Automated Processing of EEG Recorded During Dichotic Listening Session: Problems of Single Response Recognition

Evgeny Wasserman[1], Nikolay Kartashev[2]
[1,2]Saint Petersburg Institute for Informatics and Automation of Russian Academy of Sciences, Saint Petersburg, Russia
[1]Saint Petersburg State University, Saint Petersburg, Russia
[1]Herzen State Pedagogical University of Russia, Saint Petersburg, Russia
[1]*ewasser@ev7987.spb.edu*, [2]*kolq@spiiras.ru*

***Abstract*— The traditional dichotic listening method requires active participation of the subject. In some cases that limits the usability of the method. We are looking for a way of obtaining dichotic listening results through automated analysis of synchronously recorded electroencephalograms. Three prospective approaches to solve this problem are considered. The preliminary results of experiments are included.**

Keywords*— *dichotic listening; lateralization of speech; electroencephalogram; pattern recognition

Dichotic listening (DL) is a psychophysiological method used by neurologists and neurosurgeons primarily to determine hemispheric lateralization of speech sound perception (for review see e.g. [3, 4, 5]). Although the reliability of DL method is not as high as of some alternative methods, in many cases it proved to be sufficient. The DL method is simple, affordable, noninvasive and safe. Moreover, it can help to investigate not only speech processing, but also several other brain functions [4, 5, 6].

The traditional DL technique is based on simultaneous presentation of pairs of identical or different sound stimuli (usually syllables) separately to each ear of the subject. The subject reports after each presentation, what he has heard; and the investigator records, which of two stimuli: the one presented to the left ear or the one presented to the right ear was uttered. As a result, the investigator obtains a series of binary values $S \in \{\text{"}left\text{"}, \text{"}right\text{"}\}$. Using this series it is possible to calculate the laterality index (LI) in the following way: $\text{LI} = 100\,(R - L) / (R + L)$, where R is the number of correctly reported stimuli presented to the right ear; L is the number of correctly reported stimuli presented to the left ear. The LI helps the physician or the psychologist prove some of their diagnostic assumptions. The sign of LI points at predominant language lateralization in the subject, its absolute value — at the degree of language asymmetry.

In 2008 we developed "Dichotic" — a computer program implementing the traditional DL technique [8]. The program has the following original features: runs on a regular PC and does not require special audio equipment. Also, it estimates statistical significance of the DL results using adjusted Wald confidence interval [7]. It has been introduced in the practice of several medical facilities in Saint Petersburg, Russia, where it is still being applied successfully.

The traditional DL technique employs the behavioral activity of the subject: the subject should tell the investigator what he has heard or press the respective button or key. On the one hand, it brings the additional data that can be used to estimate not only language lateralization, but also a broad range of cognitive and neurodynamic processes activated by the stimulus in the subject [4]. On the other hand, it is not always possible to obtain the satisfactory level of participation from the subject especially in cases of neurodynamic disorders, mental retardation, or in children [5].

We think some alteration of the traditional DL technique is worth a try. It can help us to overcome the abovementioned limitations and, at the same time, make the results of DL more objective. The active participation of the subject in the process of DL should be minimized and, ideally, replaced by fully passive participation i.e. by pure listening to stimuli, without giving any replies. Instead of behavioral replies we suggest to record an electroencephalogram (EEG) of the subject, firstly, because EEG is one of the most obtainable signals of the brain; and secondly, because it contains information about processes of perception, recognition, and decision making, activated by presented stimuli (for review see e.g. [1]). Other studies show that, depending on the different or identical stimuli that were presented, or which of the two different stimuli was selected by the subject, there are significant differences in corresponding EEG patterns [2].

The replacement of the active participation of the subject in DL by the recording and analysis of EEG can be performed at least in three different ways.

The first approach employs the analysis of short EEG epochs and complies well with the traditional DL technique. The result of the procedure is also the series of binary values S, but in this case they are obtained by recognition of EEG-patterns that correspond to the periods of sound stimuli perception. The advantage of this approach is the applicability of previous experiences of DL, but the possible drawback is the difficulty of detection of the desired signal in the background EEG, because the background EEG, having a similar spectrum, is 10 to 20 times more powerful [1].

The second approach uses the coherent averaging of EEG epochs corresponding to the periods of sound stimuli perception, as in evoked potential (EP) technique (for review see e.g. [1]). In this case the series of binary values *S* is not available, but it becomes possible to estimate the analogue of LI by the analysis of EPs.

The third possible approach consists in the analysis of the overall brain activity during DL, without selection of specific epochs. Although neither special DL settings nor EEG preprocessing is required to implement it, the possible difficulties would be the unknown ratio of informative and non-informative epochs of signal and the unclear physiological interpretation of LI analogue estimated in such way.

Thus, our final goal is to develop the new, EEG-based DL method. The first step might be the assessment of the potential value of information being collected using each of three approaches to the EEG-based DL. The further discussion is devoted to the settings we applied and results we got exploring the first approach.

The subject (a clinically healthy male volunteer, right-handed, 50 years of age) participated during four months in four DL sessions (2234 stimuli were presented in total). During sessions, the subject was passively awake with eyes closed. He gave oral report to each stimulus being presented. To perform DL we used "Dichotic" program [8] with syllables stimuli set. No special instructions as to which ear to attend were given. In parallel we recorded 19-channel EEG (10-20%, dedicated reference electrode). We used "Telepat-104" digital EEG system (16-bit ADC; 250/s sampling; bandwidth 0—100 Hz; developed by Potential ltd, Russia)

To ensure precision of synchronization between audio stimuli and EEG (an error of no more than one EEG sample) we released the special edition of syllable stimuli set for "Dichotic" program. We used a 5.1 layout: the front left (FL) and the front right (FR) channels were used to present stimuli, the surround left (SL) channel contained synchronization signals for the EEG system. The three remaining channels were silent. The audio signal SL was fed into the EEG system through one of its vacant universal channels using an adapter we have developed before.

