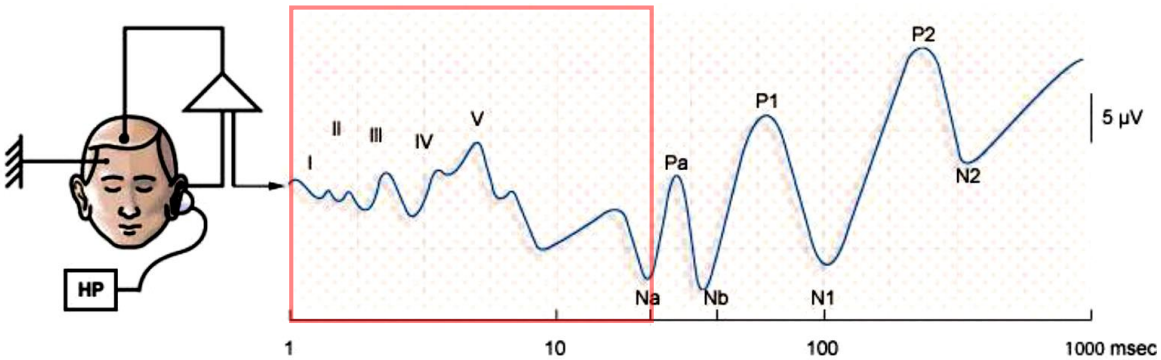
Evoked potentials

Introduction:

Evoked potentials (EP) are brain reaction to sensory stimulation: auditory evoked potentials AEP, visual evoked potentials VEP, and somatosensory evoked potentials SEP. A voltage of EP is lower than random background activity because is generated only limited neuronal population. Average of repetitive stimulation and EP measurement suppresses the random EEG component and highlights common waveform. If you average *M* responses, the noise to signal ratio (SNR=EP/EEG) increase value to $\sqrt{M}$. A peak voltage of EP is in units of microvolts therefore hundreds of repetitions are required to extract a clear evoked response.

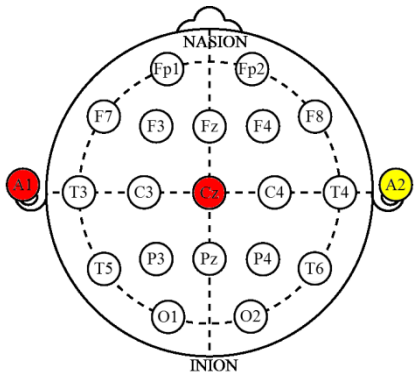
AEP-auditory evoked potentials are responses to short (100 µs) acoustic stimulus measured in the central area (Cz).



Latency	Responses	
0 až 20 ms	early, brain stem	BAEP – brainstem auditory EP
20 až 70 ms	middle cortical	MLR – middle latency response
70 až 500 ms	late cortical	SVP – slow vertex response

Measuring:

- bipolar lead from the central area – A1(-) + Cz(+)
- referential electrode A2(ref)
- audio output to left earphone

