

Brain dynamics in young infants' recognition of faces: EEG oscillatory activity in response to mother and stranger

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The brain electrical responses of 3-month-old infants were compared between images of familiar and unfamiliar faces. Infants were shown images of their mothers and of appearance-matched female strangers for 500 ms per trial while their electroencephalography was recorded. Electroencephalographic signals were segmented from stimulus onset through 1200 ms, and segments were analyzed in the time–frequency domain with a continuous wavelet transform. Differentiated responses were apparent in three time windows: 370–480, 610–690, and 830–960 ms. Across response windows, event-related synchronization or desynchronization was observed in beta or gamma frequency bands at the left frontal, midline central, bilateral temporal, and right parietal sites. In conclusion, these findings provide the first evidence of organized brain activity underlying familiar face recognition

in very young infants and are discussed in relation to comparable patterns that have been observed in adults. *NeuroReport* 24:359–363 © 2013 Wolters Kluwer Health | Lippincott Williams & Wilkins.

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Introduction

Identifying caregivers is vital for young organisms, and human infants depend largely on visual recognition to do this. Under typical conditions, the majority of infants' facial experience is with their primary caregiver, and even newborn infants appear capable of storing that experience for use in subsequent recognition of faces [1]. As progress accumulates in understanding brain bases of face processing [2], recognition memory [3], and the maturational differences between infant and adult brains [4], new questions are emerging about the underlying processes infants draw on to recognize faces.

Both event-related potentials (ERPs) and near infrared spectroscopy (NIRS) have been used to study neural bases of face recognition in infants. Infants' ERP responses differ between images of mothers and female strangers [5], with smaller deflections at the bilateral temporal sites in response to mothers' faces both in a midlatency (400–800 ms) positive response and in a long-latency (1050–1450 ms) negative response. Using NIRS, increased activation was observed at the right temporal cortex in 6- to 9-month-olds in response to mothers' faces compared with baseline, but not strangers' faces [6].

Although ERP and NIRS studies have provided key insights into face recognition in infancy, many gaps remain because much of the work on adults has examined processing by imaging and oscillatory activity. PET

imaging, for example, revealed left prefrontal activation during adults' encoding of strangers' faces, and subsequently revealed right lateralization during recognition of those encoded faces [7]. Also, alpha rhythms desynchronize when adults recognize previously seen faces [8]. One challenge with addressing such questions developmentally is that PET and fMRI procedures pose many difficulties in research with infants. In contrast, electroencephalographic (EEG) oscillations are readily measured at any age and, furthermore, can map more closely to imaging results than ERP results do [9].

Present concerns

Despite its advantages, oscillatory activity has not been utilized to understand face recognition in infancy. It is also the case that very little work on the electrophysiological correlates of recognition memory has been conducted before 6 months of age. Pascalis *et al.* [10] studied 3-month-olds using a highly structured laboratory procedure. Following familiarization to one face and a 2-min delay, they observed ERP positive slow wave differences between the familiar face and a novel face. It is not clear, though, how their results relate to long-term memories of faces infants form by seeing them everyday.

Research conducted to date leaves open several important questions. First, are neural signatures of long-term memory for faces dependent on many months of experience and brain maturation? If they are not so dependent, how are brain responses organized to support face recognition in early infancy? Also, can the examination of EEG rhythms enable a clearer understanding of

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young infants' brains through linkage to the rapidly expanding literature on neural oscillations and cognition in adult brains? In the present work, we examine the differentiation of brain electrical responses to images of mothers' faces (familiar) and female strangers' faces (unfamiliar) in 3-month-old infants, and we do so focusing on temporal analyses of the frequencies investigated previously in adults.

Methods

This research was approved by the Institutional Review Board of the Division of Intramural Research, Eunice Kennedy Shriver National Institutes of Child Health and Human Development.

Participants

Twelve 3-month-olds (mean age = 95.42 days, SD = 7.39; nine females) participated in the study. Participants were predominantly of European descent and median socio-economic status. An additional 16 infants were tested, but their data were not included because of the experimenter error or equipment failure [4] or failure to meet the trial criterion for inclusion [11].

