Introduction

Different type of flirting is used to filter biomedical signals. One the famous one is synchronized averaging. This filter is used to reduce the noise by leaving the original signals intact. In this lab, synchronized averaging is used to filter the noise in Event-related potential (ERP) which may be obtained several times by repeating the application of stimuli. The focus of this lab is to reduce the ratio of signal to noise (SNR) by using synchronized averaging and expose students to habituation phenomenon that happens in the brain. Also, this lab will measure the distance between the original signals and their average. Different sizes of epochs will be tested on signals to understand the effectiveness of synchronized averaging and habituation.

Background

The most frequent method for generating ERPs to esophageal stimulation has been synchronized averaging [1]. With k = 1,2,…,M, M representing the ensemble index and n = 1,2,…,N representing the time-sample index, Yk(n) represents one realization of a signal [2]. M is the number of accessible copies of the signal (events, epochs, or realizations), and N is the number of time samples in each copy of the signal (events) [2]. Synchronized averaging formula is shown below:

$$y_k(n) = x_k(n) + \eta_k(n),$$

where Xk(n) is the uncorrupted original signal and k(n) is the noise in the kth duplicate of the observed signal Now, if we average the M copies of the signal at each moment of time n,

$$\overline{y}(n) = \frac{1}{M} \sum_{k=1}^{M} y_k(n) = \frac{1}{M} \sum_{k=1}^{M} x_k(n) + \frac{1}{M} \sum_{k=1}^{M} \eta_k(n); \quad n = 1, 2, ..., N.$$

Synchronized averaging is used to reduce the SNR value. However, it was discovered that as the number of stimuli was increased beyond a certain point, habituation occurred, and that using ERPs acquired after habituation in averaging resulted in a drop in the SNR. Below are the formulas that is used in this lab to calculate SNR.

Noise power:

$$\sigma_\eta^2 = \frac{1}{NT(M-1)} \sum_{k=1}^{M} \sum_{n=1}^{N} [y_k(n) - \overline{y}(n)]^2.$$

Signal power:

$$\sigma_y^2 = \frac{1}{NT}\sum_{n=1}^{N}[\overline{y}(n)^2] - \frac{\sigma_\eta^2}{M}$$

$$SNR = \frac{\sigma_y^2}{\sigma_\eta^2}$$

The Euclidean distance measure can be used to objectively assess adaptability. The formula is shown below:

$$D = \frac{1}{M}\sum_{k=1}^{M}\sqrt{\sum_{n=1}^{N}[y_k(n) - \overline{y}(n)]^2}$$

Result

Figures below show the different epochs for synchronized averaging and there is a table that shows signal to noise ratio (SNR), signal power, noise power and Euclidean distance. The signals were captured at 1000Hz and filtered to the 0:1-100Hz range. Each signal has a total of N = 511 samples. Also, T=0.001s which is the sampling interval.

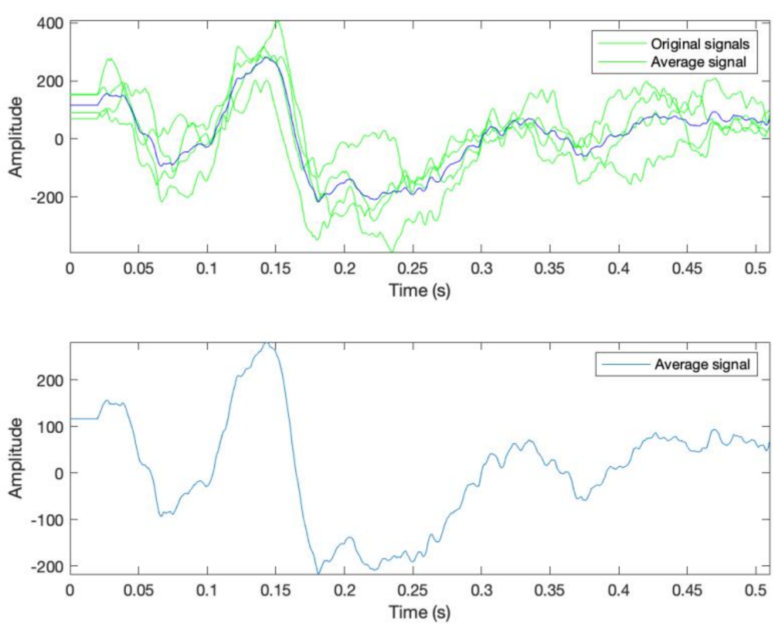

Figure 1: E1-E4 synchronized averaging plot and original singles and the average plot

