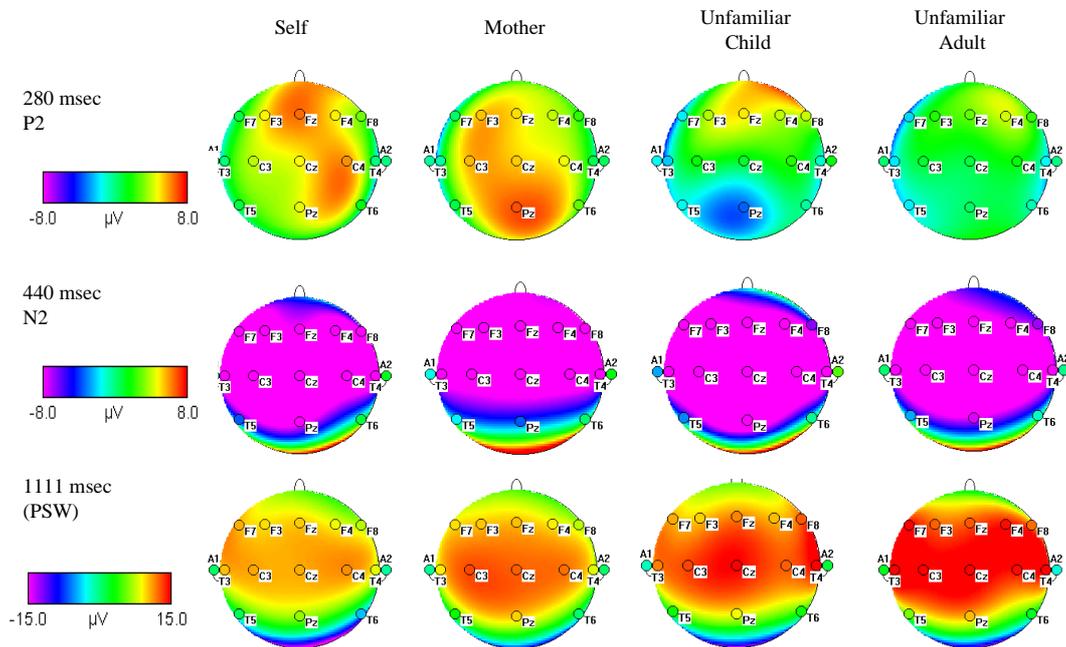
Regional amplitude analyses comparing the frontal and temporal recording sites revealed no main effect of condition, a main effect of region ( $F(1, 18)=13.37, p<.01$ ), and no significant interaction. The main effect of region was due to a greater amplitude response in the frontal compared to the temporal scalp regions. Latency analyses also indicate a earlier latency to peak response in the frontal compared to the temporal scalp regions ( $F(1, 18)=4.612, p<.05$ ). There was not a main effect of condition, and no interaction between condition and region.

There were no significant differences between hemispheres.

N2. Minimum amplitude analyses at the midline leads revealed a main effect of lead ( $F(2, 17)=15.02, p<.001$ ), no main effect of condition and no significant interaction. The main effect of lead was primarily due to greater negative amplitude at Cz compared to Pz and Fz. Latency analyses indicate no main effects of condition or lead and no significant interaction.

Regional amplitude analyses comparing the frontal and temporal recording sites revealed no main effect of condition, a main effect of region ( $F(1, 18)=19.60, p<.01$ ), and no significant interaction. The main effect of region was due to a greater amplitude response in the frontal compared to the temporal scalp regions. There were no latency differences.

There were no significant differences between hemispheres.



**Figure 5.** Topographic head plots using a spherical spline interpolation of the ERP response to the self, unfamiliar adult, and unfamiliar infant at the P2, N2, and PSW in four-year-olds.

**Table 3.** Descriptive Statistics for Midline Peak Amplitude ( $\mu\text{V}$ ) and Latency (msec.) at the P200, and N200 in Children. Descriptive Statistics of the PSW is the Average Area Under the Waveform and Above Baseline.

