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PERCEPTION OF FAST TIME FLUCTUATIONS IN THE SOUND LEVEL BY PERSONS WITH A COCHLEAR IMPLANT

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The paper presents results of scaling of loudness changes of natural sounds for persons with a cochlear implant by the so-called NSLE method. The possibilities of the use of this method of loudness scaling of natural sounds in the rehabilitation of persons with a cochlear implant have been analysed.

Keywords: perception, fluctuations in the sound level, persons with cochlear implant.

1. Introduction

The correct perception of speech requires that the hearing system would be capable of:

- following the fast time fluctuations of the sound level in a certain range of the hearing dynamics,
- detection of frequency components,
- detection of frequency changes in the sound signal pitch.

Evaluation of all those psychoacoustic features of hearing requires complex and time-consuming measurement procedures. Moreover, interpretation of the results obtained, taking into regard the significance of individual effects in the speech perception, remains an open question. This paper reports an attempt to evaluate the ability to follow fast time fluctuations of the natural sound level by persons with a cochlear implant using the NSLE method developed for adjustment of hearing aids (HOJAN, GEERS, JEZIERSKA) [3, 4, 7, 8]. The thesis of this study is that the ability based on natural sounds of complex temporal and spectral structure reflects all the above psychoacoustic features of hearing and significantly affects the comprehension of speech by persons with a cochlear implant [1, 11]. The starting point is the physical course of time changes of speech, which can be treated as an amplitude modulated acoustic signal [2, 9]. Another thesis is that the improvement of the ability to follow fast temporal fluctuations in the level of natural sounds (by training) can accelerate the process of rehabilitation of the persons with the a cochlear implant in the area of speech comprehension.

To verify those theses, a study was undertaken on the ability of scaling of loudness of natural sounds by persons with a cochlear implants.

2. The method

2.1. Measuring signals

The sounds used in the study included:

- Music:
  - fragment of the piano concerto G-major by Ravel,
  - fragment of the fugue B-minor by Bach;
- Noise:
  - from the sports stadium during a football match,
  - street noise of moving cars and trams,
  - office noise of typing, steps, conversation, door slam.

These sounds are characterised by specific acoustic parameters [7] whose measurement by the NSLE method is possible with the help of a computer program TRAX [3]. The parameters measured are:

- the sound duration T;
- the sound equivalent level L_{eq}

$$L_{\text{eq}} = 10 \cdot \log \left[\frac{1}{T} \int_0^T 10^{0.1 \cdot L_p(t)} \, \mathrm{d}t \right], \tag{1}$$

where L_p is the sound level.

$$D(\text{dynamic}) = L_{\max} - L_{\min}. \tag{2}$$

The measured values of the acoustic parameters of the sound signals used are given in Table 1.

The above acoustic signals were recorded on a computer hard disk in digital form to ensure the possibility of a many times use at the same quality of reproduction.

Table 1. Parameters of the signals used in the study.

No.	Sound type	L_{eq} [dB]	$L_{\min}$ [dB]	$L_{\max}$ [dB]	D [dB]	T [s]
1	Ravel	65	43.2	77.6	34.43	163
2	Bach	65	40.2	72.6	32.4	190
3	Street	65	48.2	76.7	28.5	174
4	Office	65	49.4	81.8	32.4	82
5	Match	65	39.7	76.5	36.8	180

2.2. Categorical scaling

The method applied for the determination of correct relations between the objective and subjective evaluations of time changes in the sound level is based on the categorical assessment of the sound perceived by the listener and a simultaneous recording of the time changes in the amplitude of acoustic pressure of the sound [2]. To measure the level of the signal loudness the scale of categorical scaling proposed by HELLER has been adopted [5]. This scale differentiates 5 categories of the signal loudness: very low, low, normal, high and very high. The range corresponding to each of these categories was divided into 10 sub ranges so that the full scale spreads from 1 to 50. The low part of the scale ends with an additional category "not heard" at 0, while the high part is open allowing the recording pain sensations expressed by numbers 51, 52, 53.

Figure 1 presents the monitor screen displaying the scale of categorical evaluations.

