Face processing during infancy: an electrophysiological approach
FINAL PROJECT PROGRESS REPORT

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Publication of results and findings

The results of the study we have done were presented at the Society for Neuroscience conference which took place on 8-12 November 2003 in New-Orleans, USA (copy of the poster is attached to this report). The final results of the grant were also presented at the Bial 5th Symposium which was held from 31st of March until 3rd of April 2004 in Porto, Portugal.
We have now started writing up those results as an article that we are planning to submit to Cognitive Brain Research within the next few months

Summary of findings

Event-related potentials (ERPs) were recorded in adults, 6-month and 12-month old infants during a face processing task where the subjects passively viewed upright (HU) and inverted (HI) pictures of human faces. The analysis was guided towards finding evidence of developmental changes in the neural mechanisms involved in face processing, for studying cortical specialisation for faces versus the effect of experience on the development of face processing within the first year of life.

The electrophysiological signal (EEG) of interest was a negative potential called the N170 that peaks in adults around 170 ms after the presentation of the stimulus, while subjects passively view pictures of upright human faces. This negative potential shows smaller amplitude and shorter latency for upright human faces (HU) as compared to inverted human faces (HI). It is believed to be an electrophysiological marker of specialised mechanisms for face processing.

The conventional ways of processing ERP signals is to perform averaging of a large number of trials. Averaging was therefore performed on the data as a pre-processing step, as it is a very efficient method for improving the signal-to-noise ratio of the data. The averaging showed the classic N170 in adults and a putative "infant N170" in 6-month and 12-month old infants. Both amplitude and latency differences between inverted and upright human faces conditions was observed in adults, whereas none was observed in 6-month old or 12 month old infants. The averages also suggested that the infants N170 seemed to be a broader version of the adults N170. Further analysis was performed on the averages in order to test for this apparent bandwidth difference. The EEG being a mixture of processes produced by several neural generators at the same time, it was interesting to apply techniques that would decompose the signals into its different frequency components.

The wavelet-based multi-resolution analysis (MRA) was applied to the averages and the results were compared across the 3 age groups. This technique decomposes each time-series into its various frequency band components. The results of the MRA analysis demonstrated evidence of developmental bandwidth changes of the N170 activity across the three age groups. The N170-related brain activity was extracted mainly in the alpha band (8-13 Hz) for adults, in the delta band (0-4 Hz) for 6-month olds and in both the theta (4-8 Hz) and alpha bands for the 12-month olds. These findings suggest that 6-month olds may be slower than adults and 12-month olds at processing pictures of human faces. This might reflect these infants' more limited exposure to faces and/or a physiological characteristic of infants' immature brains that makes them generally slower at processing information as a whole. As observed in the averages, both amplitude and latency differences between inverted and upright human faces conditions was observed in adults, whereas none was observed in 6-month old infants. However, some differences in the latency and amplitude properties of the N170 potential were detected in the 12 month old infants. Those differences were spread across two components suggesting that the possibility of two developmental precursors of the adults N170. Indeed it was also found that at 12 months of age, not only sensitivity to faces is already present in the neural mechanisms of infants, but also that these mechanisms are separated into two individual components that belonged to different frequency bands and which have different properties with respect to the inversion effect and latency properties. The latency difference observed between both HU and HI conditions was present in the theta component only, whereas the amplitude difference was detected in the alpha component only, with peak activity in the right temporal area for the HI condition as observed in adults. The distinctiveness of these two components became apparent when MRA decomposition was performed on the data.

Further analysis will be required to elucidate whether one or both of these components observed in 12-month old infants might be possible developmental precursors for the mature N170 component observed in adults. This analysis will further contribute towards understanding the neural mechanisms involved in face processing as it develops. This will help towards the current debate on face specialisation which supports several different views on the subject: (1) face specialisation exists from birth and there exists a neural system dedicated only to faces, (2) neural specialisation for faces arises during development due to experience with faces or (3) sub-cortical structures mediate a tendency of newborns to orient towards face-like pattern which is followed by experience-dependant specialisation of cortical areas.

Technical part

Stimuli presentation programs and Data Recording

The stimuli presentation programs were implemented in Matlab. The stimulus consisted in showing upright and inverted images of female human faces. The program was made flexible so that the user could display images either in random or pre-defined sequential order, at the desired rate and speed. The participants were instructed to passively look at the images that were shown on the computer screen.
Some technical issues related to connecting the different parts of equipments together needed to be solved. These equipments were involved in the electrophysiological data recording and acquirement of data as well as the display of stimuli. The stimuli presentation program was implemented and run on a Laptop (portable PC). The laptop was synchronised with the EEG recording system in order for a pulse that marked the stimulus onset to be sent in one of the channel of the recording machine via the communication port. This was needed for timing analysis purposes.