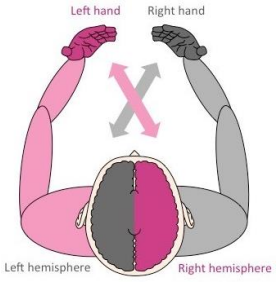


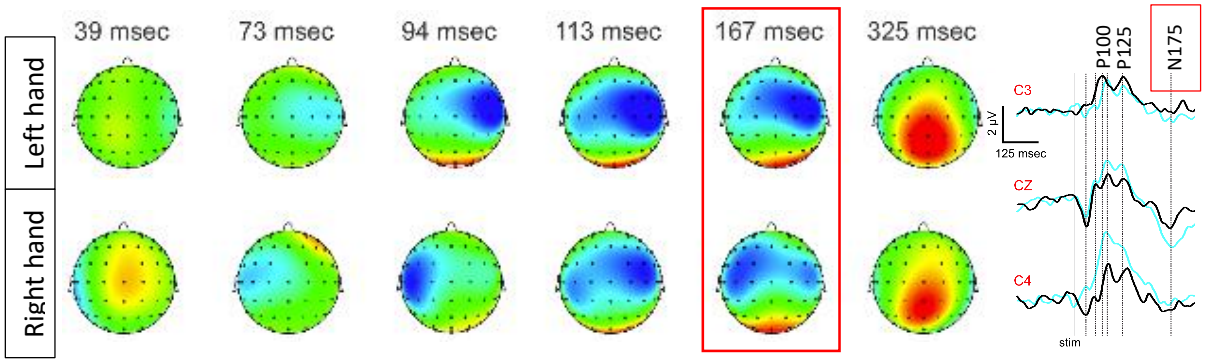
Recording of AEP signals (fs = 25 kHz) in sit, in relaxed mode with closed eyes, few minutes' duration:

1. 1000 stimulus
2. stimulus' duration 100 µs

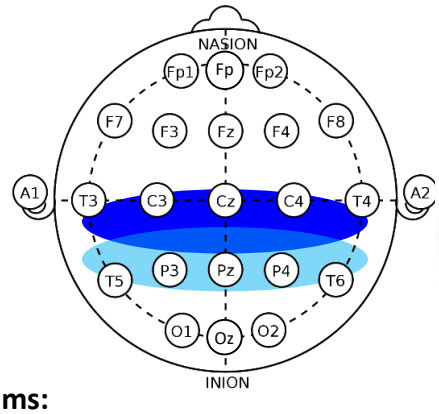
Responses are recorded automatically in 40 ms segments.

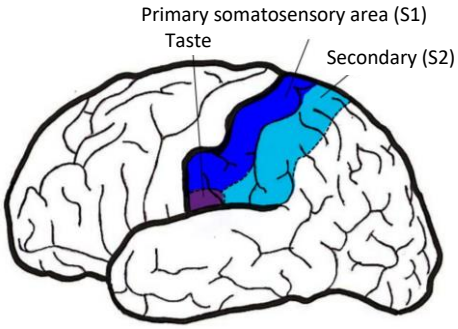
SEP-Somatosensory evoked potentials are responses to touch or pain. The most often stimulation is by electric impulse (0.2 ms, 2 Hz repetition) applied in wrists close to *nervus medianus*. The evoked potentials occur after time delay caused by the distance from stimulation place to the brain cortex. Motor and sensory cortex are contralateral to half of the body. Early EP occurs in 25-100 ms in primary somatosensory cortex (S1), which process physical information coded the stimulus. Associating **secondary somatosensory cortex** (S2) are activated later together with parietal and bilateral frontal regions. The strongest contralateral responses can be expected in time 150-200 ms after stimulation in positive wave N175 (negative voltage) close in time 175 ms.

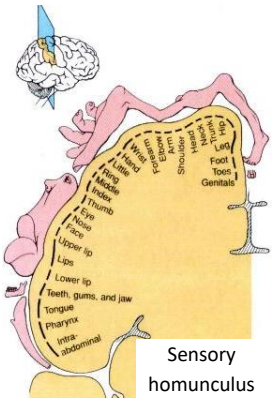




Legon, W., Rowlands, A., Opitz, A., Sato, T. F., and Tyler, W. J. (2012). Pulsed Ultrasound Differentially Stimulates Somatosensory Circuits in Humans as Indicated by EEG and fMRI. *PLoS One* 7, e51177. doi:10.1371/journal.pone.0051177.