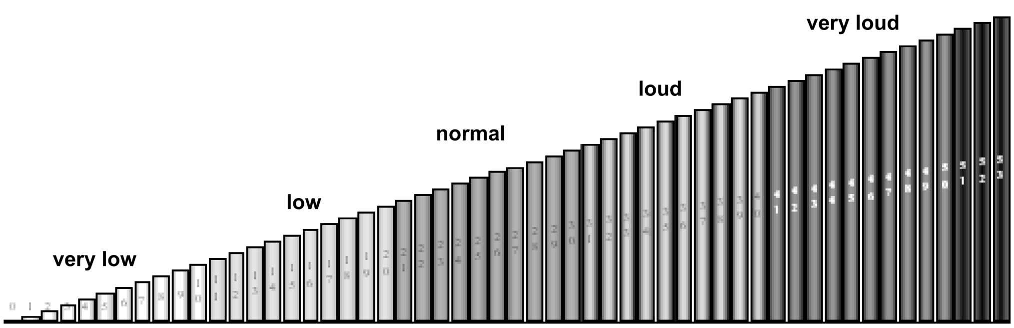

Fig. 1. The scale of categorical evaluations of loudness [3].

The division of the particular categories into sub ranges has substantially increased the resolution of the scale with respect to that of the usual categorical scale, which permits a reduction of the repetitions in the psychoacoustic tests. The categorical evaluation of the sound loudness established in earlier studies has shown a high repetition of individual results and the mean deviation did not exceed 3 points from the mean value on a 50 point scale [5].

2.3. Evaluation of speech intelligibility

The speech intelligibility was evaluated on the basis of standard Polish test lists used for speech audiometry recorded on a CD Westra no 14. The speech intelligibility was determined in the free field using both the number and word tests. In the number tests, the list was made up of 10 numbers of two digits and each number understood correctly was scored as 10%. In the word test the list was made up of 20 nouns and each noun understood correctly was scored as 5%.

2.4. Listeners

The subjects of the study were 7 patients of the Laryngological Rehabilitation Centre at the Otolaryngology Clinic of the Medical University in Poznań with cochlear implants Nucleus 24 or Nucleus 22. Table 2 gives general information on the patients: the time of the implant use, level of rehabilitation, duration and origin of hearing impairment.

Table 2. Characterisation of the patients.

Patient	1	2	3	4	5	6	7
Patient’s age in years	17	30	43	45	34	15	15
Duration of hearing impairment in years	1	14	1.5	6	12	12	14
Origin of hearing impairment	genetic	ototoxic drugs	meningitis	ototoxic drugs	ototoxic drugs	acquired	ototoxic drugs
Use of hearing aid	yes	initially	no	yes	yes	yes	yes
Duration of use of cochlear implants in month	3	2.5	1	4	62	60	17

The only criterion of the listeners selection was to make sure that they understand the procedure of the study and their agreement for an active participation in the study. For the process of selection, the information from the speech therapists working with the patients with cochlear implants proved to be useful. Only subjects no 1 and 3 got the CI very fast. The subjects no 2 and 7 have waited 13 years; the last one was practical deaf from the beginning of live.

2.5. Experimental conditions and measuring apparatuses

The listening was performed in a room specially adapted for a hearing study. The noise level in the room was lower than 40 dBA. The calibration of the apparatuses were made independently for the study of each patient with an acoustic pressure level in the free field at a distance of 1 m from the loudspeakers established as 65 dB SPL by a sonometer. The calibration signal was the CITT noise [2]. The experiment was performed with a measuring set-up commonly used in studies of this type (see Fig. 2) composed of a computer with the operation system Windows XP, a Sound Blaster Card, a CD-ROM player, a set of loudspeakers of the Perfect 150 type and an audiometer permitting measurements in the free field.

