

# **40 Hz Event Related Auditory Potential**

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## **Abstract**

Main focus of this paper is an EEG experiment on observing frequency of event related auditory potential in response to series of clicks. Based on the past research, it was expected to observe 40 Hz potential, which was not the case. The experiment was conducted on one subject, and the average observed frequency of 61 Hz could be explained by individual differences. However, an additional step should be taken to validate this result. Furthermore, the paper contains detailed description of EEG and data acquisition setup, including the discussion of solutions to encountered technical challenges.

## **Introduction**

Event related potentials (ERP) are stereotyped brain responses to sensory, cognitive or motor stimuli, measured with electroencephalography (EEG). Investigation of ERP in response to auditory stimuli of short duration, such as clicks, could be regarded as observation of impulse response of auditory system. This notion was first explored in 1981, by Robert Galambos (Galambos et. al.) who demonstrated that auditory ERPs exhibit oscillations at 40 Hz. Such oscillations were detected in the series of experiments where subjects listened to clicks played at rates of 3.3 Hz, 10 Hz, 20 Hz and 40 Hz, regardless of the rate. Consequently, when presented with 40 clicks per second, ERPs were synchronized with stimuli. Today, this finding is used in research and evaluation of hearing.

The decision to investigate phenomenon described above was made due to technical difficulties with experimentation equipment. Several other experiment designs were conceived, but the time did not allow carrying them through. Hence, first portion of this paper details the EEG equipment setup and challenges encountered in attempts to collect experimental data. This is followed by the description of methods, procedure and experiment results.

## **Methods**

### **I. Experimentation equipment setup**

One laptop was used to play auditory stimuli and at the same time record brainwave data. Subjects listened to sounds via electromagnetically shielded earphones *E-A-RTONE Gold 3A* in order to avoid contamination of EEG recordings with stimulus signals (Figure 1). Brainwave data was collected using three electrodes: active (vertex), reference (earlobe) and ground, which reduces the effect of external interference (contralateral earlobe). Signal obtained via electrodes was amplified by *DAM-80* bio-amplifier and then sent to the laptop via *National Instruments* data acquisition card (DAQ). No data analysis was performed during the acquisition stage.

The basic equipment setup described above was tested by recording and analyzing frequency following responses to pure and complex tones. Several major challenges had to be addressed in order to improve the recordings.

#### ***Power line noise***

Recordings obtained in the student laboratory were contaminated by 60 Hz power line noise and its higher harmonics. With several electric devices in the room and without adequate shielding, amplitude of the noise was considerably higher than EEG signal. An attempt was made to remove the noise from recordings using *Chronux* routines (Mitra et al.) which resulted in significant attenuation. Nevertheless, in order to simplify equipment testing process and avoid unexpected data analysis difficulties, it was decided to collect the data in a field outside of the building.

#### ***Low amplitude of the recorded signal***

Voltage of the recorded signal depends on electrode impedance, which was not possible to measure with existing setup. Impedance, in turn, depends on the quality of electrodes and their correct placement. Recommended placement procedure was followed. However, expected frequency following response was hardly distinguishable from irrelevant frequencies in the power spectrum of a test recording. By better securing vertex electrode in place with a headband and playing greater number of stimulus sounds, data quality was sufficiently improved and final experiment results were satisfactory.

#### ***Alignment of response with stimulus onset***

Brainwave responses to series of tones have to be averaged in order to observe the ERP. However, due to sound card latency and processes being executed on the computer simultaneously with stimuli presentation, tones were not always played at equal intervals as it was intended. As a consequence, the alignment of ERP and stimulus onset was not possible. To solve this problem, stimulus tones were sent to DAQ and recorded along with responses.

Possible crosstalk between different channels on DAQ can result in contamination of EEG data with stimulus. If this is not prevented, such contamination can be mistaken for brainwave response. In order to test the possibility of crosstalk, dummy recordings were made by playing 440 Hz pure tones. Both dummy EEG and stimulus data were band-pass filtered around 440 Hz. It was observed that they align exactly, which implies that there was indeed crosstalk between the channels. This problem was solved by increasing the frequency of stimulus sent to DAQ, which does not prevent contamination but allows filtering from the response.