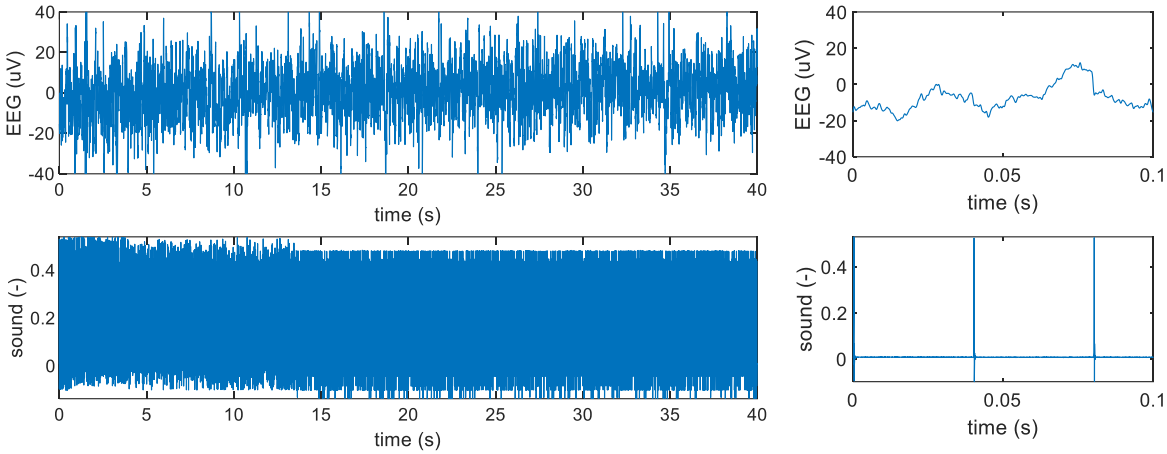


Aims:

1) Extract auditory evoked potentials (**AEP**) from one channel EEG (Cz).
    a. Divide the signal into 40 ms segments without for-cycle
    b. Show the AEP after a stimulus, an average of 10, 100 a 1000 stimulation
    c. Identify the time of the wave V.
2) Extract somatosensory evoked potentials (**SEP**) from multi-channel EEG (10-20)
    a. For stimulation of the right hand
    b. For stimulation of the left hand
3) Localize the local extreme of N175 wave in central electrodes (C3, C4). Display electric field distribution of EEG on the scalp – **brain mapping**.
    a. For stimulation of the right hand
    b. For stimulation of the left hand

Data structure:

```
AEP_S01.mat (fs=25 kHz)
aep01: 1. column ... EEG (uV)
       2. column ... acoustic pulses
```




```
SEP_P203.mat (fs=512 Hz)
d10_20... EEG(uV) (time X channels)
fs...     sampling frequency
t...      time axis (seconds)
labels... cell of channel labels
M_LH...   stimulation time of the left hand (sec.)
M_RH...   stimulation time of the right hand (sec.)
MAP_10_20... cell of channel position in the scalp (10-20)
```

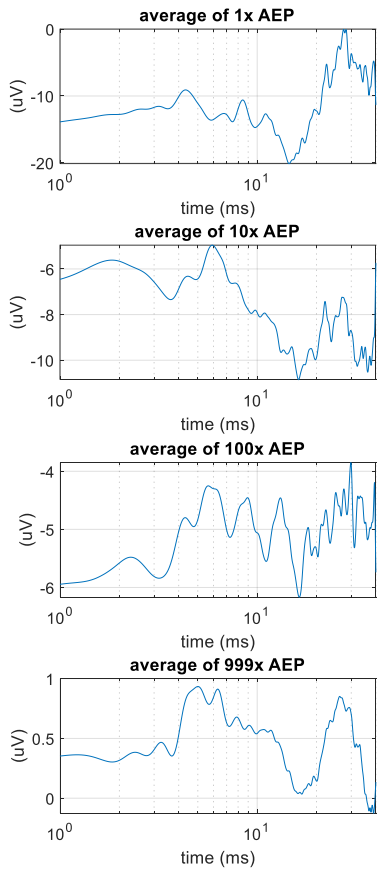
MAP_10_20	5x5 cell
M_LH	512x1 double
M_RH	512x1 double
d10_20	417231x21 double
fs	512
labels	21x1 cell
t	1x417231 double

Useful functions: reshape, repmat, cellfun, meshgrid, interp2, pbaspect, imagesc, colorbar, colormap, rectangle, ind2sub, sub2ind, strcmpi