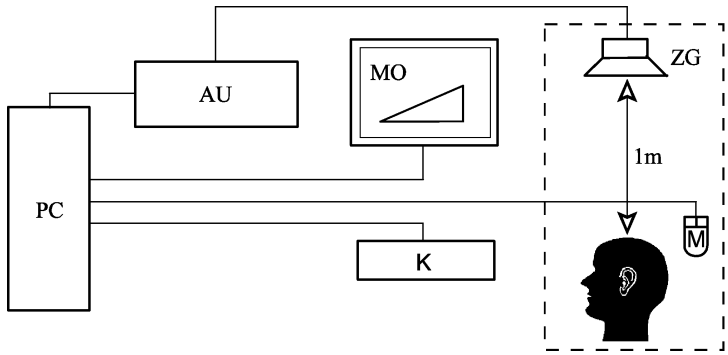

Fig. 2. Block diagram of the measuring system used in the study: PC – computer, MO – monitor, K – keyboard, M – mouse, ZG – loudspeakers, AU – amplifier.

The preliminary step was to adjust the speech processor of CI of the listener at a level of good perception of the speech from the word test.

2.6. Measurements

The subjects were asked to listen and follow the changes in the signal intensity and to assign the subjective sensations of the loudness to points on the categorical scale displayed on the monitor screen. Figure 3 presents an exemplary result of the categorical assignment to the sounds of the Bach Fugue by a listener.

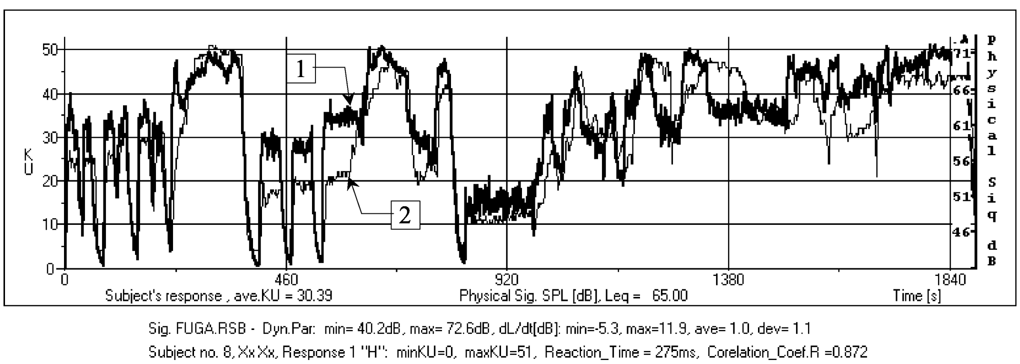

Fig. 3. Exemplary result of the categorical assignment and changes in the acoustic pressure of the natural sound after the experiment of listening to the Bach Fugue recorded in the TRAX program.

In order to determine the zero point for the subjective (curve 2) and objective (curve 1) time courses of the signal, the time of direct response of the listener was measured prior to the listening.

The listener's indications are recorded automatically and sampled with the frequency of 41.4 kHz, then they are displayed against the corresponding objective values recorded in the computer memory. The TRAX program determines the degree of agreement between the objective change in the acoustic pressure level as a function of time and the categorical evaluation of these changes are mathematically expressed by the correlation coefficient between these two functions and assumed as the "follow up" index of perception of the sound level changes q:

$$q = \frac{\sum_{i=1}^{N} (x_i - \overline{x}) \cdot (y_i - \overline{y})}{\sqrt{\sum_{i=1}^{N} (x_i - \overline{x})^2 \cdot \sum_{i=1}^{N} (y_i - \overline{y})^2}}, \tag{3}$$

where x, y – the measured values of the studied amplitude functions, $\overline{x}$, $\overline{y}$ – the mean values of the amplitude functions, N – the number of measuring points.

3. Results

3.1. Word tests

Figure 4 presents the results of speech intelligibility evaluation by particular subjects determined in the number and word tests.