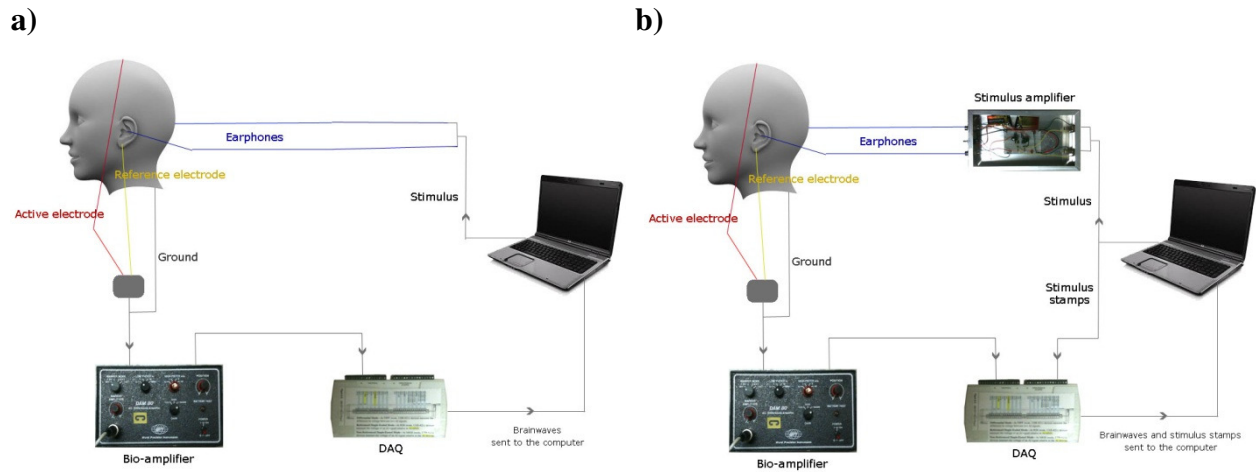


Figure 1. a) Basic equipment setup, b) Improved setup in which copy of the stimulus was sent to the DAQ. Setup also contains stimulus amplifier which was necessary because audio signal was significantly attenuated due to the effect of one of the splitters

## II. Experiment preparation and procedure

Strict preparation and cleaning up procedure should be followed in order to ensure good quality recording and maintain the quality of electrodes for future usage. Silver-silver chloride electrodes were used in this experiment. They present less low frequency "noise" than either gold or silver electrodes. Following are the steps necessary for data acquisition:

### 1. Determining vertex position

Three electrodes were used to obtain the brainwave signals: active (vertex), reference (earlobe) and ground (contralateral earlobe). Measuring tape was used to find the midline between nasion (top of the bridge of the nose) and inion (underneath the bump at the back of the head) to determine the vertex position on the head. Intersection of this line and a midline between the ears is the location of vertex.

## 2. *Placing electrodes*

Cleaning the electrode placement areas with alcohol improves the impedance. Conductive gel is applied to electrodes prior to their placement.

## 3. *Testing signal quality*

Impedance should be less than 20K $\Omega$  but with current equipment setup there was no way of measuring it. Instead, quality of brainwave data being recorded was subjectively evaluated by observing eye blinks in the brainwave signal on the oscilloscope

## 4. *Data acquisition (see next section for experiment design)*

Subjects should avoid moving during the experiment. Since the data is being collected from auditory brainstem, subjects can watch videos during the experiment to keep attention.

## 5. *Cleaning up*

It is important to clean the electrodes properly after the experiment. Silver-silver chloride electrodes have to be washed with distilled or deionized water only, as any soap would damage them.

