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NUISANCE ASSESSMENT OF DIFFERENT ANNOYING SOUNDS BASED ON PSYCHOACOUSTIC METRICS AND ELECTROENCEPHALOGRAPHY

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Abstract

The aim of the study was to assess whether four psychoacoustic parameters (sharpness, roughness, fluctuation strength and tonality) are useful in describing the perceived annoyance of selected noise sources with respect to an objective assessment based on the acoustics standards. Second goal was to verify if the perceived annoyance of such noises correlates with dominant frequency in electroencephalography (EEG) frequency bands. Twenty sound sources, varying in the degree of nuisance, have been assessed by 178 respondents in an Internet-based psychoacoustic test. Obtained annoyance grades were correlated with calculated psychoacoustic and normative parameters and the positive correlation between perceived annoyance and three psychoacoustic parameters (sharpness, roughness and fluctuation strength) was found. In the second part EEG study during listening of recorded sounds was performed on 18 healthy volunteers. Spearman's rank correlation confirmed that dominant frequencies in alpha (7-14 Hz) and beta2 band (20-30 Hz) were rising with the increasing annoyance of the sounds. Results obtained may be useful in specifying and clarifying permissible noise levels for annoying sounds.

Keywords: noise assessments, annoying sounds, sound nuisance, sound quality, EEG, psychoacoustics

OCENA UCIĄŻLIWOŚCI WYBRANYCH ŹRÓDEŁ HAŁASU NA PODSTAWIE PARAMETRÓW PSYCHOAKUSTYCZNYCH I BADAŃ ELEKTROENCEFALOGRAFICZNYCH

Streszczenie

Celem prac było zbadanie czy psychoakustyczne parametry takie jak ostrość, szorstkość, siła fluktuacji, tonalność mogą być użyteczne do opisu uciążliwości wybranych źródeł hałasu, w odniesieniu do obiektywnej oceny opartej o akustyczne standardy. Drugim celem pracy było sprawdzenie, czy postrzegana uciążliwość tych dźwięków koreluje z częstotliwościami dominującymi w pasmach częstotliwości stosowanych w elektroencefalografii (EEG). W pierwszej części badań 178 osób wypełniło ankietę, oceniając uciążliwość prezentowanych dźwięków. Otrzymane oceny zostały skorelowane z wyliczonymi psychoakustycznymi i normatywnymi parametrami. Potwierdzono, że wraz ze wzrostem wartości parametrów takich jak ostrość, szorstkość i siła fluktuacji, wzrasta także postrzegana przez słuchaczy uciążliwość dźwięków. W drugiej części eksperymentu wykonano badania EEG 18 osób podczas odsłuchu powyższych 20 nagrań. Test korelacji rang Spearmana potwierdził, że dominujące częstotliwości w paśmie alfa (7-14Hz) i beta2 (20-30Hz) wzrastały wraz ze wzrostem średniej oceny uciążliwości. Wyniki przeprowadzonych badań mogą być przydatne do doprecyzowania parametrów oceny hałasu i ich dopuszczalnych wartości.

Słowa kluczowe: ocena hałasu, uciążliwe dźwięki, uciążliwość hałasu, jakość dźwięku, EEG, psychoakustyka

1. INTRODUCTION

There are many different annoying and extremely unpleasant sounds in our daily lives. Couple of them may provoke physiological reactions such as goose bumps or cause the shiver down spine when we only think about them. As example may serve archetypal worst noises such as scraping fingernails on blackboard, cutlery scraping on plates or rubbing two styrofoams together. Even though those feelings and reactions are virtually universal, their causes and effects are still not well understood. Some research on functional magnetic resonance imaging (fMRI) demonstrated that unpleasant sounds influence the signals in auditory cortex and amygdala [1,2]. The purpose of this study was to verify if non-invasive and well established technique of EEG may be used to find out a relationship between type of sound source and electrical activity of the brain.