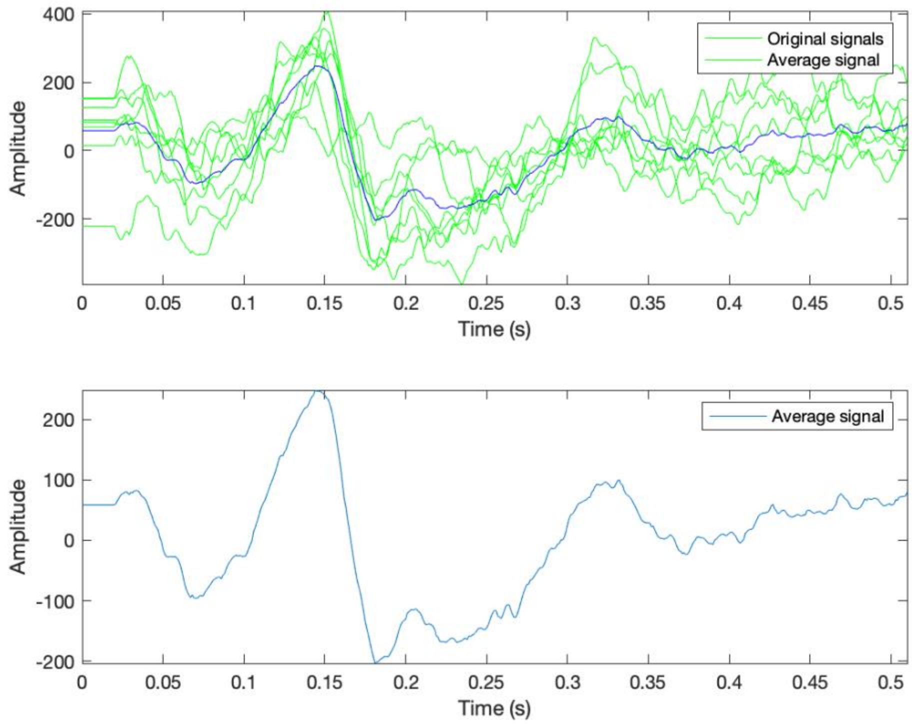

Figure 2: E1-E8 synchronized averaging plot and original singles & the average plot

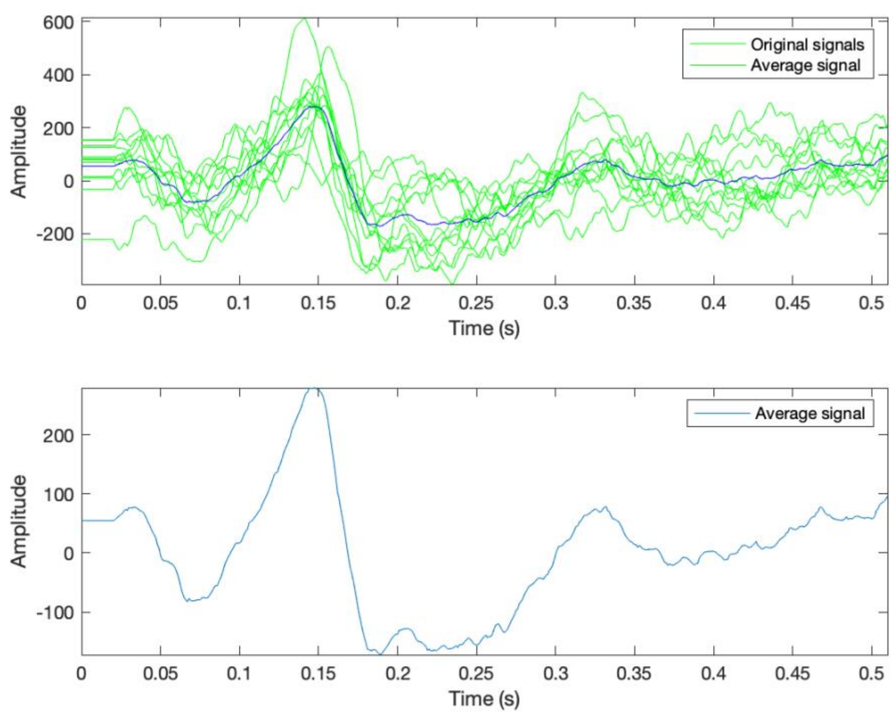

Figure 3: E1-E12 synchronized averaging plot and original singles and the average plot