Help:

1) Load and display AEP signal, filter EEG by low-pass filter <1000 Hz, crop the signal before first stimulus and remaining parts after whole multiple of 40 ms window.

```
load('AEP_S01.mat');
fs=25e3;
tdur=0.04*fs; % 40 ms
t=linspace(0,(size(aep01,1)-1)/fs,size(aep01,1));
... % eeg=aep01(:,1) filtering <1000 Hz

% find the first stimulus index in aep01(:,2) and crop the signal onset.
aep=aep01(idx:end,1);
rem=mod(size(aep,1),tdur); % compute remained samples out of whole multiple
                             of 40 ms
aep=aep(1:end-rem); % crop ending
N=length(aep)/tdur; % number of AEP responses

% use reshape function for reordering aep-signal from vector to matrix,
which each column contains one from N 40 ms responses in EEG.
aep=reshape(...

% display average AEP for 1, 10, 100 a N responses. Limit the time axis in
1-40 ms, use logarithmic scale.
...
plot(taep,mean(aep(:,1:10),2)); % 10 responses
set(gca,'XScale','log')
...
```

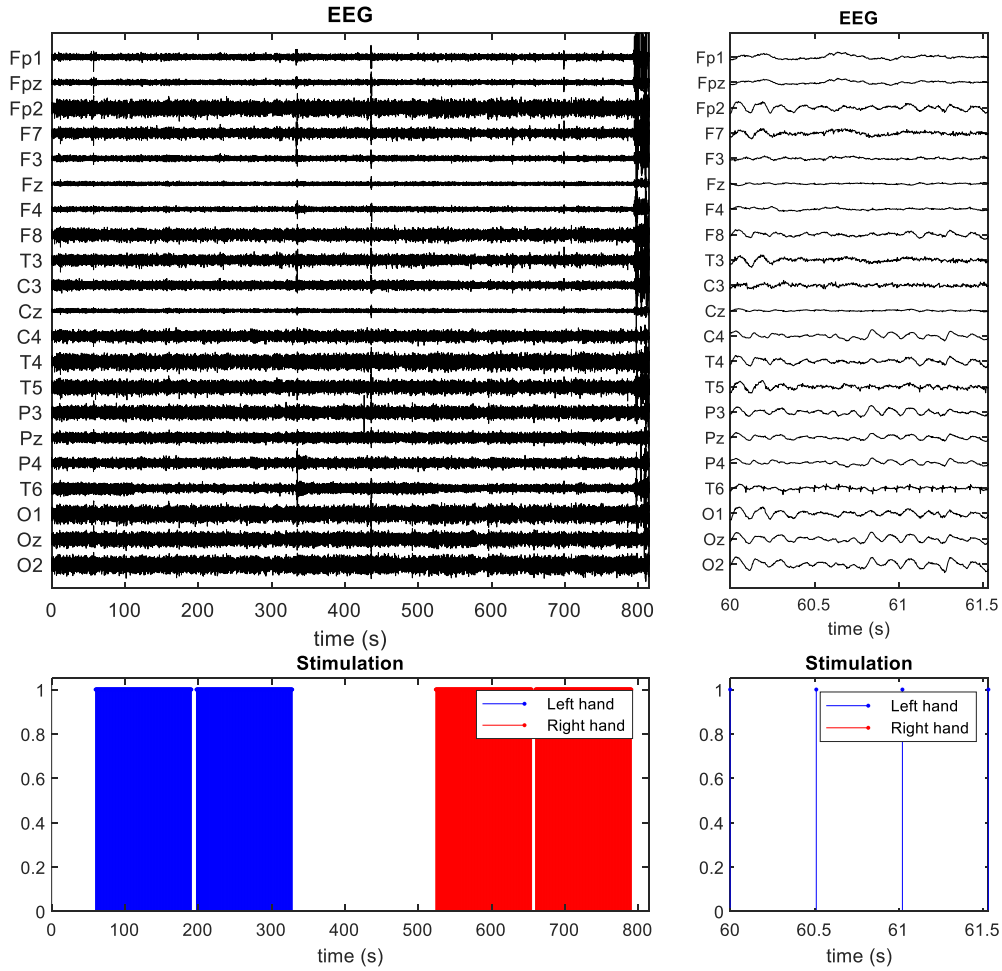


How many AEP responses are necessary for reliable identification of IV. and V. Wave?