Conventional parameters – levels of acceptable noise in the environment [3] or at work place [4] – are established by legal regulations. However, parameters such as equivalent sound level A, maximum sound level A or peak sound level C [5], are only small fraction of the factors which influence perceived sound annoyance. Even though sound levels are approximately equalised, the listener still can grade the nuisance of various sounds differently. Thus the conventional parameters, which take into account only weighted energy of the sound, are not enough to describe the unpleasantness of different sound sources. Therefore psychoacoustic parameters are believed to characterise the human hearing system structure and frequency spectrum of the sounds. The most popular among them are: (i) sharpness, which is a measure of the high frequency content, (ii) roughness, (iii) fluctuation strength quantifying perception of fast and slow amplitude modulation and (iv) tonality which is responsible for assessment of tone-noise ratio in the sound [6-8]. The intention of this study was to check whether psychoacoustic parameters correlate with noise nuisance of recorded sounds.

2. MATERIALS AND METHODS

2.1. Recording and processing audio signals

Firstly the research was conducted on different sounds to find out the ones which are believed to be annoying and unpleasant. Then 65 sounds of different sound sources were recorded with Olympus LS-100 recorder. The recordings were diversified from those usually perceived as pleasant (like the murmur of the brook or birdsongs) to those regarded as unpleasant (scraping fingernails, squeezing of polystyrene foam, etc.). Afterwards, 20 recordings were chosen and they were limited to 20-second samples with uniform time series without artefacts which can influence their perception. Tracks were converted from stereo to monaural and normalised. Impulse-like signals (high dynamic range) were normalised with amplitude peak normalisation equal to -1 dB and noise-like recordings were normalised to one root-mean square (RMS) level. Last step was a calculation of psychoacoustic parameters in Labview software – Sound and Vibration Measurement Suite.

2.2. Psychoacoustic experiment – Internet survey

To check the respondents' reaction to different sound sources, the survey was created using HTML, PHP and JavaScript. The Internet-based psychoacoustic experiment was performed, in which the respondents graded 20 tracks using a direct scaling. When users first went to the survey website, they were informed about aim of the study and they accepted its conditions. Next, some basic personal data were collected, e.g. gender, music education (yes/no question) and age (within 10-year ranges). Before starting the experiment, the users were asked to make sure that loudspeakers/headphones work properly and to adjust the loudness to hear the tone clearly and loudly. To minimise the rating variance introduced by length of listening time, participants were requested to listen all of recordings to the end. To reduce time of the experiment and to avoid discouragement of the participants, the sounds were limited to 10-second samples. It caused the shortening of the whole experiment to around 7 minutes. Then the main assessing part started: the users by pressing the play button graded sounds with the ordinal scale from 1 to 7, where 1 means very pleasant sound, 4 – neutral sound and 7 stands for extremely unpleasant and annoying sound. Additionally, participants could add comments about other feeling which they had during listening to sound – chill/shiver, goose bumps. Assessment of sounds in 1-7 scale were required to send the questionnaire, other fields were optional. The results of the survey were sent to the author's mailbox and then stored in Excel sheet. Questionnaire was filled by 178 respondents: 101 women and 77 men. Participants age groups were as follows: 10-20 years – 12 persons, 21-30 years – 129 persons, 31-40 years – 13 persons, 41-50 years – 15 persons, 51-60 years – 9 persons and one person in the age 60+.

2.3. EEG study

EEG study took place in a small anechoic chamber in the Department of Mechanics and Vibroacoustics, AGH University of Science and Technology in Kraków (Figure 1).