Recorded EEGs were subjected to a virtual montage with Cz as a reference electrode, then they were digitally filtered with 0.3 s time constant for high-pass filter, 30 Hz cutoff frequency for low-pass filter, and 50 Hz band-stop frequency. Then EEGs were visually analyzed and epochs containing apparent artifacts (signals of non-cerebral origin) or abnormal background patterns not related to the stimulation were marked. Also, using synchronization channel and logs of "Dichotic" program, we automatically marked fragments of EEG corresponding to four possible types of report of the subject:

- syllable presented to the left ear (case of different syllables);
- syllable presented to the right ear (case of different syllables);
- correct answer (case of identical syllables);
- wrong answer (the subject uttered the syllable had not been presented at the time).

For further processing at this (beginning) stage of our investigation we used only fragments of the first two types (we named them L-fragments and R-fragments respectively). The fragments that fully or partially contained artifacts were rejected.

The LIs of the subject in all four sessions were positive, so the total amount of R-fragments exceeded the total amount of L-fragments. To balance the sample we randomly truncated the R-fragments class.

For each type of fragment and EEG channel we calculated and plotted averaged patterns. (Fragments being averaged were aligned along the time axis by the first nonzero sound sample in one of two stimuli channels FL or FR.) In general, principal elements of the resulting auditory EP complied with the patterns described by the other authors [2].

Next we attempted to perform an automated recognition of the fragment type in the following way. Each of the fragments, one by one, was taken out. The remaining fragments served as a training sample. The further processing was performed for each EEG channel independently. An average among the fragments was calculated for each class in the training sample. The proximity of this average to the fragment being recognized at the moment was used to classify the fragment. As a measure of proximity the correlation coefficient between respective vectors was selected. After classification, the fragment was put back into the sample and the procedure was repeated for the next fragment.

We have tried different durations of the fragments from 0.42 s (the longest stimulus) to 2.42 s (the smallest distance between two subsequent stimuli) with the step 0.2 s. For each duration and EEG channel we have calculated the ratio of correctly classified fragments to the total amount of fragments in percentage form. An average value for all trials is 54.5%; standard deviation is 3.6%. In comparison, an artificial sample consisting of the equal number of L- and R-fragments in each class has been classified with the average 49.5% and standard deviation 3.7%.

Also we selectively have made calculations for several different settings: 1) using as a measure of proximity the square root of the sum of the squared differences of samples in corresponding vectors; 2) using the k-nearest neighbor method to perform classification; 3) aligning fragments by the last nonzero stimuli samples; 4) aligning fragments by the maximum of the averaged amplitude in FL and FR channels; 5) applying a sliding mean with the window size from 5 to 55 to the averaged patterns but never gaining any significantly better results.

These not very exciting results should not be considered as final. By no means do we claim to have completed the exhaustive analysis of the problem. Besides, there is a possibility of the methodical errors since we have not had an independent testing sample.

We are going to continue the exploration of the first approach to EEG-based DL by switching from raw EEG fragments processing to the derived characteristics. Also, the experimental data being collected during this investigation will make possible an assessment of applicability of the second and the third approaches. As a result, we hope to develop the reliable EEG-based DL method and the computer system implementing it.

REFERENCES

[1] Auditory evoked potentials: basic principles and clinical application / R.F. Burkard, J.J. Eggermont, M. Don (Eds.). Philadelphia: Lippincott Williams & Wilkins, 2007.

[2] Bayazit O., Oniz A., Hahn C., Güntürkün O., Ozgören M. Dichotic listening revisited: trial-by-trial ERP analyses reveal intra- and interhemispheric differences // Neuropsychologia. 2009, V. 47, N. 2, P. 536–545.

[3] Handbook of Dichotic Listening: Theory, Methods, and Research / K. Hugdahl (Ed.). New York: John Wiley & Sons, 1988.

[4] Hugdahl K. What can be learned about brain function from dichotic listening? // Revista española de neuropsicología. 2000, V. 2, N. 3, P. 62–84.

[5] Pelletier I., Sauerwein H.C., Lepore F., Saint-Amour D., Lassonde M. Non-invasive alternatives to the Wada test in the presurgical evaluation of language and memory functions in epilepsy patients // Epileptic Disorders. 2007, V. 9, N. 2, P. 111–126.

[6] Takio F., Koivisto M., Jokiranta L., Rashid F., Kallio J., Tuominen T., Laukka S.J., Hamalainen H. The effect of age on attentional modulation in Dichotic listening // Dev Neuropsychol. 2009, V. 34, N. 3, P. 225–239.

[7] Wasserman E., Kartashev N. Dichotic listening: computer implementation, methodical problems, and modeling prospects // The Third International Conference «Problems of Cybernetics and Informatics» (PCI'2010), September 6–9, 2010, Baku, Azerbaijan. V. 1. Baku: Elm, 2010. P. 106–109.

[8] Wasserman E.L., Kartashev N.K. A program for dichotic presentation of acoustic stimuli // XI Saint-Petersburg international conference «Regional Informatics — 2008» (RI–2008), Saint-Petersburg, October 22–24, 2008: Conference proceedings. SPb:: «SPOISU» Publishing, 2009, P. 269–272 [in Russian].