Special care was taken to ensure that the EEG recording set-up complied with the EN 60601-1 standard (aka BS5724) which is the British Standard for electro-medical equipment safety, as it would be effectively 'patient connected', being on the patient side of the EEG machine's isolation barrier.
Data of 6-month and 12-month old infants were recorded and added to data that were already available from previous study. Data from adults were already available and also used in this study for comparison purposes. A dozen of participants from each population were recorded during experiments. The data were stored on hard-drive for offline analysis using the tool developed in Matlab.
Over the summer 2003, the EEG recording system was updated to a newer version that was brought from the EGI company in the USA. This has caused the work to be slightly delayed of about 3 months. At this effect, we have asked that the payment of the salary be suspended during this 3-month period (from 1st October 2003 until 31st December 2003) and be postponed until January 2003 until 31st March.

Signal processing tool

Program code and subroutines were implemented using Matlab in order to perform the analysis and processing of the acquired data. Two main aspects were taken into account.
The user-friendliness aspect of the program was emphasised as the objective was to make it usable by a population of clinicians who do not necessarily have a computer background. At this effect, a range of user-friendly items such as choice menus and dialogue windows, yes/no question buttons, field boxes to enter or change various parameters, help windows to help and guide users into understanding the various techniques and parameters used in the analysis.
Another important aspect of the tool was the choice of appropriate signal processing techniques that would be suitable for the analysis of electrophysiological signals. The electroencephalogram (EEG) being a mixture of several neural processes, it was important that the analysis techniques could not only clean up the signals from the ongoing background noise and improve the signal-to-noise ratio, but also decompose the signals into its different components. At this effect, basic pre-processing techniques such as baseline correction, filtering, artefact removal, averaging, as well as more advanced signal processing techniques such as the time-frequency wavelet-based multi-resolution analysis (MRA) decomposition technique were implemented in Matlab programming language and included as part of the data analysis tool.

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Face Processing Electrophysiological Signals in Infants and Adults and their Frequency Decomposition

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Introduction

- The adults N170 event-related potential (ERP) tells us that adults can differentiate between Upright and Inverted Human faces [1].
- The 6-month olds 'putative' N170 ERP tells us that up to 6 months, infants cannot differentiate Upright from Inverted human faces [2].
- The N170 ERP of 12 month olds shows that 12 month infants begin to show some sensitivity to Human Upright faces, but not quite like that of adults yet [3].

Aim of the study

- Find more evidence of developmental changes in the face processing brain activity as it develops.
- Carry out an analysis approach in the frequency domain in order to complement the time-domain analysis already carried out by [2] and [3] so as to obtain further insight into the data.

Take-home messages

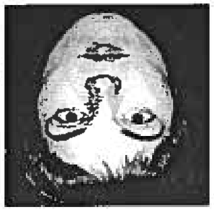
- Evidences of developmental changes in the bandwidth of face processing electrophysiological signals were found. The N170-related brain activity was extracted mainly:
  - in the alpha band in adults
  - in the delta band for 6 month-olds infants
  - in both the alpha and the theta band in 12 month olds.
- 2 possible developmental precursors of the adult N170 was identified in 12-month olds, they belonged to different frequency bands
- Sensitivity to orientation is present from at least 12 month of age in infants, this was reflected in the latency, amplitude and scalp distribution differences.
- Fast Fourier Transform (FFT) spectral analysis was not as good as MRA for identifying developmental changes in the N170 activity.

Experiment [2][3]

- Participants: 10 adults, 10 twelve-month olds and 10 six-month olds.
- Stimuli: Passively view pictures of upright and inverted human female faces, viewing distance: 60 cm from computer screen.

Human Face Upright (HU)

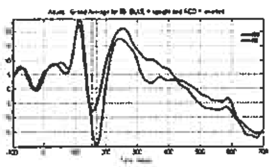
Human Face Inverted (HI)



- EEG Recording: GeodesicSensor Net, 62 electrodes, Ref: Vertex, Sampling rate: 250Hz, Bandpass: 0.1-100Hz
- ERP analyses:
  - Grand average
  - Wavelet-based Multi-Resolution Analysis (MRA)

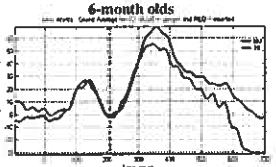
Grand Averages

Adults



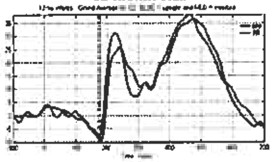
- In adult subjects, the N170 negativity was observed in the grand averages around 160 ms for HU, 170 ms for HI. This confirmed previous published results [2].

6-month olds



- In 6-month old infants, the "infant-N170" showed similar latency range for both conditions around 210 ms. This confirmed previous published results [2].