Fig. 1. Research setup in a small anechoic chamber to evaluate EEG of the volunteers during listening of recorded sounds

The table with Creative Gigaworks T40 loudspeakers was placed in the middle of the chamber and one meter from that the chair for the participants was located. Amplification of the loudspeakers was chosen subjectively and sound level was measured with SVAN 958 sound analyser. Measuring cohesion has been ensured by reference sound source type 4231 Brüel & Kjær with a level of 114 dB at 1 kHz. Mitsar-EEG 201 amplifier was used with standard 19 channel caps positioned to the international 10-20 method of electrode placement. The EEG signal was sampled with sampling rate 250 Hz and the built electronic filters were applied (45-55 Hz notch filter and 0.53 Hz high-pass filter). EEG segments were analysed using epoch length of 2 seconds, Hanning window was used and successive frames were overlapped by 50%. Waveforms were subdivided into bandwidths: delta (1.5-4 Hz), theta (4-7.5 Hz), alpha (7.5-14 Hz), beta1 (14-20 Hz), beta2 (20-30 Hz) and gamma (30-40 Hz).

Eighteen healthy volunteers (10 males, 8 females, age range 23-49 years) participated in the study. During the trial the experimenter was with the participant in the anechoic chamber to mark on the EEG recording respective sounds and to note down the appearing artefacts. The stimuli consisted a set of 20 sounds, ~20 seconds duration each, alternated with 10 seconds samples of silence. After that part participants were asked to fill in the internet-based survey, in which they graded the sounds previously heard. Their responses were added to the results of internet survey respondents, receiving in total 178 filled surveys.

Signal analysis was performed in WinEEG program and in Excel 2007. Obtained EEG spectra were averaged for each of 20 recorded sounds. In an ideal case each of 20 result sound spectra should be an average of 18 EEG spectra (one per participant), but due to the appearing artefacts it varied from 13 to 18 spectra components.

3. RESULTS

3.1. Psychoacoustic analysis

Part A in Table 1 presents the psychoacoustic parameters (sharpness, tonality, fluctuation and roughness) and Part B shows three normative parameters (L_{Aeq} , L_{Amax}, L_{Cpeak}) of 20 recordings analysed in this study. To visualise the nature of the recorded sounds, they were shown in time domain series (above each histogram, Figure 3).

Bat squeak (13) and sound of styrofoam rubbing against wet windowpane (19) have the highest sharpness while noise of tram (3) and piano piece (15) have the lowest values among all examined recordings. Tonality is the highest for piano piece (15) and sound of scraping fork moving quickly against the mess kit (5), while fluctuation is the strongest for the recording of scraping fingernail (12) and scraping fork (17). Spur gear (10) has highest value of roughness and the lowest is calculated for bat sounds (6,13). For sounds with extreme values of sharpness and roughness, the FFT spectra were presented in Figure 2.

Table 1. A) Psychoacoustic parameters and B) Normative parameters, calculated for 20-second recordings

Recordings	A				B		
	Sharpness (acum)	**Tonality** (tu)	**Fluctuation strength** (vacil)	**Roughness** (asper)	L_{Aeq} (dB)	L_{Amax} (dB)	L_{Cpeak} (dB)
1. Wibratig mill	4.424	0.063	0.615	0.519	73.2	75.0	90.7
2. Styrofoam creak	5.747	0.002	2.383	0.585	70.8	78.4	90.5
3. Tram squeak	1.671	0	0.756	0.166	60.8	66.3	90.6
4. Birdsong: chaffinch	4.495	0	1.721	0.337	72.3	85.4	92.8
5. Scraping fork (quick)	5.323	0.261	2.708	0.556	65.0	82.7	87.9
6. Bat hiss: Frosted bat	5.396	0.009	1.131	0.04	56.1	63.6	77.9
7. Knives sharpening	5.711	0.005	1.204	0.344	69.1	74.0	87.1
8. Jet plane	2.536	0	0.312	0.343	71.1	75.5	90.4
9. Washing mashine spin	3.766	0.159	0.486	0.205	65.4	67.8	87.2
10. Spur gear	4.611	0	0.492	2.852	73.8	76.9	92.5
11. Murmuring brook	1.841	0	0.457	0.073	48.4	55.8	88.5
12. Scraping nails	4.778	0.005	3.888	0.731	66.9	78.3	89.0
13. Bat squeak: noctule bat	6.811	0	3.761	0.032	60.5	75.7	84.3
14. Screech of sand	5.342	0	1.834	0.402	73.7	81.7	93.6
15. Piano piece	1.533	0.488	1.617	0.152	71.7	76.5	90.2
16. Squeaking hinge	3.478	0.101	0.902	0.356	71.0	75.6	87.4
17. Scraping fork (slow)	4.113	0.002	4.187	0.786	68.4	87.1	92.9
18. Highway noise	2.372	0	0.697	0.328	71.2	77.1	90.8
19. Styrofoam squeak	6.756	0.005	1.628	0.161	71.8	81.0	89.7
20. Birdsong: blackcap	3.894	0	2.234	0.554	69.2	83.1	91.9