Stimuli

Two stimulus conditions were used: familiar faces and unfamiliar faces. Photographs were taken in the laboratory after obtaining consent. To obtain familiar images, each mother was seated in front of a gray background, and a gray cloth was draped around her neck and torso to eliminate the view of clothing. Mothers were asked to remove their jewelry (e.g. earrings) but not their glasses. To obtain unfamiliar images, each mother image was paired with a female stranger image from an archive. Care was taken to match the mother and stranger images on several dimensions including skin tone, hair and eye color, and other distinguishing features, such as the presence or absence of glasses. The images measured 15.2×21.6 cm ($13.69 \times 19.30^\circ$). Light intensity, measured on a scale from 0 to 1, did not differ between familiar (mean = 0.39, SD = 0.04) and unfamiliar (mean = 0.38, SD = 0.01) faces [$t(22) = 0.30$, NS]. To compare spatial frequency content, images were analyzed with a Fourier transform that recovered 187 frequency bins ranging from 0.1 to 9.7 cycles/degree. Spectral power was log-transformed and averaged over the lowest and highest thirds of the frequencies for each image. Power at low frequencies did not differ between familiar (mean = 0.89, SD = 0.29) and unfamiliar (mean = 8.99, SD = 0.28) faces [$t(22) = 0.82$, NS]. Likewise, power at high frequencies did not differ between familiar (mean = 3.80, SD = 0.76) and unfamiliar (mean = 3.91, SD = 0.79) faces [$t(22) = 0.36$, NS].

Procedure

Infants were seated on a parents' lap 65 cm from a computer monitor. Parents wore occluding glasses and were instructed not to talk and to refrain from directing

their child. On 72 randomly presented trials, infants viewed photographs of familiar and unfamiliar faces. On each trial, a 100 ms baseline period preceded the stimulus. The stimulus appeared for 500 ms and was followed by an intertrial interval, during which the screen was uniform blue. The minimum intertrial interval ranged from 1800 to 2200 ms; however, it could be longer because each trial was initiated once it was determined that the infant was looking at the screen.

Recording and segmenting of electroencephalography

EEG was recorded with the Electrical Geodesics Incorporated (Eugene, Oregon, USA) 128-channel EEG recording system (Net Station 4.1.1). The EEG signal was referenced to the vertex, recorded with 20 K amplification, at a sampling rate 250 Hz, with band-pass filters set at 0.1–100 Hz, and with 40 Ω impedance.

Preprocessing of the data was conducted using Net Station 4.3 Waveform Tools. Recordings were digitally filtered with a 0.4-Hz high-pass filter, a 40-Hz low-pass filter, and segmented into familiar and unfamiliar face trials. The data were referenced to the average of all channels, and a baseline correction was applied to the 100 ms prestimulus recording interval. Recordings were segmented to 1200 ms following the onset of the stimulus. Segments were inspected for artifacts, defined as signal amplitude exceeding 200 μ V or a differential amplitude exceeding 100 μ V. A trial was excluded if more than 20% of the channels exceeded these thresholds. Participants needed to have at least 10 artifact-free trials per stimulus condition to be included.

Data analysis

Channels selected for analysis correspond to a subset International 10–10 system (see Table 1). The spectral decomposition was done with a Morlet wavelet transform. The analysis was conducted using EEGLAB [11] running in Matlab v7.13. A 100-ms window, and wavelet cycles varying linearly from 1 to 12 were used to recover frequencies from 2.5 to 60 Hz over 47 equal-interval bins. Event-related spectral perturbation was calculated by subtracting the spectral power of the prestimulus baseline from the poststimulus response. The parameters used for decomposition resulted in truncation of the response measure at both the beginning and end of each epoch, with the resulting time window ranging from 123 to 977 ms, following stimulus onset.