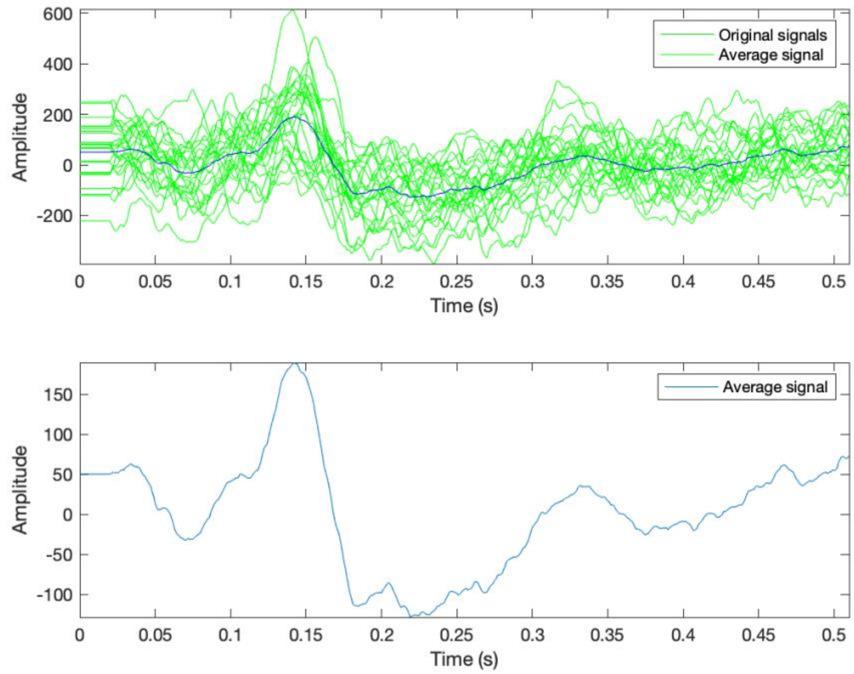

Figure 4: E1-E24 synchronized averaging plot and original singles and the average plot

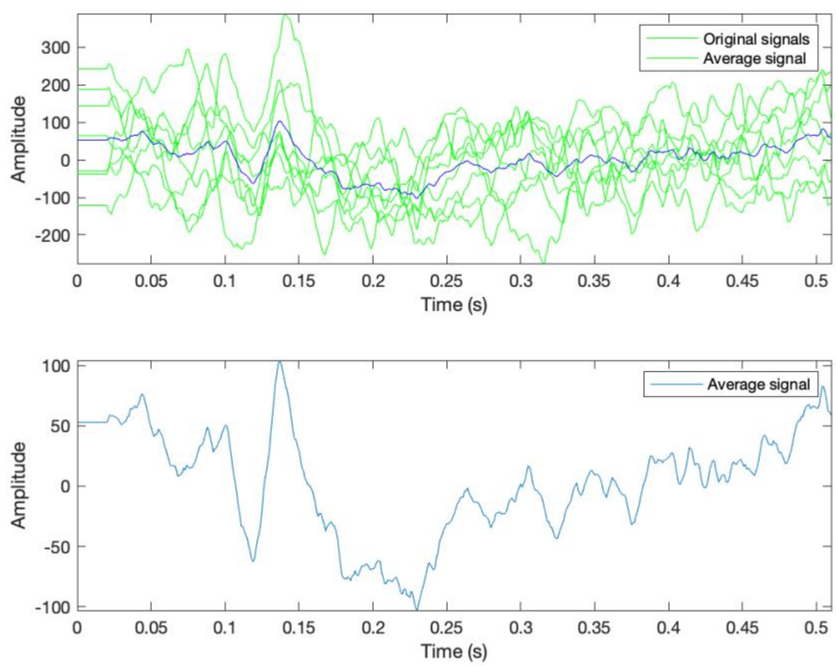

Figure 5: E17-E24 synchronized averaging plot and original singles and the average plot