The results clearly show the spectral dependence of those metrics: the sharpness is the measure of high frequency content and roughness is the parameter of fast amplitude modulations.

In Table 2 part A the median of votes and averaged value of votes (n=178) are presented. The median, mode or quantiles metrics should be used when the data are presented on the ordinal scale. However, in that case the median "flattened" the obtained data, so majority of sound samples were given the grades of 5 or 6. Thus, it was impossible to rank sounds from the most pleasurable to the most annoying on that basis. Therefore the average was chosen to rank orders as shown in the last column of part A, Table 2. The most horrible and annoying sound was the noise of scraping fork slowly against the mess kit (17), followed by styrofoam creak (2) and squeak (19).

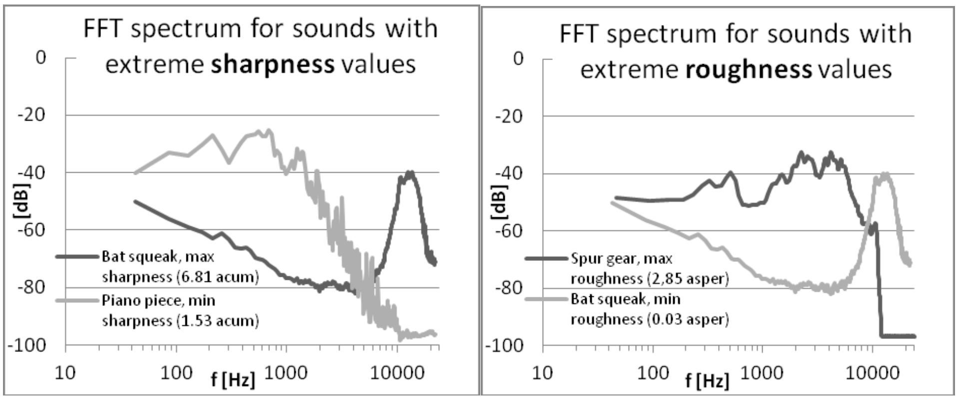

Fig. 2. FFT spectra for sounds with extreme sharpness: bat squeak (13) and piano piece (15) (left), and roughness: spur gear (10) and bat squeak (13) (right). Hanning window, 1024

Table 2. A) Median, mean value of recordings mean value, calculated on the basis of 178 responded surveys. B) Differences in grading between gender and music education (ME=1 - yes, ME=0 - no music education), a letter indicates whether females (F) or males (M) found sounds more unpleasant, "ns" indicates no statistically significant difference ($p<0,05$), Mann-Whitney test.

Recordings	A			B
	Median	**Mean**	**Rank**	**Higher grades** *(more annoying sound)*
1. Wibratig mill	5	4.84	9	F (p=0.012)
2. Styrofoam creak	6	5.88	19	F (p=0.044)
3. Tram squeak	4	3.93	5	ns
4. Birdsong: chaffinch	2	1.85	3	ns
5. Scraping fork (quick)	6	5.76	16	F (p=0.034); ME=1 (p=0.001)
6. Bat hiss: Frosted bat	5	4.71	8	ns
7. Knives sharpening	6	5.80	17	F (p=0.015)
8. Jet plane	4	4.10	6	F (p=0.016)
9. Washing mashine spin	5	5.12	10	ns
10. Spur gear	5	5.37	12	ns
11. Murmuring brook	2	2.33	4	ns
12. Scraping nails	6	5.42	14	F ($p=2*10^5$)
13. Bat squeak: noctule bat	5	5.30	11	ns
14. Screech of sand	5	5.38	13	F(p=0.039)
15. Piano piece	1	1.51	1	ns
16. Squeaking hinge	6	5.69	15	ns
17. Scraping fork (slow)	6	5.93	20	F (p=0.042)
18. Highway noise	5	4.60	7	ns
19. Styrofoam squeak	6	5.84	18	F (p=0.028); ME=0 (p=0.001)
20. Birdsong: blackcap	1	1.73	2	M (p=0.035)