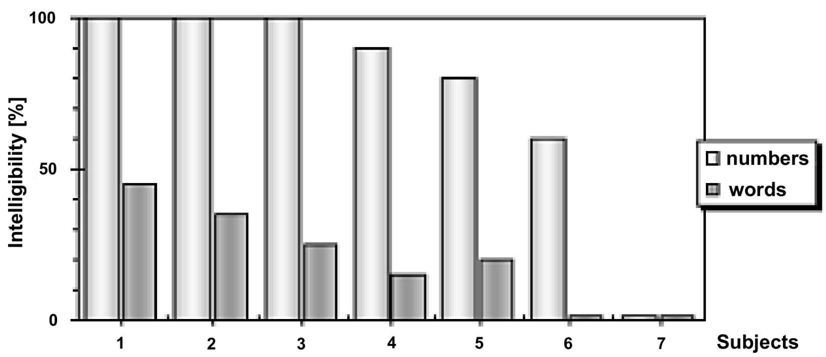

Fig. 4. Graphic illustration of the results of the speech intelligibility tests.

The lowest intelligibility index had subject no 7. In each case the intelligibility index for numbers was bigger than 60%.

3.2. Dependence of the q index on the type of sound

Figure 5 presents the mean values of the q index obtained for individual subjects from three listening experiments by the NSLE method for 5 types of natural sounds.

Only for subject no 7 the "follow up" index q was very small for the Bach signal. For each subject the lowest "follow up" index q was noticed for the sound "Office" (very short dynamic change in sound).

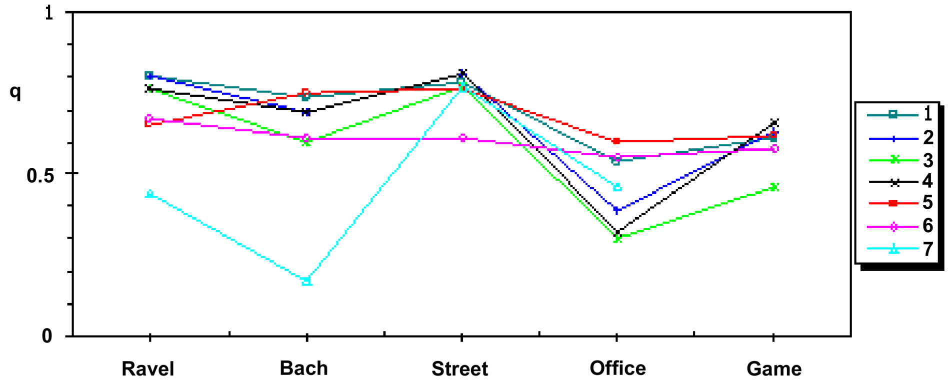

Fig. 5. Mean values of the "follow up" index q obtained byparticular subjects (1–7) by five types of sounds.

The standard deviation of the values of q for particular sounds varied from 0.01 to 0.08, which indicates a high reproducibility of the results (Table 3).

Table 3. Mean values and standard deviations of the "follow up" index q determined for individual subjects 1–7.

no.	Signal	1	2	3	4	5	6	7	mean	SD
1	Ravel	0.80	0.80	0.76	0.76	0.65	0.67	0.44	0.70	0.13
2	Bach	0.74	0.69	0.60	0.69	0.75	0.61	0.17	0.61	0.20
3	Street	0.78	0.81	0.77	0.81	0.76	0.61	0.77	0.76	0.07
4	Office	0.54	0.39	0.30	0.32	0.60	0.55	0.46	0.45	0.12
5	Game	0.61	0.63	0.46	0.66	0.62	0.58	–	0.59	0.07

3.3. Categorical evaluation of the loudness of the acoustic signals

Figure 6 presents the mean values of the categorial evaluation calculated by the program TRAX, of three listening experiments in which the seven subjected were exposed to the 5 types of sounds.

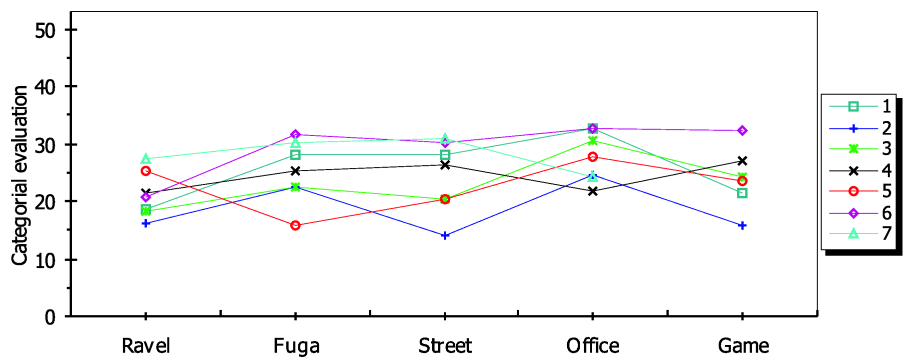

Fig. 6. Mean values of categorical evaluation of 5 types of sounds for 7 subjects.