		Amplitude M (SD)			Latency M (SD)		
		Fz	Cz	Pz	Fz	Cz	Pz
P2	Self	6.2 (11.0)	6.5 (9.8)	8.3 (7.3)	279.5 (21.7)	272.6 (15.9)	277.4 (18.2)
	Mother	9.8 (10.2)	8.7 (8.5)	7.3 (8.1)	280.0 (22.9)	269.5 (25.0)	268.4 (24.1)
	Child	-8 (11.0)	3.3 (8.9)	6.9 (5.6)	272.1 (28.2)	273.2 (20.3)	271.6 (18.6)
	Adult	2.2 (8.5)	2.3 (8.2)	4.5 (7.6)	277.4 (24.9)	276.8 (20.3)	277.9 (18.1)
N2	Self	-13.4 (11.6)	-15.2 (10.9)	-11.8 (8.3)	475.8 (61.9)	475.3 (64.0)	453.1 (72.3)
	Mother	-8.7 (7.1)	-13.6 (8.7)	-12.5 (11.8)	442.6 (77.5)	434.2 (68.4)	438.4 (67.4)
	Child	-16.5 (9.6)	-18.1 (8.5)	-15.4 (9.3)	436.8 (65.6)	431.1 (72.1)	462.6 (61.0)
	Adult	-13.2 (8.0)	-16.9 (9.3)	-14.2 (7.8)	424.2 (67.8)	432.2 (65.5)	444.7 (59.5)
PSW		Area Fz	Area Cz	Area Pz			
	Self	3380.4 (6041.1)	4837.0 (6838.8)	4412.7 (5798.8)			
	Mother	4815.1 (6072.3)	4974.4 (6165.0)	3966.3 (6813.3)			
	Child	4026.6 (4926.2)	6674.4 (5911.0)	5075.1 (5657.3)			
Adult	4134.5 (3824.9)	5666.9 (5601.2)	4595.9 (4842.3)				

**Table 4.** Descriptive Statistics for Peak Average Temporal and Frontal Regional Amplitude ( $\mu\text{v}$ ) and Latency (msec.) in children. Descriptive Statistics of the PSW is the Average Area Under the Waveform and Above Baseline.

		Amplitude M (SD)		Latency M (SD)	
		Temporal Region	Frontal Region	Temporal Region	Frontal Region
P2	Self	2.8 (5.5)	5.3 (7.0)	279.3 (17.7)	277.6 (16.7)
	Mother	3.6 (5.6)	5.9 (6.5)	275.9 (15.8)	270.7 (18.0)
	Child	.95 (5.1)	4.6 (6.0)	281.4 (12.5)	272.2 (18.1)
	Adult	1.1 (5.0)	3.9 (6.8)	280.3 (12.8)	278.8 (16.0)
N2	Self	-10.1 (5.0)	-14.1 (8.9)	445.1 (62.5)	448.9 (45.7)
	Mother	-9.75 (5.0)	-13.3 (9.5)	432.8 (47.5)	444.5 (40.8)
	Child	-11.4 (6.2)	-15.4 (8.6)	440.1 (54.5)	452.9 (34.7)
	Adult	-9.5 (5.7)	-13.4 (7.1)	428.3 (44.0)	435.4 (47.5)
PSW	Area Temporal		Area Frontal		
	Self	2722.6 (4712.9)	4042.5 (6487.4)		
	Mother	3082.5 (5394.3)	3983.6 (5823.6)		
	Child	3570.7 (4687.9)	4673.3 (5344.7)		
Adult	4290.0 (2989.0)	5146.8 (4510.4)			

**PSW.** For the PSW, the area under the slow wave was used for all analyses. Midline area analyses revealed a main effect of lead ( $F(2, 17)=5.62$ ,  $p<.01$ ), but no main effect of condition and no interactions. The descriptive statistics revealed that the area under the curve increased from Pz, to Fz, to Cz. Pz was marginally different from Cz ( $p=.058$ ) and Fz was significantly different from Cz ( $p<.01$ ).

Regional area analyses comparing frontal and temporal activation revealed a main effect of region ( $F(1, 18)=4.42$ ,  $p<.05$ ), in the absence of a main effect of condition and any interaction. The main effect of region was due to a greater response in the frontal compared to the temporal region.