### **III. Experiment design**

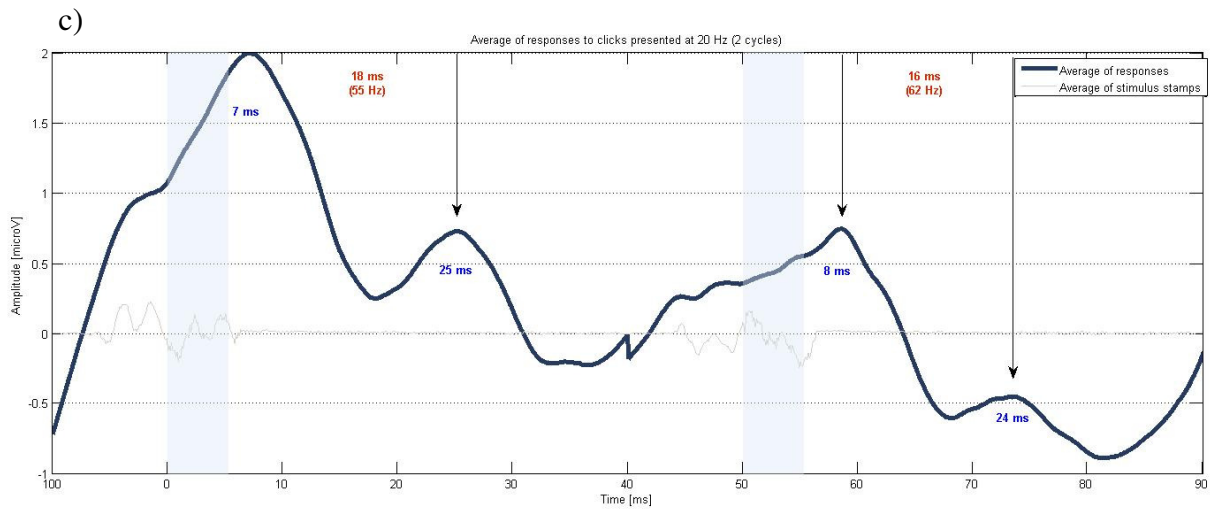
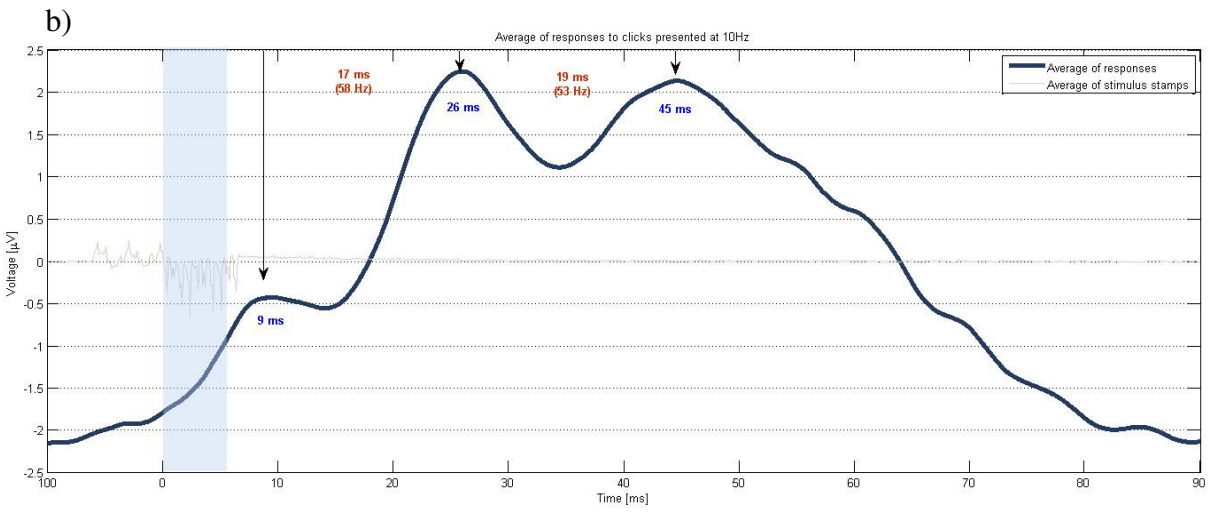
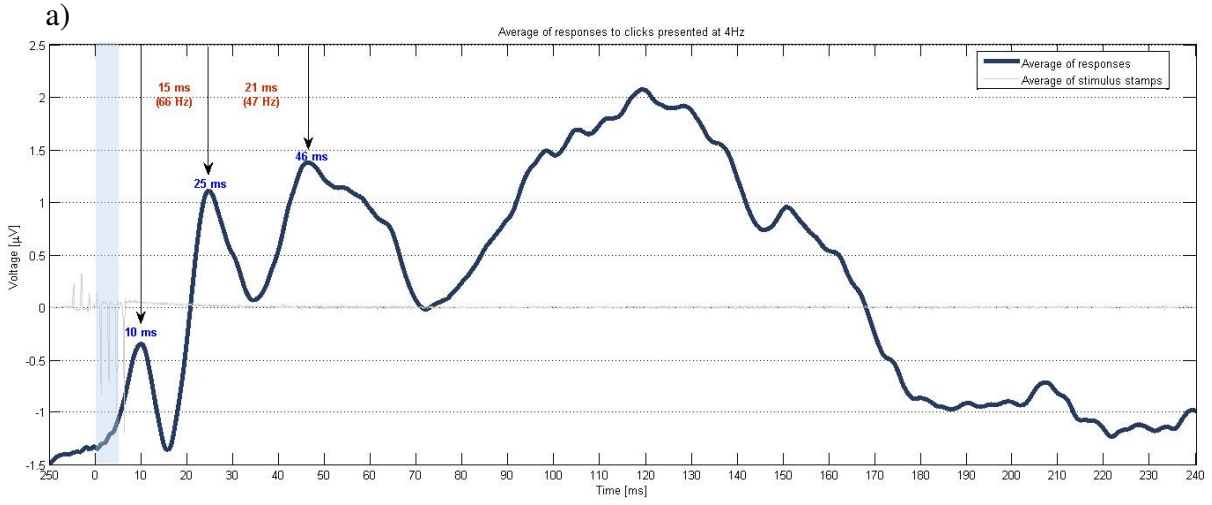
Series of clicks were presented in four different trials, at rates of 4, 10, 20 and 40 clicks per second. Clicks were generated in Matlab as pure tones of 500 Hz, lasting 6 ms, with 2 ms fade in and fade out time. Series of 2000-4000 clicks were recorded as *wav* files that were later played to the subject. This was done in order to minimize the variability of time duration between the clicks due to sound card latency. In addition, *wav* files contained two channels – one for stimulus and the other one for stimulus stamps sent directly to DAQ. Clicks sent to DAQ had frequency of 10 KHz.