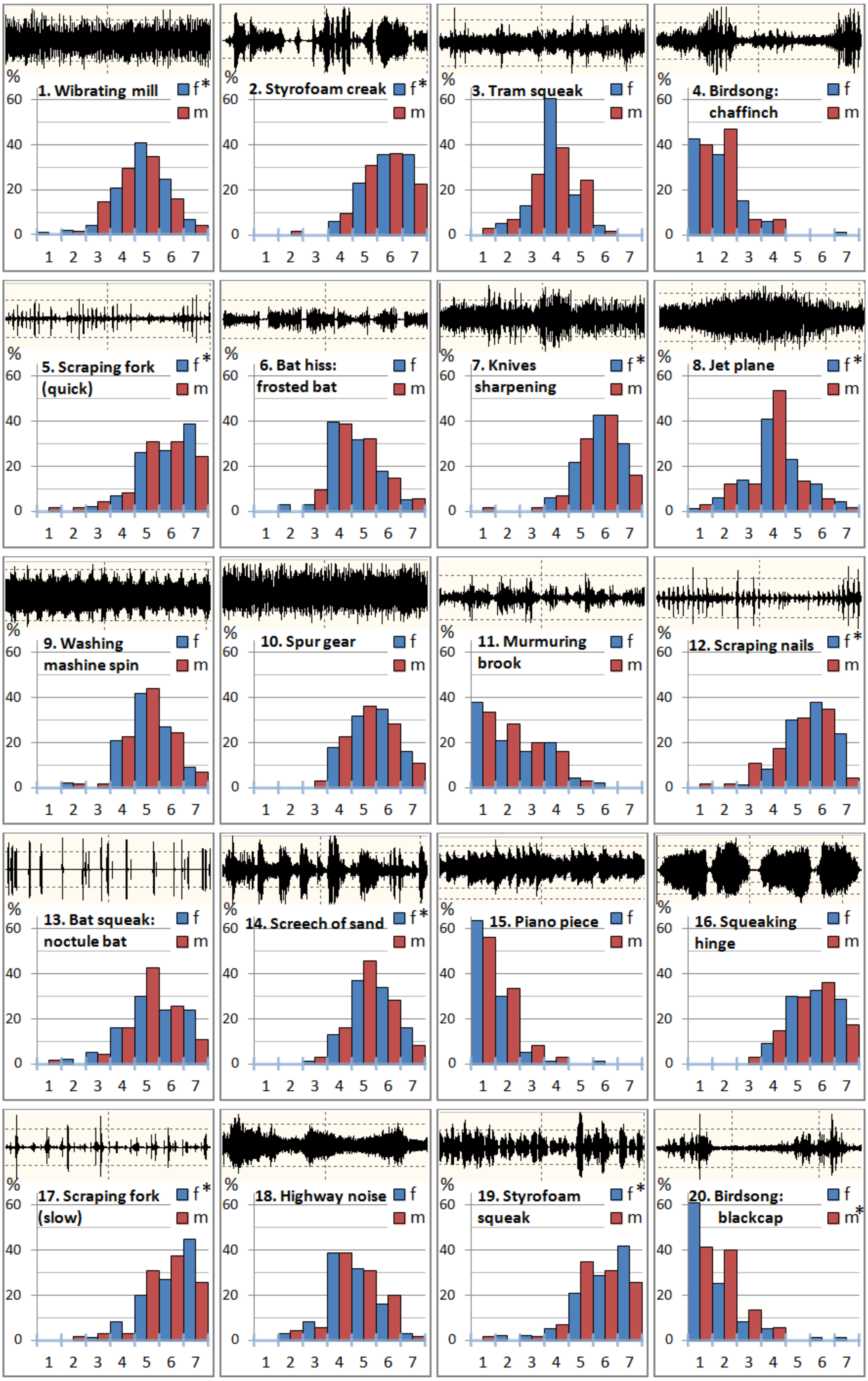

Fig 3. Normalised histograms of votes (for men and women). Vertical axis – distribution of the grades by gender (f – females and m – males), in %, horizontal axis – grades from 1 (very pleasant) to 7 (annoying, horrible sound). Above the histograms, the time series of the sounds are presented

Sounds of tram (3) and starting jet (8) were perceived as neutral (median=4, average ~4). The piano piece (15) was graded as the most pleasurable sound, followed by songs of blackcap and chaffinch (4, 20) and murmuring of the brook (11). The results of the respondents' grades to 20 different sounds are presented in the form of normalised histograms in Figure 3.

Then the analysis concentrated on changes in grading with gender and music education. The Mann-Whitney test was performed and for ten sounds per twenty the significant difference in grading according to gender was observed (Table 2 part B, $p<0.05$). It showed that women tended to give higher grades, especially to sounds perceived as annoying and horrible. Only in one case men gave the higher grade to the sound than women, but it was a sound of singing bird, so it was just less pleasant to them, not more annoying. Normalised histograms of votes given by males and females for all 20 sounds are presented in Figure 3. For music educated and non-educated people the difference was significant only in two cases (Table 2 part B, $p<0.05$). Sound of scraping fork (5) was found as more annoying for music educated respondents, whereas sound of styrofoam squeak was perceived as worse by non-music educated people ($p<0.05$). Voting trends according to age were not analysed because of overrepresentation of 20-30 year-old group (~72% of all respondents).

The Spearman's rank correlation was preformed: obtained annoyance average of sounds was correlated with calculated psychoacoustic parameters. The results are presented in Table 3.

