

WIRELESS MEASUREMENT BAND FOR EEG MISMATCH NEGATIVITY REGISTRATION IN MOBILE ACTIVITIES

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Abstract: Specialized equipment for measuring certain phenomenon in human brain called electroencephalogram mismatch negativity (EEG MMN) is presented. The equipment is wearable and features a wireless telemetry link for transmitting measurement data to an analyzer computer thus enabling new kind of research with EEG MMN being made in mobile situations.

Keywords: EEG, mismatch negativity, event related potential, wireless measurement.

1. INTRODUCTION

Mismatch negativity (MMN) is an automatic response generated by the brain to a change in an auditory stimuli [1]. MMN currently provides the only objective measure of the central auditory function [2]. The interest in MMN and its clinical and scientific applications has been steadily growing since the discovery of this phenomenon in 1978 [2]. The MMN has been used as a tool for studying cerebral functions and dysfunctions. It has been used for mapping, among others; accuracy of perception, duration of memory, speed of processing consecutive sounds, familiarity of sounds etc. MMN is an event related potential (ERP) elicited by a change in a sound stream. It can be evoked with many fashions. Mostly used are; change in frequency between standard and deviant stimulus, change in the interval of stimuli, change in stimuli amplitude or duration, and change in stimulus pattern if stimuli are constructed of a pair or a series of stimulus bursts. Stimulus burst can be for example a sinusoidal signal or a certain syllable.

The MMN is seen as a difference in brain's response to a deviant stimulus versus response to a normal stimulus. First, the event related component is separated from other EEG signal by averaging a large number of responses so that "not event related" part of the EEG which is seen as noise is diminished and only the event (stimulus) related part is left. After this, the average response to the normal stimulus is subtracted from the average response to the deviant stimulus. The EEG MMN is then found from the difference signal. [3]

We present a wireless and wearable device for measuring the MMN in mobile activities. The measurement system also includes a receiver device connected to a PC-

computer and software running on the PC for generating the measurement results.

2. MEASUREMENT SYSTEM

The measurement system consists of a measurement unit, receiver unit, a data logging and visualization software, and also data analyzing software running in a computer. The measurement unit is a flexible but firm head band made of plastic. All the electronics needed for the measurement and wireless data transmission is integrated into it. Block diagram of the measurement system is shown in the Fig. 1.

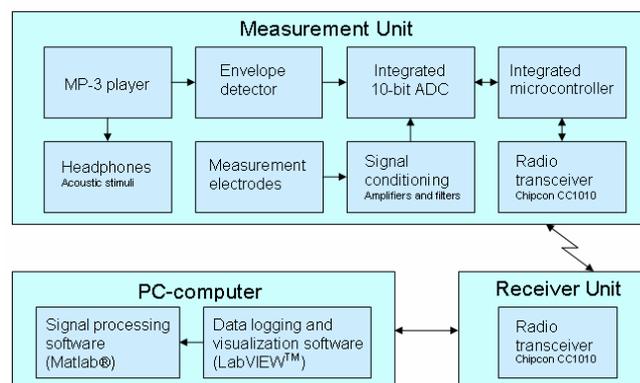


Fig. 1. Block diagram of the measurement system.

2.1. Stimulus signal

We are using a sinusoidal signal bursts as stimuli. The frequency of the standard stimulus is 1 kHz and deviant 1050 Hz. Standard and deviant stimuli also differ in amplitude. Deviants are 1.5 times higher in amplitude than standards. Duration of each stimulus burst is 100 ms and repetition interval 1 s. Stimuli have a random order so that average of approximately 20 % of stimuli are deviant and deviant stimulus is always followed by at least two standard stimuli. Each stimulus burst is windowed from both ends with 30 ms long, half Hanning window for making it to sound more comfortable. We made a Matlab® function for generating stimulus signals. The function takes as an input the frequencies, durations, repetition intervals, and lengths of stimuli and returns the generated stimulus in wav-format. Finally the stimulus signal is encoded into MP3 format and

repeated to both ears of the test subject with an MP3 player when recording the EEG signal.

2.2. The Measurement unit

As seen from the Fig. 1, the measurement unit consists of stimulating section (headphones, MP3-player, and envelope detector), amplifier section (electrodes, signal conditioning), and microcontroller section (radio transceiver with integrated microcontroller and AD-converter).

Measurement electrodes

We are using standard reusable Ag/AgCl-electrodes. Reference and ground electrode are EMG cup electrodes and recording electrode is an EEG cup electrode located firmly beneath the head band in the Cz electrode site of the standard 10-20 EEG electrode setup. Ground electrode is located onto middle of the upper forehead between the electrode sites FpZ and Fz of the 10-20 system. The reference electrode is placed to a neutral site behind the left ear. The electrode setup is similar to what was used in [3].