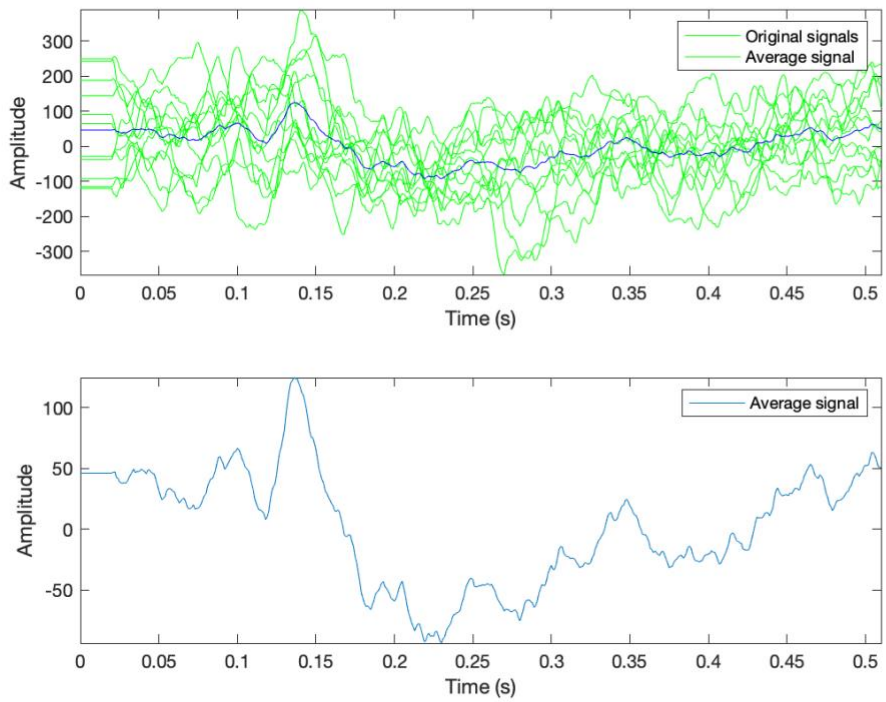

Figure 6: E13-E24synchronized averaging plot and original singles and the average plot

Table 1: Each stimulus matrices value

Number of stimuli	Noise Power(NP)	Signal Power(SP)	SNR	Distance
E1-4	7.66E+06	2.61E+06	0.3401	2.61E+03
E1-8	1.15E+07	4.83E+06	0.4213	4.19E+03
E1-12	1.13E+07	8.24E+06	0.7293	5.26E+03
E1-24	1.19E+07	4.85E+06	0.4075	7.97E+03
E17-24	1.04E+07	2.15E+06	0.2074	4.55E+03
E13-24	1.10E+07	1.62E+06	0.1471	5.48E+03

Discussion

The lab consisted of 6 experiments. It started with E1-to E4 signals and finding the synchronized averaging signal for them. It continued till E1 to E24 which was all the signals. As it can be observed from the results in table 1, till the third experiment which is E1-E12 the SNR value was increasing. It means the filter was performing well, and it was able to extract the noise from the original signal. Also, table 1 shows ERP has direct correlation with the number of signals that are used for averaging. The higher the number of signals Euclidean distance gets larger. However, from experiment 4 which is E1 to E24, it was observed that SNR was decreasing. It was expected the more signal is used the better the result of SNR will be. This experiment proves that is not the case.

The reason for this discrepancy is the habituation phenomena in the brain. A reduction in responsiveness to a stimulus after repeated exposures is known as habituation [1]. The Euclidean distance between the EEG response to single stimuli and the averaged ERP, which serves as an objective measure of similarity between the averaged ERP and the single-stimulus EEG, is used to define habituation [1]. The observations suggest that for the signals E13 to E24 habituation took place, and SNR went down significantly. Synchronized averring worked best for the first half of the signal, and because of habituation signal content got reduced.

Conclusion

To wrap up, the objective of this lab was to familiarize students with the concept of habituation and its effect on SNR and synchronized averaging filter. In the six experiments that were done for a different number of signals, it is known that the number of factors influences SNR. The number of signals does not necessarily have a direct impact on the SNR. The nature of the biomedical signal is also playing a critical role.