Table 3. Correlation between psychoacoustic parameters and mean value of ratings. Rs – Spearman's rank correlation coefficient, t – t-test value, *0.95 significance level

Psychoacoustic parameter	*Rs*	*t*	*Proba-bility*
Sharpness (acum)	0.633	3.469	0.0058*
Tonality (tu)	0.303	1.347	0.1416
Fluctuation Strength (vacil)	0.474	2.280	0.0384*
Roughness (asper)	0.468	2.245	0.0414*

The positive correlation between perceived annoyance and three psychoacoustic parameters (sharpness, roughness and fluctuation strength) was found. Also the correlation between perceived annoyance and three normative parameters – L_{Aeq}, L_{Amax} and L_{Cpeak} – was performed (Table 1, Part B). Those classical parameters have similar values for every recording – it was the aim of normalisation, to have almost the same L_{eq} (not weighted) values, and because of that, similar values of other weighted energetic parameters. Thus, the correlation was not significant for those three normative parameters, as it was expected.

3.2. EEG analysis

The Spearman's rank correlation was preformed between annoyance averages of sounds and dominant frequencies in six EEG bands; the data are summarised in Table 4.

Table 4. Correlation between dominant frequencies and mean value of ratings. Rs – Spearman's rank correlation coefficient, t t-test value, *0.95 significance level

Dominant frequency in band:	*Rs*	*t*	*Proba-bility*
delta	-	-	-
theta	-0.356	-1.616	0.121
alpha	0.452	2.153	0.048*
beta1	-0.180	-0.776	0.435
beta2	0.639	3.527	0.005*
gamma	0.130	0.558	0.562

Changes in dominant frequencies in two bands per six were significantly correlated with the subjective annoyance of the sounds. There were alpha band (range 7.5-14 Hz, dominant frequency around 10 Hz) and beta2 band (range 20-30 Hz, dominant frequency around 20 Hz), where dominant frequencies increased when the sound was perceived as annoying.

