DICHOTIC LISTENING: COMPUTER IMPLEMENTATION, METHODICAL PROBLEMS, AND MODELING PROSPECTS

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One of the typical problems solved in neurology and neurosurgery when somebody plans directed medical intervention on structures of the brain is a determination of predominant language lateralization. As a reference method they regard the amobarbital Wada test, however it is an invasive and rather unsafe procedure. As a modern alternative they consider functional magnetic resonance imaging, positron and single photon emission tomographies, functional transcranial Doppler sonography, magnetoencephalography, etc [1, 2]. However even these methods, having a number of advantages, have the essential constraints limiting their application: the majority of them are very expensive, not always accessible locally or have contraindications or it is difficult to apply them to children. The best known simple and accessible method replacing Wada test at preliminary tests stage and for the control over efficiency of treatment, and also allowing to solve a number of specific clinical psychophysiologic problems, is a dichotic listening (DL) of speech [3, 4].

We have developed the original software allowing to carry out the traditional DL technique without use of the special acoustic equipment [5]. The application runs on the commercially available personal computer equipped by a sound card, headphones and working under control of operating system Microsoft Windows.

In a basis of DL technique lies simultaneous presentation of pairs of identical or different sound stimuli in both ears of the subject. According to instructions, the subject after each presentation reports what he/she has heard, and the investigator puts down, with which of two stimuli: with one presented in the left ear or with one presented in the right ear, this answer coincides. Thus, the immediate result of the investigation is a series of binary values $S \in \{'left', 'right'\}$. On the basis of this series it is possible to calculate the laterality index (LI) using the formula:

$$LI = 100\frac{R-L}{R+L}\,[\%],$$

where *R* is the number of correctly reported stimuli presented in the right ear, *L* is the number of correctly reported stimuli presented in the left ear. The value *LI* allows the physician or the psychologist to prove some diagnostic assumptions. First of all it concerns predominant language lateralization in subject which can be left- or right-sided (it is determined by sign of *LI*), and also more or less expressed (it is determined by absolute value of *LI*) [for the review see, e.g., 2, 6, 7].

In our software three modes have been implemented: a calibration mode, an audiometry mode and a DL mode proper. The first two modes are auxiliary: the calibration mode is used for adjustment of parameters of an audio channel of computer referring to absolute values, and an audiometry mode is used for determination of thresholds of hearing of the subject.

Values of a level of loudness in audiometry and DL modes are determined and set in decibels. The level of loudness *X* expressed in decibels is connected with amplitude of sound pressure by a following ratio:

$$X = 20\lg\frac{A}{A_0},$$

where *A* is an amplitude of sound pressure, A_0 is an amplitude of sound pressure corresponding to the standard threshold of hearing.

In DL mode the investigator chooses the type of stimuli which will be presented to the subject. If the given subject is investigated for the first time, it is advisable to present firstly a series of pairs of identical stimuli to estimate whether the volume adjustment is correct and whether responses of the subject are adequate. If it is necessary, it is possible to instruct him again, turn the volume up or down, etc.

Then the investigator starts a countdown of seconds (4 seconds by default) after which the pair of identical or different sound stimuli are synchronously presented to the subject bilaterally. The subject reports, what he/she has heard, and the investigator inputs the response in the program. Then the cycle repeats: the countdown, the next pair of stimuli, etc.

Pairs of stimuli for presentation are selected randomly from group of stimuli of the given type (let us call it 'basket'), then they are not returned to the same basket, but are moved to the other basket. When the first basket is empty, contents of the second basket is shuffled, baskets are swapped and the process repeats.

The basic version of the program contains a set of specially crafted audio files with speech stimuli of the following types: syllables, monosyllabic words and disyllabic words, uttered by male human in Russian. Stimuli are divided into following groups: identical syllables in both ears (6 pairs), identical monosyllabic words in both ears (8 pairs), identical disyllabic words in both ears (20 pairs), syllables(36 pairs), monosyllabic words (64 pairs), disyllabic words with an accent on the first syllable (196 pairs), disyllabic words with an accent on the second syllable (36 pairs).