There were no significant differences between hemispheres.

## Discussion and general discussion

Based on the electrophysiological data collected in the above experiment, it appears that four-year-old children are not differentiating their own face from their mother's face, but do differentiate their own face and their mothers face from the unfamiliar adult and the unfamiliar four-year old for the P2 component. Additionally, for the N2, P2, and PSW, the frontal regions elicited a greater response to all stimuli than the temporal regions.

Although there has been extensive study of adult ERP components invoked by a variety of cognitive tasks (Regan, 1989) and a growing infancy literature (see Nelson & Monk, 2001 for review), there is a paucity of work with young children. This makes it difficult to interpret equivalent components across development and into adulthood. For the P2, the amplitude response to the familiar faces was significantly greater than to the unfamiliar faces, this suggests that the ERP

waveform that is elicited when four-year-old children view pictures of the mother and self-face is different from that of an unfamiliar adult female face and unfamiliar four-year-old child's face. It is important to note that these findings do not suggest that four-year-olds are not able to differentiate themselves from their mothers. Behaviorally, we know they are capable of this type of differentiation. The similar electrophysiological response to the mother and the self can be interpreted relative to other demands placed upon the child during task performance. For example, perhaps these two familiar faces were responded to similarly because they were presented in the context of the two unfamiliar faces. However, these results do support our hypothesis that the two emotionally salient and personally relevant faces are treated differently than non-emotionally salient faces. It is possible that this emotional information is influencing how the brain processes the faces. The results of this experiment are intriguing because past behavioral research has implicated the development of self-recognition and the development of mother recognition as important for very different developmental processes. For example, in light of the research on autobiographical memory and perspective taking, one might expect to see a differential response between the mother and the self-face. The results of the current study suggest that the mother and self faces are treated similarly; therefore these data have implications spanning the fields of cognitive and social development, which often claim that the development of self-recognition is a special process that is necessary for the onset of many adult-like cognitive and social processes.

These data also have implications for the role of experience versus maturation in the development of face recognition. Many researchers have hypothesized that the ability to recognize ones own face develops independently of perceptual experience (Gopnik & Meltzoff, 1994; Howe & Courage, 1997). If this were the case we would expect to see a differential ERP response to the self versus the mothers face. For example, if the response to the self face develops independent of the amount of experience one has viewing their own face, given controlled mirror experience (similar to the amount of experience ones has viewing their mothers face) we would expect to see differences in the electrophysiological response, especially in young age groups. In future studies, it may be informative to examine the role of perceptual experience in the development of self versus other recognition, including other familiar faces. It will also be particularly informative to extend this study to younger infants and older children to determine whether the processing of these faces changes over the course of development.

The results of the above two experiments indicate that electrophysiological correlates of familiar and unfamiliar, as well as self face processing are fundamentally different in adults and four-year old children. The adult ERP waveform appears to increase in specificity over time, in that for the VPP, faces that can be thought of as having emotional significance (self, friend and infant face) are differentiated from the unfamiliar faces. As mentioned above, these results support the hypothesis that emotionally salient stimuli may be processed very early in the ERP waveform. The later negative component (N200/300)

appears to primarily process the familiarity of a stimulus, evidenced by a greater amplitude response to unfamiliar compared to familiar faces. Finally the P300 appears to continue to carry the information about familiarity but the response to the self-face is now also greater than the response to the familiar adult face. Despite the lack of full coverage of the scalp, it appears that there is regional cortical specificity, as evidenced by more frontal and right hemisphere activation.

Unlike the adult population, four-year-olds did not appear to process the self-face differently from the mother, but did process familiarity as inferred by changes in the P2 component. Consistent with a previous report (Passarotti et al., 2003) we found that children exhibited a more diffuse pattern of activation compared to adults in that they did not show any hemispheric differences. These results suggest that four-year-old children are processing familiar and unfamiliar faces somewhat differently than adults as evidenced by both processing specificity differences (the self face does not appear to elicit a differential response compared to the mothers faces), and cortical specificity differences.

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