To identify responses, the time–frequency maps were averaged over trials, participants, and stimulus conditions for each recording site, and grand average maps were examined. Responses were apparent in three time windows: 370–480, 610–690, and 830–960 ms. Responses were predominant in the lower range of the beta frequency band (13–21 Hz) and in the lower range of the gamma band (30–47 Hz). For each recording site and stimulus condition,

event-related spectral perturbation values were averaged over time windows and trials within the predominant frequency ranges, and the resulting mean values were compared between stimulus conditions by site.

Results

Event-related spectral perturbation

Figure 1 displays topographic maps of each differentiated response. Figure 2 (Supplementary digital content 1, <http://links.lww.com/WNR/A236>) displays time–frequency maps of the same responses. At 370–480 ms, lower gamma responses at site Fp1 were more desynchronized in response to unfamiliar faces (mean = -0.31 , SD = 0.79) than familiar ones (mean = 0.23 , SD = 0.55) [$F(1,11) = 5.34$, $P = 0.041$, $\eta_p^2 = 0.33$]. In the same time window, lower beta responses at T8 were more desynchronized in response to unfamiliar (mean = -1.19 , SD = 1.39) than familiar faces (mean = 0.11 , SD = 1.24) [$F(1,11) = 5.80$, $P = 0.035$, $\eta_p^2 = 0.35$].

At 610–690 ms, lower gamma responses at P7 were more desynchronized in response to familiar (mean = -1.13 , SD = 1.23) than unfamiliar faces (mean = 0.02 , SD = 1.03) [$F(1,11) = 6.15$, $P = 0.031$, $\eta_p^2 = 0.36$]. In the same time window, lower gamma responses at P8 were more synchronized in response to familiar faces (mean = 0.73 , SD = 1.78) than unfamiliar ones (mean = -0.38 , SD = 1.70) [$F(1,11) = 7.50$, $P = 0.019$, $\eta_p^2 = 0.41$].

Table 1 Recording sites analyzed (corresponding EGI Geodesic Sensor Net channels)

	Fp1 (22)	Fz (11)	Fp2 (14)	
F7 (34)	F3 (25)	Cz (129)	F4 (124)	F8 (122)
T7 (46)	C3 (37)	Cz (129)	C4 (105)	T8 (109)
P7 (59)	P3 (53)	Pz (62)	P4 (87)	P8 (92)
	O1 (72)		O2 (77)	

Within the last time window, 830–960 ms, three additional differences emerged. Lower beta responses at P8 were more desynchronized in response to familiar (mean = -3.43 , SD = 4.07) than unfamiliar faces (mean = -0.89 , SD = 1.54) [$F(1,11) = 8.56$, $P = 0.014$, $\eta_p^2 = 0.44$]. Lower gamma responses at P8 were more desynchronized in response to familiar (mean = -2.40 , SD = 2.64) than unfamiliar faces (mean = -0.77 , SD = 1.66) [$F(1,11) = 9.70$, $P = 0.009$, $\eta_p^2 = 0.40$]. Lower gamma responses at Cz were more desynchronized in response to unfamiliar (mean = -0.62 , SD = 0.69) than familiar faces (mean = -0.08 , SD = 0.80) [$F(1,11) = 10.39$, $P = 0.008$, $\eta_p^2 = 0.49$]. No other comparisons were significant.