4. DISCUSSION

The conveyed experiment showed, that the most horrible and annoying sounds were noises of scraping fork and different types of styrofoam sounds. Scraping nails, the archetypal worst sound, was not graded so highly (5^{th} worst sound). In similar experiments made by Halpern et al. [9], the most annoying sounds amongst examined were the noise of a garden tool scraped across a piece of slate (noise similar to scraping nails) and scraping styrofoam. In the works of Kumar et al [1] sounds of scratching knife on the bottle and fork on the glass were perceived as most unpleasant. Thus, it is hard to find one most unpleasant sound as the recordings vary between experiments. Other study on annoying and disgusting sounds [10] found fingernails scraping down a blackboard and styrofoam noises came midway down in the rank list, with a slight differences between gender in former (female found that noise worse). In our study, seven out of eight sounds graded as most annoying were significantly more unpleasant for females. It may suggest that they are more sensitive to annoying sounds or they use wider scale than men. This finding may support the hypothesis of Halpern's group that a vestigial response concerning warning cries is responsible for perception of scraping sound. Females were usually more involved in protecting the offspring from attack [10,11], so they can be more prone to that type of unpleasant noises.

Psychoacoustic parameters are commonly applied for assessment of sound quality. Usually individual parameters are not used, but combinations of them create the models, such as general psychoacoustic annoyance PA [8] or models applied to specific appliances e.g. shavers, vacuum-cleaners, sprays [12], car engines [13] or heating, ventilation and air conditioning systems [14]. In this study four individual parameters of annoyance prediction were analysed for different types of noises. Three parameters out of four (sharpness, roughness and fluctuation strength) were positively correlated with subjective noise annoyance.

Considering classical and psychoacoustic approach to sound nuisance, one can get an impression that classical normative parameters only take into account energetic properties of the annoying sounds. Additionally, it should not be forgotten that normative parameters are then assessed by different legal regulations, associated with type of areas where people reside and places where they stay or work. Psychoacoustic parameters seem to be more universal – they are independent of the type of human activity and whereabouts and also they take into account frequency spectrum of the sounds. On the other hand, calculation of psychoacoustic parameters are still not standardised and unified [11]. Hence, it is important to create normalised standards for calculation of psychoacoustic parameters. It seems to be the most appropriate to develop a metric assessment of subjective noise nuisance, independent of legal regulations. These issues were pointed out in many publications, e.g. in articles concerning vibroacoustic annoyance of wind turbines [15-18].

The EEG results proved the significant correlation between dominant frequencies in alpha and beta2 bands and subjective annoyance of sounds. Similar type of studies were performed by Du and Lee [19], who found out, that depending on type of sound stimuli (emotionally loaded sounds excerpts characterized as fear, happy and neutral) differences in frequency in alpha, beta and gamma bands occur (in some brain regions). Weisz et al [20] pointed out, that depending on the task, the alpha rhythm may appear in varying frequency ranges.

5. CONCLUSIONS

In this study we investigated a problem of nuisance prediction of different annoying sounds. A range of sounds was examined in a psychoacoustic experiment. Survey showed that the most annoying and unpleasant sounds were scraping noises of the fork and styrofoam squeaks and creaks. For sounds perceived as most unpleasant, the difference in grading with gender was observed – in most cases women graded that nuisance higher. What is more, the positive correlation between perceived annoyance and three psychoacoustic metrics was found. Sharpness, roughness and fluctuation strength are widely used in different annoyance models, but seldom are applied independently, as in our study. Those results may be useful in refinement of the noise assessment methods and creating simple corrections for annoying sounds.

The EEG study showed that dominant frequencies in two bands vary during listening to sound recordings of different rate of annoyance. Dominant frequencies in alpha and beta2 bands were rising with the increasing annoyance of the sounds. That information expands our knowledge of brain activity during different acoustic stimuli and may be valuable in development of cognitive science studies.