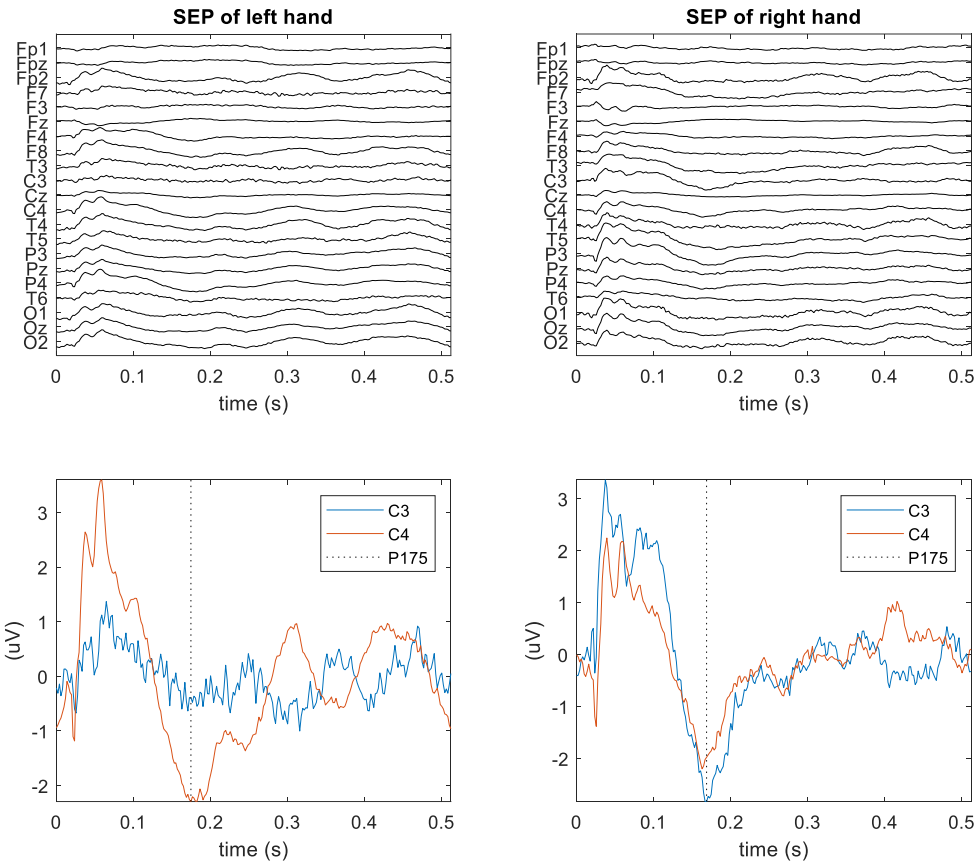
What is the time of V. wave?