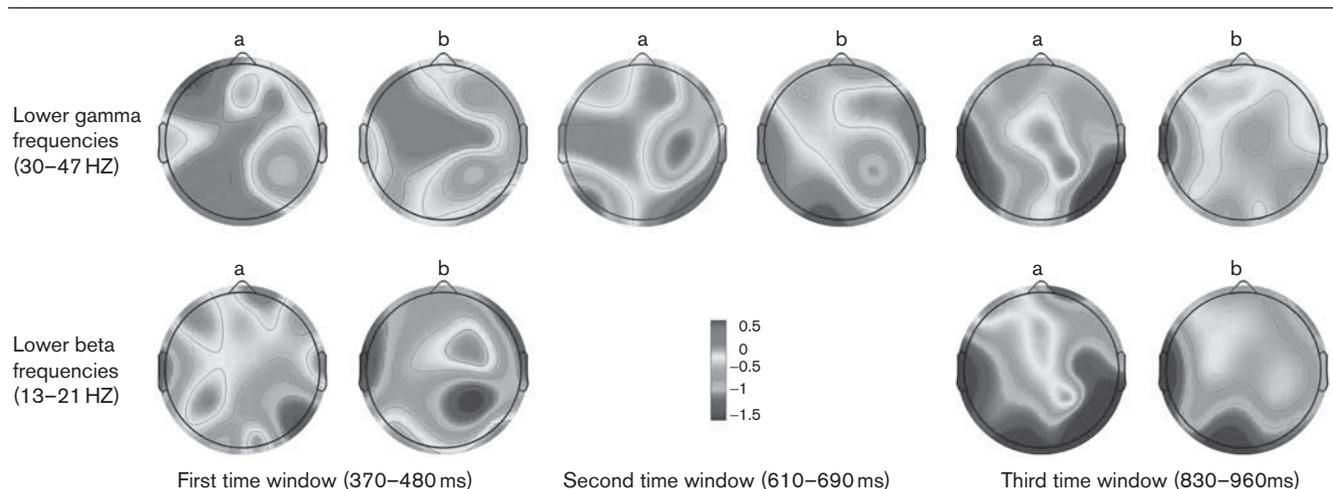
Phase locking

The consistency of rhythmic phase relations over trials is a correlate of elementary visual processes and visual attention [12,13]. To determine the relative phase locking of responses to the stimulus events, a phase-locking factor (PLF) [12] was calculated for the time–frequency window of each response, collapsing over stimulus conditions. PLF values can range from 0 (phase independent) to 1 (strictly phase-locked). PLF values were averaged within response windows for each infant and then tested for difference from 0. All response windows differed from 0, ranging from the lowest PLF at Cz (mean = 0.20 , SD = 0.05) [$t(11) = 14.70$, $P < 0.001$, $d = 4.0$] to the largest PLF at P8 (mean = 0.24 , SD = 0.05) [$t(11) = 15.49$, $P < 0.001$, $d = 4.8$]. These results indicate that responses were at least moderately phase-locked to the stimulus events.

Discussion

The present findings reveal differentiated brain activity in response to images of familiar and unfamiliar faces in infants at 3 months of age. These results provide

Fig. 1



Topographic plots of each of the differentiated response windows (a: familiar, b: unfamiliar). The plots represent event-related spectral perturbation values averaged over the time–frequency windows.

evidence that young infants' brains discriminate and differentially process the images of familiar and unfamiliar faces. Because there was no familiarization procedure in the task used [10], and no low-level visual differences between stimulus conditions (e.g. size, brightness, spatial frequency content), this pattern of results reflects familiar face recognition on the basis of as little as 3 months of accumulated experience.

Across all of the responses that differed between stimulus conditions, all but one differed by the amount of desynchronization elicited by the stimuli. Beta frequencies were more desynchronized in response to unfamiliar than familiar faces at P8 and T8. Gamma frequencies differed in the same way at Fp1, Cz, P7, and P8. Pfurtscheller and Lopes da Silva [14] reviewed a large literature on event-related oscillations and concluded that desynchronization of EEG can result from an increase in the excitability of cortical cells. Therefore, event-related desynchronization (ERD) can be interpreted as cortical activation associated with processing a task event. They reasoned that larger ERDs result from recruitment of larger neural networks in processing.

A number of researchers have reported adult data that are consistent with the position advanced by Pfurtscheller and Lopes da Silva [14]. Hanslmayr *et al.* [15] reviewed research on memory and concluded that successful retrieval of long-term memories in adults is often accompanied by alpha and beta-band ERD. They argued on mathematical grounds that asynchronous rhythms, by virtue of their greater complexity and lesser redundancy, may be capable of transmitting more information than comparatively simpler synchronous rhythms. With respect to word processing, Krause [16] reviewed numerous studies showing that recognition elicits desynchronization of alpha rhythms, and Lutzenberger [17] reported that gamma synchronization is also reduced by recognition. Relatedly, rhythmic activity in the upper alpha band is desynchronized by focused attention and by mental effort [3]. In relation to the present work, it is well known that infants selectively attend to faces [18], and effortfully encode unfamiliar stimuli [19]. Thus, the ERD observed here may be associated with several different processes including attention and encoding as well as recognition.