The user interface of the program is optimized for presentation of this speech stimuli with a purpose of non-invasive determination of predominant language lateralization. However if necessary the program can be easily modified for presentation of other types of sound stimuli (according to the purposes of planned investigations).

In 2008 the program has been introduced in practice of establishments of public health services of St.-Petersburg where it continues to be applied successfully until now, however during its development and usage a number of methodical problems not solved in full or in part showed up. First, the traditional variant of DL technique assumes presentation of empirically picked up fixed number of stimuli and does not allow to determine the statistical significance of the results of the test. Secondly, while examining children the investigator quite often has to stop the test ahead of time because of an exhaustion of attention of the subject, and in the further analysis either has to use results knowingly not comparable to others or to reject them as not interpretable. Therefore, the purpose of next stages of our work became the solution of the problems specified above, i.e. development and program implementation of DL technique for determination of predominant language lateralization on the basis of the analysis of the statistical significance of testing results.

We had led the review of the scientific publications touching questions of application of statistical methods to DL results. As a result of the review, absence among investigators of the consistent approach to definition of number of stimuli which it is necessary to present during DL has been revealed. In most cases this number is chosen empirically, and a series of binary values *S* is not analyzed at all. Only *R* and *L* are counted. We also have analysed the variants of DL technique described in the literature from the point of view of the significance and robustness of received results (that is especially important when the number of presented stimuli varies).

It appeared that the easiest for interpretation and the most universal method is calculation of a confidence interval (CI) for LI because it requires only one assumption: that each iteration of DL algorithm is an independent trial of the subject. And as generally we cannot determine a priori the importance in the sense of lateralization of stimuli pair, we consider these pairs equivalent. In practice we suggest to consider that if CI for LI, calculated with the given confidence level, includes zero, then the advantage of an ear is insignificant. If zero is not included in CI, then the advantage is significant.

In our program for determination of limits of CI we use an adjusted Wald interval [8, 9] as one easy enough to implement and at the same time providing better, than traditional Wald and a number of other methods, covering at the small sample sizes [10, 11]. The interval is symmetric with respect to biased estimate p_a:

$$p_a = \frac{np + z^2/2}{n + z^2},$$

where *n* is a total number of correctly reported stimuli; *p* is a ratio of number of correctly reported stimuli presented in the right ear to *n*; *z* is a quantile of standard normal distribution, corresponding to given confidence level (when $p = 0$ or $p = 1$ *z* for one-sided CI is used). The width of CI is calculated as follows:

$$z\sqrt{\frac{p_a(1-p_a)}{n+z^2}}.$$

We calculate CI limits for LI using the following formula: $LI = 100(2p - 1)$. If the absolute value of one of the limits is above 100%, for the user we display 100%. The limits of CI are updated on each step of DL algorithm that gives the user the possibility to estimate the potential informativeness of investigation results in real time.

But one problem still remains unsolved. The matter is that long DL experiments specially conducted by us (with presentation of 300-400 pairs of stimuli) have shown instability of LI and low speed of narrowing of its CI. Even little change in the attention of the subject can alter the answer to the question, whether the advantage of the ear is significant. At the same time there is no adequate adaptive model of behaviour of the subject and, therefore, of behaviour of LI. That is why our further efforts will be concentrated on the analysis of logs of real investigations (as series of binary values *S*, and values of LI calculated on each step), carried out using our program, and on creation of one or several models of an investigation process. As a result we hope to create a DL technique allowing us on each step of the algorithm to automatically determine the probability of the event that the increase in number of iterations will lead to qualitative change of the significance of an estimation of advantage of an ear and, therefore, allowing us to judge the possibility to reduce the number of stimuli without damage to informativeness of the whole research.

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