2) Load and display the multichannel EEG signal. Use time indexes M_LH (for left hand) and M_RH (for right hand) to compute SEP responses. Find the wave N175 in central area channels and display electrical field in the scalp using 10-20 electrode scheme – brain mapping.

```
% Show multichannel EEG signal. Use constant 150 uV offset between
channels. Display the detail of EEG during somatosensory stimulations. Use
channel labels stored in cell „labels".
...
offset=linspace(0,-size(d10_20,2)*150,size(d10_20,2)); % ch x 150 uV
plot(t,d10_20+repmat(offset,[size(d10_20,1) 1]),'k')
set(gca,'ytick',offset(end:-1:1),'yticklabel',labels(end:-1:1));
...
% Display time markers of SEP for left and right hand. See the detail of
few stimulations.
...
stem(M_LH,ones(size(M_LH)),'b.');
...
```



```
% Extract 0.5 sec. segments (2 Hz stimulation) of EEG using time markers
M_LH and M_RH
win=round(0.5*fs);
ch=size(d10_20,2);

% SEP of left hand ===
SEP_LH=zeros(win,ch,length(M_LH)); % time x channel x stimulus
for i=1:length(M_LH)
   SEP_LH(:,:,i)=d10_20(...);
end
avr_SEP_LH=mean(SEP_LH,3); % average through simulations (dim=3): time x
                             channel

% SEP of right hand ===
SEP_RH=zeros(win,ch,length(M_RH)); % time x channel x stimulus
...
avr_SEP_RH=mean(SEP_RH,3); % average through simulations (dim=3): time x
                             channel


% Show average SEP for left and right hand. Use 4 uV offset between channels.
Separately display average SEP for channel C3 and C4. Localize time of the
wave N175.
```




```
[~,N175_C4]=min(avr_SEP_LH(:,...));
[~,N175_C3]=min(avr_SEP_RH(:,...));
```

Time of wave N175 for SEP of the left hand (in C4): ...

Time of wave N175 for SEP of the right hand (in C3): ...

3) Display the EEG voltage in 10-20 scheme of electrode placement in times of N175 - **brain mapping**.

```
% Scheme of system 10-20 is stored in map „MAP_10_20"
```

```
% Localize position of each electrode labels in
the map. E.g.: 2nd channel (Fpz) has coordinates
x=3, y=1.

You can use for-cycle to test whole map table
and sequentially compared lavles{i} by strcmpi
and store coordinates in x(i), and y(i).
```

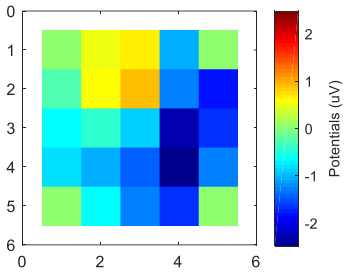
MAP_10_20

5x5 cell

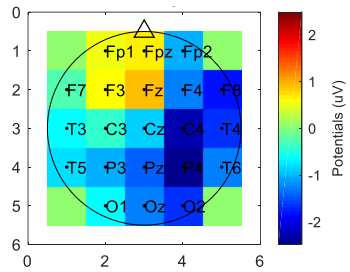
	1	2	3	4	5
1	NaN	'Fp1'	'Fpz'	'Fp2'	NaN
2	'F7'	'F3'	'Fz'	'F4'	'F8'
3	'T3'	'C3'	'Cz'	'C4'	'T4'
4	'T5'	'P3'	'Pz'	'P4'	'T6'
5	NaN	'O1'	'Oz'	'O2'	NaN

```
A better way is using cellfun, which compare individual cells of labels
@(x)~@(labels{i}) to map MAP_10_20. Application function find with one
output to matrix replies linear indexes of matrix element in columns. E.g.
matrix 5x5 is linearly indexed: 1~(1,1), 6~(1,2), 11~(1,3)~11, ... 25~(5,5)
```

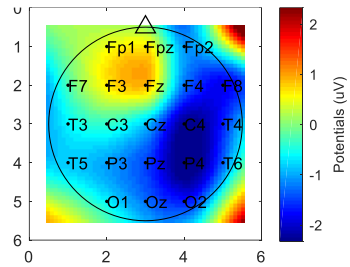
```
idx=cellfun(@(x) find(strcmpi(MAP_10_20,x)),labels,'UniformOutput',1);
[y,x]=ind2sub(size(MAP_10_20),idx); % linear indexes transformation to
                                      [rows, columns]

% brain mapping in 2D (image 5x5) ================================
imgL=zeros(max(y),max(x)); % zeros matrix
imgL(idx)=avr_SEP_LH(N175_C4,:); % insert avr. SEP voltage in N175 time to
pixels corresponds to channel in map
imagesc(imgL); % image matrix as picture
pbaspect([1 1 1]); % symmetric aspect ration 1:1:1
axis([0 6 0 6]); % xlim, ylim
caxis([-1 1]*max(abs(avr_SEP_LH(N175_C4,:)))); %
colormap limits ±max. of SEP voltage
colormap('jet'); % colormap JET (-blue, +red)
cb=colorbar; cb.Label.String = 'Potentials (uV)'; %
colorbar label
```