References

[1] M. V. Kamath *et al*, "Estimation of habituation and signal-to-noise ratio of cortical evoked potentials to oesophageal electrical and mechanical stimulation," *Medical and Biological Engineering and Computing,* vol. 35, *(4),* pp. 343-7, 1997. Available: DOI: http://dx.doi.org.ezproxy.lib.ryerson.ca/10.1007/BF02534088.

[2]Sirdhar Krishnan, Department Electrical and Computer Engineering (2021) , BME772 Lab Manual, Toronto, Ryerson University, Retrieved from class website:
https://courses.ryerson.ca/d2l/le/content/516288/viewContent/3744946/View

Appendix

```
% BME 772: LAB 1: Synchronized Averaging for Noise Reduction
% Name: Sadaf Safa

% Signal E1-E4
s1=bme772_lab1(1,4,511);
%%
% Signal E1-E8
s2=bme772_lab1(1,8,511);
%%
% Signal E1-E12
s3=bme772_lab1(1,12,511);
%%
% Signal E1-E24
s4=bme772_lab1(1,24,511);
%%
% Signal E17-E24
s5=bme772_lab1(17,24,511);
%%
% Signal E13-E24
s6=bme772_lab1(13,24,511);

%%
sz=[6 5];
varTypes = ["string","double","double","double","double"];
varNames = ["Number of stimuli","Noise Power(NP)","Signal Power(SP)","SNR","Distance"];
t= table('Size',sz,'VariableTypes',varTypes,'VariableNames',varNames);

t(1,:)=s1;
t(2,:)=s2;
t(3,:)=s3;
t(4,:)=s4;
t(5,:)=s5;
t(6,:)=s6;
t
```

Function:

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% BME 772: LAB 1: Synchronized Averaging for Noise Reduction
% Name: Sadaf Safa

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%M1 = Starting index of the signal
%M2 = Last index of the signal
%N  = Length of the signals
```

```
function yavrg=bme772_lab1(M1,M2,N)

M=M2-M1+1;

%%%%%%%%%%%%%%%%%%%%%%%%%LOADING THE
SIGNALS%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

sig_mat(M,N)=0; %initialize matrix to store the signals


j=M1;
for i = 1:M
%      data=load(strcat('/Users/sadafsafa/Desktop/Lab1_data/E',num2str(j),num2str(j),".txt"))
     sig_mat(i,:) = load(strcat('/Users/sadafsafa/Desktop/Lab1_data/E',num2str(j),num2str(j),".txt"));
     j=j+1;
end




%%%%%%%%%%%%%%%%%%%%%%%%% AVERAGING
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% compute the signal average



template = zeros(1, 511);



for i = 1:511
   template(i) = mean(sig_mat(:,i));
end

sampleF=1000;
sampleR=1/sampleF;
time=0:510;
t=sampleR*time;

%plot signal average and original sugnal

subplot(2,1,1);

for i = 1:511
   plot(t,sig_mat, 'g');
   hold on
end
plot(t, template, 'b');
legend('Original signals','Average signal');
ylabel('Amplitude');
xlabel('Time (s)');
```

```
axis('tight');

subplot(2,1,2);
plot(t,template);
legend('Average signal');
ylabel('Amplitude');
xlabel('Time (s)');
axis('tight');

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% SNR_COMPUTATION
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


np=0; % Initialize noise power
sp=0; % Initialize signal power

 % compute noise power

np=0;

for j=1:M
  for i=1:N
    np=np+(sig_mat(j,i)-template(1,i))^2;
  end
end

np=np/(N*.001*(M-1));  % compute noise power

% compute signal power

sp=0;
for j=1:N
  sp=sp+(template(1,i)^2);
end

sp=sp/(N*.001);
sp=sp-(np/M);

SNR=sp/np % compute SNR

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% EUCLIDEAN_DISTANCE
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

D=0;
d=0;
 % compute Euclidean distance
for j=1:M
  for i=1:N
    d=d+(sig_mat(j,i)-template(1,i))^2;
  end
```

```
    D=D+sqrt(d);
end

D=D/M
n=strcat('E',num2str(M1),"-",num2str(M2));

yavrg=table(n,np,sp,SNR,D,'VariableNames',["Number of stimuli","Noise Power(NP)","Signal Power(SP)","SNR","Distance"]);

end
```