12-month olds



- In 12-month old infants, the grand averages showed both the N290 and P400 components reported in [3], and additionally showed a negativity that peaked slightly before 200 ms (around 175 ms for HU and 177 ms for HI).

- For adults the N170 activity was better detected in the temporal areas (T5 and T6) whereas in 6-month and 12-month old infants it was better detected in the occipital electrodes (O1 and O2).

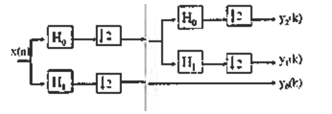
Wavelet-based Multi-resolution Analysis (MRA)

A time-frequency technique that decomposes the EEG into its various frequency bands. Based on Wavelet transform: time-shift and scaling of a prototype basis function. The technique decomposes time-series X into local time-dilated and time-translated Wavelet components Ψ, where W represents the energy in X of temporal scale a at $t = b$.

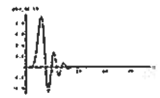
$$W(a,\ b;\ X,\ \Psi) = |a|^{1/2} \int_{-\infty}^{\infty} X(t)\,\Psi\left(\frac{t-b}{a}\right) dt$$

Mode of operation of the MRA decomposition (also known as discrete wavelet transform):

MRA decomposition tree structure



Daubechies Wavelet filter coefficients



Advantages of Wavelet-based MRA over the conventional FFT (Fourier Transform)
- time and frequency localisation properties.
- time-series do not need to be stationary.

References

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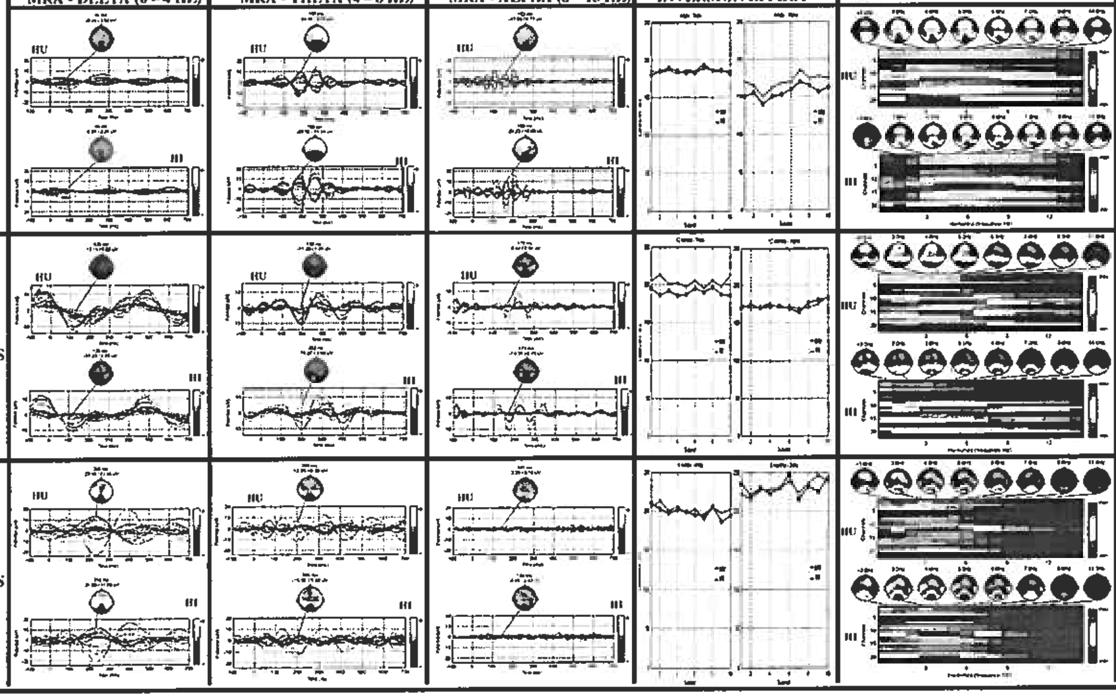
MRA decomposition Results

ADULTS / 12 MONTHS / 6 MONTHS



OBSERVATIONS

Adults:
- In adults, most of the N170 energy lies in theta/alpha bands
- the N170 component with amplitude and latency differences between HU and HI was extracted in the alpha band
- spectra distribution shows larger peak for HI in higher-theta to alpha band and located mainly on left temporal area

12 months:
- N170 energy splits over two bands, theta and alpha as in adults
- but latency difference present in theta band only, amplitude difference present in alpha band only, HI energy located mainly on left temporal area of theta component (as in adults)
- spectral scalp distribution of HI similar to that of 6mo infants (parietal).

6 months:
- In 6mo, N170-related energy present mainly in delta and lower theta bands.
- no latency or amplitude difference was present between HU and HI
- spectral power distribution was similar in both conditions, mainly concentrated in the parietal area.