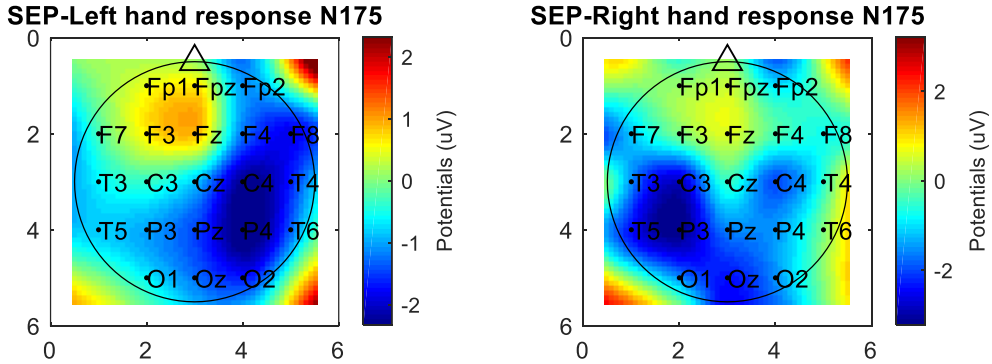

```
% labels of electrodes, ring + nasion
hold on
plot(x,y,'.k') % dots
text(x,y,labels) % labels{i} in x(i), y(i)
rectangle('Position',[0.5 0.5 5 5],'Curvature',1)
plot(3,0.5,'k^','MarkerSize',10) % nasion
```



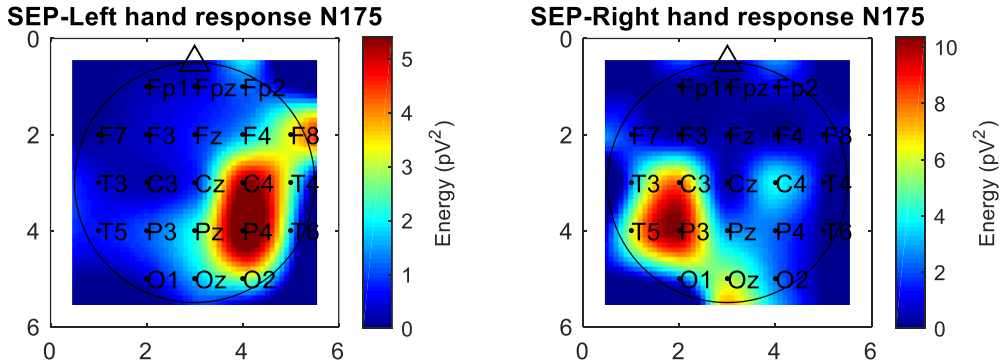

```
% higher resolution interpolation
[X,Y]=meshgrid(1:5,1:5); % original mesh, step=1
[XI,YI]=meshgrid(0.5:0.1:5.5,0.5:0.1:5.5); %
interpolated mesh + edge (step/2)
imgLI=interp2(X,Y,imgL,XI,YI,'makima'); % higher
resolution image
imagesc(.5:0.1:5.5,.5:0.1:5.5,imgLI); % image
matrix as picture
... % add labels, ring and nasion
```



```
% Compare average SEP in time of N175 between left and right hands
```




```
% Use a similar process to display energy of average SEP in time of N175.
Use appropriate colormap limits. Think about the "energy" units.
```



What electrodes cover the primary and secondary somatosensory cortex?

	For the **left** hand	For the **right** hand
Primary somatosensory cortex (S1)		
Secondary somatosensory cortex (S2)		