Only for the subject no 5 the categorical evaluation of two sounds: Street and Game was on the level 15 (low).

Figure 7 illustrates the dependence of the “follow up” index q on the mean value of the categorical evaluation of 5 types of natural sounds.

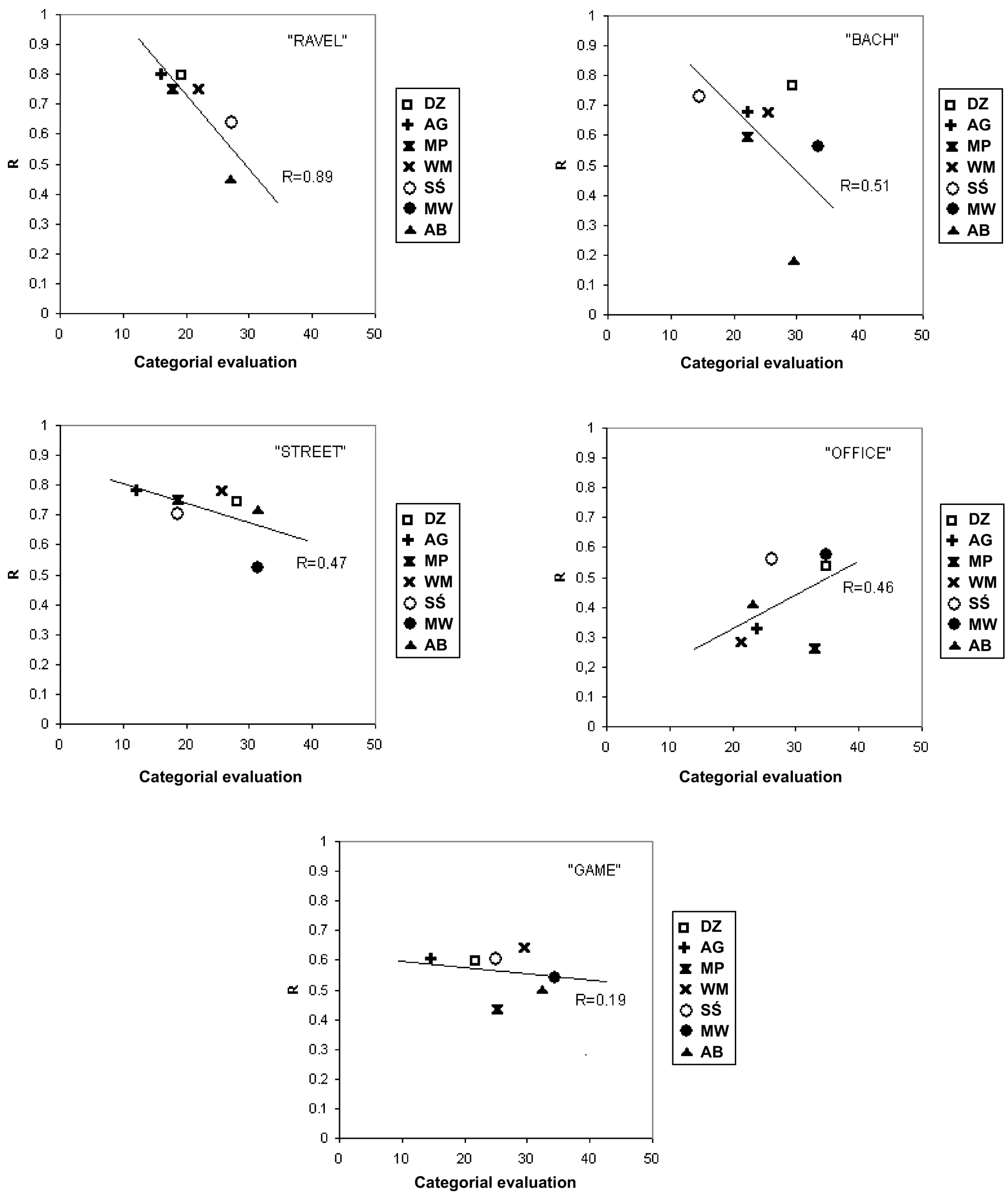

Fig. 7. The “follow up” index q as a function of the mean value of the categorical evaluation of 5 types of sounds, R – linear regression coefficient.

Only for the sound "Ravel" the regression coefficient is larger than 0.60 ($R \geq 0.89$).

Figure 8 presents the results of the speech intelligibility test as a function of the "follow up" index for 5 types of natural sounds.