Other stimuli and task contexts elicit an increase rather than decrease in rhythmic synchronization under conditions that would seem to increase activation. For example, when adults were presented with images of familiar everyday objects such as light bulbs and flowers, and novel items matched on low-level visual features, synchronization in the gamma frequency band increased more in response to familiar than unfamiliar objects [20]. Likewise, on the basis of a review of relevant MEG literature, gamma band event-related synchronization appears to reflect selective attention and top-down cognitive control processes in adults [21]. Consistent

with this literature, we observed a greater midlatency increase in gamma synchronization at the right parietal sensor when viewing familiar relative to unfamiliar faces.

With respect to the scalp topography of the responses observed, several findings are worth mentioning. The responses that were maximal to familiar faces all occurred at parietal sites (P7, P8), whereas those that were maximal to unfamiliar faces occurred more anteriorly (Fp1, Cz, T8). The mid-latency parietal responses were lateralized, with familiar faces eliciting ERD on the left and event-related synchronization on the right. The responses in the beta band both occurred parietotemporally on the right side (P8, T8), whereas those in the gamma band were more widely distributed. It is premature to interpret these patterns as localization of function; they will be informative in looking for consistencies in future research.

The pattern of responses observed here corresponds to others observed in previous work with adults. A large number of adult studies have revealed right lateralization in face processing, particularly with respect to the N170 ERP [2,22]. Consistent with this, four of the six lateralized responses reported for infants occurred on the right, and the summed area of differentiated response windows was 71% larger for right-hemisphere than for left-hemisphere responses. As noted, beta-band responses, which are often associated with face recognition in the adult literature, were wholly lateralized to the right side.

Also, we observed greater ERD at the sensor nearest infants' left prefrontal cortex (Fp1) during their responses to unfamiliar faces. Given their lack of familiarity with those faces at the beginning of the task, infants were presumably encoding the unfamiliar faces over the course of the task. As noted previously, Haxby *et al.* [7] observed left prefrontal activation during adults' encoding of strangers' faces during PET scans, then observed right lateralization subsequently during recognition of those encoded faces.

Finally, we observed differentiated responses at the vertex (Cz). Vertex responses have been highlighted in adult ERP research, with the vertex positive potential being one of the responses thought likely to be face selective [23]. Together, the similarities between the results reported here and those of previous research on adults raise the possibility that rudiments of mature face processing networks may be functional within the first months of life.

With respect to the specific frequency ranges within which face effects were observed, there is partial consistency between the adult studies cited earlier [8,24] and the infant findings we report here. Effects were observed in beta frequencies in both infants and adults. However, no effects were observed in infants' alpha frequencies, whereas most adult studies report alpha

effects. Future work may benefit from a direct comparison of alpha and beta responses in infants and children older than 3 months to examine whether oscillators of different frequencies may develop at different rates.

Another difference between adults and the infants examined here is the predominance of gamma responses in the present work, whereas gamma has received less attention in adult studies of face recognition. In one study, gamma synchrony was greater in response to human faces than to ape faces, watch faces, human hands, and buildings, suggesting that gamma activity is actually face selective [25]. The predominance of gamma responses in the present work suggests this may be true from the earliest months of life.

Conclusion

To conclude by underscoring the main findings, the rhythmic synchrony of 3-month-olds' brain responses differentiates familiar from unfamiliar faces over multiple time windows, frequency ranges, and recording sites. These findings are considered to indicate infants' accurate visual recognition of their mothers' faces from at least 3 months onward.

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Conflicts of interest

There are no conflicts of interest.

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