Only one subject participated in the experiment and the recordings were made outdoors to prevent contamination from power lines. Brainwaves were amplified 10,000 times, low-pass filtered at 100 Hz and acquired at 10 KHz sampling rate. Routines written in Matlab were used to play stimulus tones and record brainstem responses. Graphical user interface was created in order to conveniently select channels to record from, choose stimuli and specify additional experiment settings.

### **Results**

Quality of recordings was subjectively evaluated prior to averaging the brainwave responses to clicks. Epochs that contained significant drifts and eye blinks were not included in the final average.

Frequency of event related auditory potentials can be clearly observed from plots in *Figure 2*. For each click presentation rate, first peak in the response occurs 7 to 10 ms after the stimulus onset, which is consistent with neural transmission time between the cochlea and brain stem.



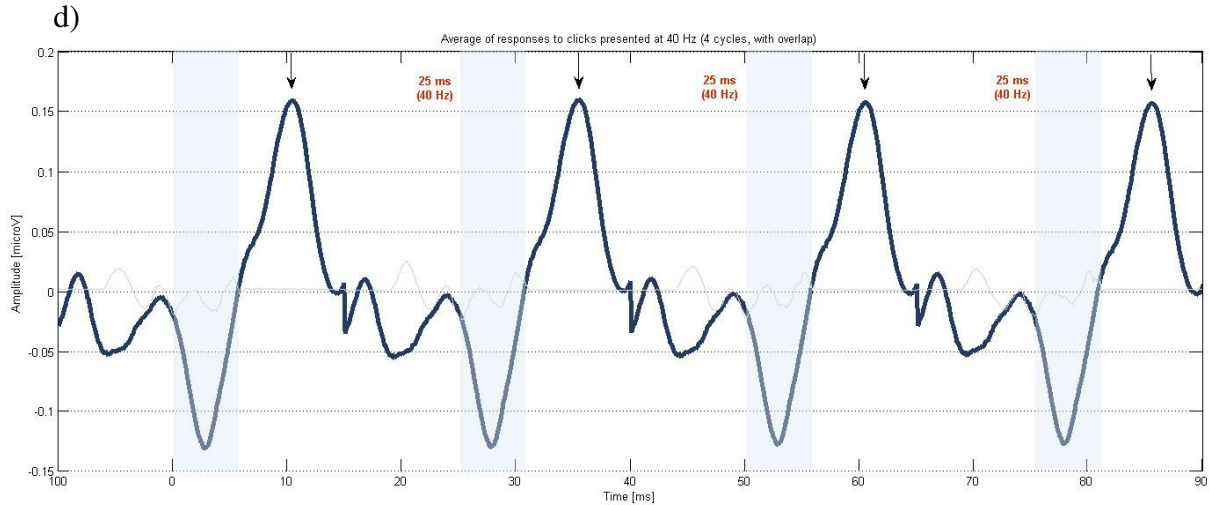


Figure 2. Average responses to clicks presented at a) 4 Hz, b) 10 Hz, c) 20 Hz, averaged over two response epochs, d) 40 Hz, averaged over four response epochs, with overlap. Thick blue line represents the ERP and light gray represents the average of stimulus stamps. Stimulus onset time ranges from 7 ms before to 7 ms after the expected onset time because of the data acquisition equipment latency. In each plot, blue stripe denotes timing of the expected stimulus which lasts 6 ms.

Since the time between two consecutive clicks is 250 ms for 4 Hz presentation rate, we can observe three prominent peaks in the ERP after the onset of the sound. We are interested in the timing between the first and second one, which is in this case 15 ms, corresponding to frequency of 66 Hz. Subsequent cycle in the response is slower; third peak can be observed after 21 ms, corresponding to frequency of 47 Hz. First cycle of the response to 10 clicks per second has frequency of 58 Hz, and the second one frequency of 53 Hz. For 20 clicks per second, frequency of the first cycle is 58 Hz on average. Second cycle cannot be observed because time between click onsets is 40 ms.

In order to observe the frequency of ERP in response to 40 clicks per second, responses were averaged over four epochs. Averaging was performed with overlap, such that two consecutive constituents of the average have three epochs in common. As a consequence of such overlap, response epochs are almost identical.

The first peak in response to 40 clicks per second is significantly more prominent than the following two. The time between first and second peak is 6.3 ms (158 Hz) and between second and third is 7.3 ms (136 Hz). Since these frequencies are more than twice as high as frequencies observed at lower click rates, it is possible that they represent some form of ringing in the response. Frequency between first peaks in each epoch is exactly 40 Hz, which is to be expected because one epoch lasts 25 ms and peaks always occur at 10 ms.

## Discussion

The experiment was conducted on one subject only and results obtained were not entirely consistent with the expected ones. However, it has been noted that: “*the 40-Hz ERP is easy to record from normal subjects... the 40-Hz ERP has with one exception always peaked in the 35 to 45-Hz region at a rate near 40 Hz, but the actual optimal rate probably varies from one person to the next.*”(Galambos et. al, 1981). Based on this statement, it is reasonable to expect replicated results on only one subject.

Most probable reason for higher frequencies observed in responses to 4, 10 and 20 clicks per second are individual differences between different subjects. On average, observed ERP frequency was 61 Hz. Yet, response to 40 clicks per second does not contain a cycle of similar frequency, but it contains ringing at rates above 130 Hz. Reported results (Galambos et. al., 1981), however, do not exhibit ringing. They instead show prominent peaks at 40 Hz.

Even though there is a small amount of stimulus jitter, this should be manifested in the increase of ERP peaks width and should not significantly affect the response frequency. It is, therefore, possible that auditory potential of the subject in this experiment is not 40, but around 60 Hz. If this is the case, responses to 60 clicks per second should be synchronized with stimuli. Additional experiment could easily verify or dispute such hypothesis. Furthermore, to rule out any other factors affecting obtained results, the same experiment method should be used on more subjects.

## References

- [1] Mitra P. et al. (2008). Chronux [computer software]. Available from <http://chronux.org>
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- [3] Skoe E, Kraus N. (2010) Auditory brainstem response to complex sounds: a tutorial. *Ear and Hearing* 31(3): 302-324.