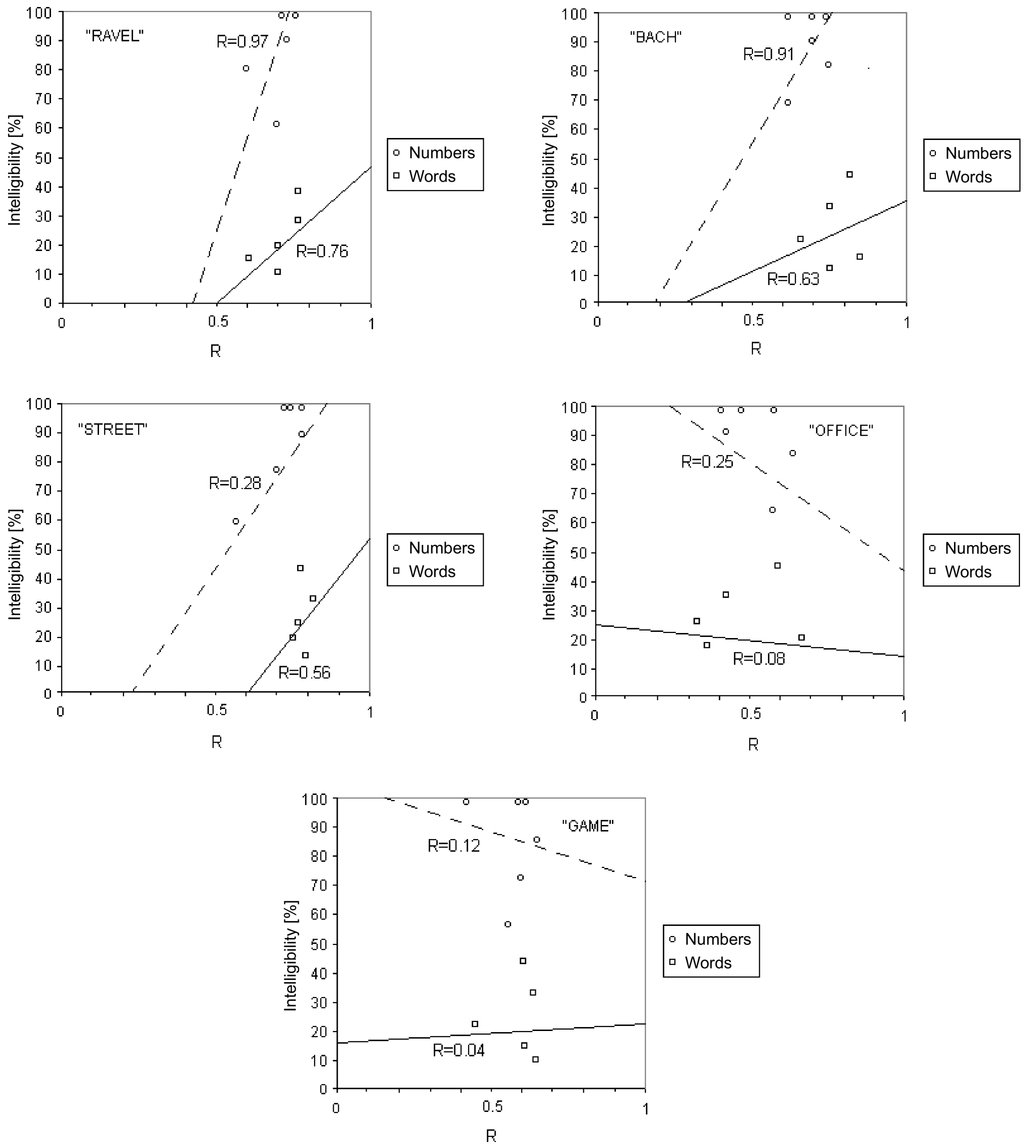

Fig. 8. Speech intelligibility test scores as a function of the follow up index, ○ – Numbers, □ – Words.

A very high correlation ($R \geq 0.90$) was noticed only for the intelligibility index of Numbers for two sounds: "Ravel" and "Bach". For these sounds, a highest correlation was noticed by the intelligibility index of Words ($R \geq 0.60$), too.

These two kinds of sounds were identified as the best ones for the use of the NSLE method for the hearing aid fitting, too [4, 7, 8].

4. Discussion

The analysis of the results of categorical scaling of changes in the natural sound level by the NSLE method obtained for the persons using a cochlear implant has led to the following observations:

1. No relation between the “follow up” index q and the experience in computer operation (data from interview) has been found.
2. The standard deviation of q varies from 0.01 to 0.08, which indicates a high reproducibility of the results. The lack of a significant improvement in the subsequent listening experiments from the same series shows that the memory effect was very small (Table 3).
3. The “follow up” index values q are related to the sounds remembered by the subjects who lost hearing later in life and to the acoustic environment they live in when using the cochlear implant (data from the interview).
4. The persons who had no problems with hearing at some period of time or those who had effective assistance from conventional hearing aids achieved for music index values $q \geq 0.6$. For one person practically having no earlier contact with music, the q value was lower and much lower in the experiment of listening to the B-minor fugue by Bach ($q \leq 0.17$) – Fig. 5.
5. The high value of the “follow up” index obtained in the experiments in which the listeners were exposed to “Street” noise seems to be a consequence of common occurrence of such sounds in everyday life and the physical parameters of the dynamics of this type of acoustic signals. Notably higher values of the q index in the experiments with exposure to “Office” noise were obtained by persons who had used the implant for a long time and by those who had contact with office or school noise. The q values obtained in the experiments with exposure to the football “Game” noise were intermediate between those obtained in the experiments with exposure to “Street” noise and to “Office” noise.