Amplifier electronics

For achieving the best quality measurement signal the EEG amplifier uses a three electrode setup, called “three electrode telemetry” in [4]. The amplifier is based on the same approved topology as was used in [5]. It has two stages, the first one realized with instrumentation amplifier and the second one with non-inverting amplifier connection. A first order passive high-pass filter with cut-off frequency 0.08 Hz is located between the stages. Low-pass filter for aliasing rejection is placed between the last amplifier and the AD-converter. 5th order switched capacitor filter from Maxim is used in aliasing rejection. The filter has Butterworth-type frequency response and cut-off frequency of 190 Hz. The gain of the amplifier in the pass-band is 5290.

The device has two channel AD-converter integrated with the microcontroller and radio circuits. One channel measures the amplified EEG signal with 490 Hz sample rate. The other channel measures stimulus signal, which is directed to the ADC through an amplifier and an envelope detector. The ADC separates standard and deviant stimuli from their amplitudes and marks the duration and the type of each stimulus by raising certain flag bits from each two byte EEG sample.

Radio transmission

The measurement data is transmitted in packets, each containing 15 two byte samples. A tiny protocol is used having 8 bytes of overhead in one 38 byte data packet. The overhead includes also 5 bytes of preamble to synchronize the receiver and transmitter. Each two byte data sample, however, has four non-useful data bits, which makes the data transmission less efficient. No return acknowledge packets are used because this would have decreased the possible amount of transmitted measurement data too much.

The radio circuit used is CC1010 manufactured by Chipcon AS and it operates in license free 868 MHz frequency band. The radio circuit has an integrated 8051-

based microcontroller in it, which makes it easy to use while many useful routines related to using the radio is readily given by Chipcon’s software support.

2.3. Receiver Unit

The receiver unit is located near the operating PC-computer. It receives the signal from the measurement unit and relays it to the PC through USB bus. Receiver also gets its power from the USB port.

2.4. Data logging software

A data logging software was made for LabVIEW™ to collect the measurement data. The program stores the received signal into the hard drive and also shows the measured signal in real time so that it is easy to see if the quality of the signal seems good and all the electrodes are properly connected.

2.5. Analysis software

We made a Matlab® program to analyze the measurement results. The software finds automatically the responses to stimuli and separates the responses for normal and deviant stimuli into different groups. The temporal accuracy of the detection of the stimulus signal is around ± 2 milliseconds. Then it averages the responses and calculates and visualizes the EEG MMN response. Averaging is done to improve the signal-to-noise ratio of the ERP waves. The SNR improvement is directly proportional to the square root of the number of averaged responses when thought that the noise is random and the EPR part is the same in all responses.

Analyzing of results from EEG MMN tests performed in different conditions is very easy with the software. The software is, however, still under development. For example it does not recognize if the measurement signal has large amount of interference in it and therefore the resulting response signals may distort when for example the electrodes has been badly connected.

3. RESULTS

We measured certain parameter from the measurement system to determine its performance. The measured parameters include amplifier noise, MMN response, radio transfer distance, and current consumption.

3.1. Amplifier noise

The performance of the EEG amplifier is good. The input referred rms noise for the amplifier in the frequency band of 0.08 – 190 Hz is less than 0.4 μVrms . When the measured signal is digitally filtered to 1 – 30 Hz, the input referred noise decreases to less than 0.1 μVrms .

Quantization step for the 10-bit AD-converter when using a 3.3 V reference voltage and a gain of 5290 is 0.61 μV . The rms quantization noise calculated for triangular waveform as reduced to input of the amplifier is 0.18 μV , refer to (1).

$$V_{Nqrms} = \sqrt{\frac{\Delta^2}{12}} = \sqrt{\frac{\left(\frac{ADC_{ref}}{2^{ADCbits} * gain}\right)^2}{12}} \quad (1)$$

3.2. EEG signal

We have made several test measurement to ensure that the system works properly. The real operational tests will be conducted by TAUCHI group in University of Tampere while they use the system in MMN research. Fig. 2. shows the EEG signal measured with the device. The signal is digitally filtered with pass-band of 1 – 30 Hz. The three spikes in the signal are N100 ERP waves aroused by the audio stimuli.

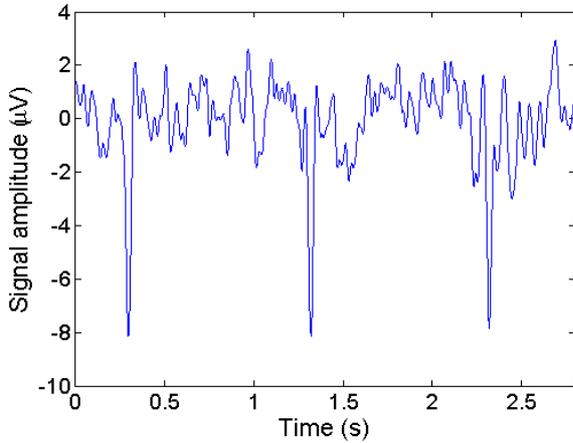


Fig. 2. Example of EEG ERP responses to audio stimuli.