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REFERENCES

1. Kumar S, von Kriegstein K, Friston K, Griffiths T D. Features versus Feelings: Dissociable Representations of the Acoustic Features and Valence of Aversive Sounds J Neurosci, 2012, 32(41), 14184 –14192
2. Zald D H, Pard J V. The neural correlates of aversive auditory stimulation, Neuroimage. 2002, 16(3,1),746-53
3. Regulation of the Minister of Environment dated 14 June 2007 (Official Journal No. 120, Item 826) amended in 01 October 2012 (Official Journal No. 0, Item 1109)
4. Regulation of the Minister of Labour and Social Policy dated 6 June 2013 (Official Journal No. 0 Item 817)
5. ISO 1999:2013 Acoustics – Estimation of noise-induced hearing loss
6. Aures W. Ein Berechnungsverfahren der Rauhigkeit (A Procedure for Calculating Auditory Roughness.) Acustica, 1985, 58, 268-281.
7. Aures W. Berechnungsverfahren für den sensorischen Wohlklang beliebiger Schallsignale (A model for Calculating the Sensory Euphony of Various Sounds) Acustica, 1985, 59, 130-141.
8. Fastl H, Zwicker E. Psychoacoustics: Facts and Models , Springer 3rd edition, 2007
9. Halpern D L, Blake R, Hillenbrand J. Psycho-acoustics of a chilling sound. Percept Psychophys, 1986, 39(2), 77-80.
10. Cox T J. Scraping sounds and disgusting noises, 2008, Appl Acou, 69,12, 1195-1204.
11. Gade S. What is Sound Quality? Brüel & Kjær Magazine, 1, 2007.
12. Hülsmeier D, Schell-Majoor L, Rennies J, van de Par S. Perception of sound quality of product sounds: A subjective study using a semantic differential. Proc Internoise 2014, Melbourne, 2014, 1-8

13. Lee S M, Lee S K. Objective evaluation of human perception of automotive sound based on physiological signal of human brain, Int J Auto Tech, 2014, 15(2), 273−282
14. Davies P, Broner N, Kim J R. A case study on predicting noise annoyance due to heating, ventilation and air conditioning systems in buildings. Proc Int Congress on Acoustics, Tokyo, 2004, II-1373-1376
15. Kasprzak C. The Influence of Infrasound Noise from Wind Turbines on EEG Signal Patterns in Humans, Acta Physica Polonica. A, 2014, 125, 4A, 20-23
16. Kasprzak C, Skrodzka E, Wiciak J. The Effect of Wind Turbine Infrasound Emission on Subjectively Rated Activation Level. Acta Physica Polonica, A, 2014, 125, 4A, 45-48
17. Kłaczyński M, Wszołek T. Acoustic study of REpower MM92 wind turbines during exploitation, Archives of Acoustics, 2014, 39,1, 3–10
18. Wszołek T, Kłaczyński M, Mleczko D, Ozga A. On certain problems concerning environmental impact assessment of wind turbines in scope of acoustic effects, Acta Physica Polonica. A, 2014, 125, 4-A, 38-44
19. Du R. Lee H J. Power Spectral Performance Analysis of EEG during Emotional Auditory Experiment. Proc Int Conf on Audio, Language and Image Processing, Shanghai, 2014, 64-68, doi: 10.1109/ ICALIP.2014.7009758
20. Weisz ,. Hartmann T, Mueller N, Lorenz I, Obleser J. Alpha Rhythms in Audition: Cognitive and Clinical Perspectives. Front Psychol, 2011, 2:73

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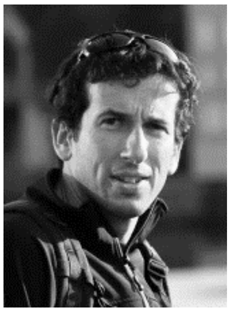

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