6. The results have shown that a higher subjective categorical evaluation of acoustic signals does not imply a better perception, in particular of low sounds. A good agreement of the categorical evaluation with the “follow up” index was obtained ($R = 0.89$) when the listeners were exposed to the Ravel music (Fig. 7). For musical sounds this agreement is related to the fast changes in the spectral characteristics of the sounds of this type.
7. In general, besides the acoustic properties of the signals used, the results should be considered in the aspect of the mode of sound coding by the speech processor and subjective sensations of the listener.

8. In the categorical scaling by the NSLE method, the scatter of the evaluation results as a function of the acoustic pressure for a particular type of signals is an individual feature of the person with the cochlear implant. A smallest scatter of results was obtained in the experiment with the fragment of the music by Ravel. The results were not significantly different from those obtained for normal hearing persons.

5. Conclusions

The analysis of the results of the above described experiments and their discussion has permitted to draw some conclusions concerning the practical application of the NSLE method for persons using a cochlear implant.

- The experience of persons with a cochlear implant following from the procedure of the speech processor adjustment has permitted their fast response by the assignment of loudness on the categorical scale to particular sounds.
- The experiment was assessed by the subjects as difficult relative to the tonal audiometry, e.g. in the free field, but as easier and more friendly than the word tests, especially by persons who have problems with speech intelligibility.
- The results have indicated an idiosyncratic character of scaling of changes in the sound level and certain relations between the results and the knowledge of the sounds from the close environment.
- Results of the NSLE method applied with musical sounds (first of all in the case of Ravel sounds) permit the estimation of the speech intelligibility in word tests.

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