Fig. 3. shows averaged EEG ERP signal for standard and deviant stimuli. The average ERP wave is calculated from 617 and 139 EEG responses for standard and deviant stimuli, respectively. As seen from the image, the averaged responses are quite much suppressed compared to the selected responses in the Fig. 2. This attenuation can be decreased by selecting more carefully, which responses are included in averaging. At present, all responses are included. Also the temporal uncertainty in recognizing the stimulus signal and fluctuation in N100 response affect to the amplitude.

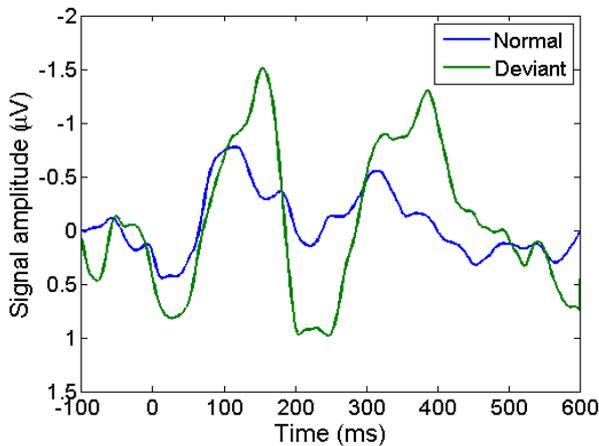


Fig. 3. Averaged ERP responses to normal and deviant stimuli.

MMN response calculated from the signals in Fig. 3, is shown in the Fig. 4. The waveform of the calculated MMN difference response is similar that can be found from the literature [1-3] but it is about a half smaller in amplitude. This difference is probably because all the EEG responses are taken into averaging and some of the responses have contained interference.

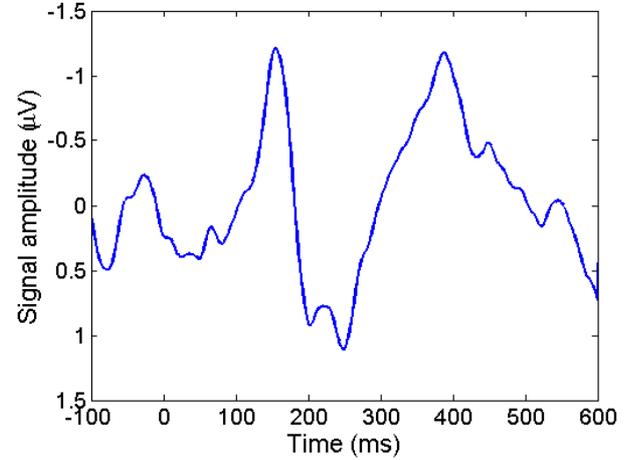


Fig. 4. EEG mismatch negativity.

3.1. Transfer distance and current consumption

We measured approximately 40 m for the maximum reliable transfer distance of the device in open air. Highest transmit power value and quarter wave monopole antenna in both ends were used. In indoors, absorption of structures decreases the transfer distance.

Current consumption of the measurement band depends on the transmit power used. The consumption varies between 26 mA and 36 mA when transmit power values -20 dBm and +4 dBm, respectively, are used. We have used -10 dBm transmit power in measurement unit. The receiver unit's transmit power is always +4 dBm. It can get its power from the USB-port of the computer and therefore the current consumption is not an issue. Operating times depend on the battery used with the device and the transmit power used. Continuous operating times of 20 h – 28 h are achieved using 720 mAh Li-ion mobile telephone battery.

4. CONCLUSION

We have presented a wireless measurement system for EEG MMN recordings in mobile activities. The post processing of the measurement data and generation of resulting EEG MMN graphs is automated. This makes performing the tests and conducting the results in various conditions straight forward and easy. Some improvements still need to be done for the system to increase its reliability as a research tool.

5. FUTURE WORK

In future we are going to design a new version of the measurement system having 16-bit measurement resolution. Another area of development to the measurement hardware will be to add a memory card to the measurement unit so

that the measurement data can be saved to the card while the connection to the receiver unit is not available. This allows even more mobility for the measurement of EEG MMN. We will also develop the signal analysis software so that it will be able to recognize and remove invalid EEG responses, e.g. responses containing too much interference.

One other problem with the present device is that the radio transmission does not have a data buffer and possibly lost data packets are not therefore retransmitted. So, if a data packet is lost during stimulus, the missing data causes interference to the calculated mean ERP complex. The problem can be solved in two ways. One, add a data buffer so that lost packets can be retransmitted or two, to add a time stamp to the data packets so that missing data can be recognized and EEG responses having data missing be ignored.

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