MONAURAL AND BINAURAL LISTENING TO INFRASOUND; CAN PHYSIOLOGY HELP?

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V prispevku predstavljamo študijo ugotavljanja vpliva načina poslušanja zvokov nizkih frekvenc z enim ali z obema ušesoma. V gluhi sobi so zdravi prostovoljci poslušali zvoke frekvenc okoli spodnjega slišnega praga na oba načina. Ob tem smo prostovoljcem dodatno merili fiziološke parametre (prevodnost kože in srčni utrip) in ugotavljali, ali bi lahko s preprosto fiziologijo sklepali o nadležnosti zvokov določenih frekvenc. Naši rezultati ne kažejo pomembne povezave med fiziologijo in načinom poslušanja.

Keywords—infrasound, monaural, binaural, EARS2, perception

1 Introduction

1.1 Infrasound

The term “infrasound” represents sounds in the very low frequency range. Normally 20 Hz is considered the lower human hearing threshold, with some variance between individuals, with sounds below that frequency being considered inaudible, hence the word infrasound (“infra”= under). This is however not true, as sounds down to a few hertz can be audible, but the amplitudes of those sounds must be much higher than in normal hearing range (20 Hz < frequency < 20 kHz). Within infrasound frequency range, the dynamic range of auditory system is known to diminish rapidly with decreasing frequency. This results in compressed equal-loudness-level contours in a certain frequency range, and it implies that a slight increase in sound pressure level can change the perceived loudness from barely audible to loud [1]. In the infrasound range, the perception of sound also changes. Sound loses its tonal properties and begins to feel discontinuous [2].

In our everyday life the infrasound is commonly generated as a side product of activities like ventilation, air conditioning, traffic, aviation, wind turbines, etc as well as from natural sources such as thunder, wind, earthquakes, volcanic eruptions and sea waves [1]. The recent trends of industrialisation and mobilisation have resulted in increase in sound pollution in all frequency ranges, which is affecting quality of our everyday lives and is also a potential health hazard [4-10]. Low-frequency noise, including infrasound, specifically poses a significant threat, as it carries more energy compared to other frequencies while also being able to traverse larger distances and loosing less amplitude when passing through buildings. Normal hearing protection was also proven to be less effective in low-frequency range [1].

1.2 Ears II project

Project Ears II (Metrology for modern hearing assessment and protecting public health from emerging noise sources) is a part of EMPIR (European Metrology Programme for Innovation and Research) initiative, which is a programme co-founded by the European Union’s Horizon 2020 and EMPIR participating states. Ears II is to be run from 2016 to 2019 as a follow-up project to the successful Ears I project.

One of the aspects of Ears II project is tied to hearing conservation and explores the response of humans to infrasound and ultrasound as well as potential health hazards of aforementioned sounds [3]. In order to properly limit potential health risks emerging from infrasound and ultrasound, a deeper understanding of human hearing and sound perception is needed. With this sounds only being audible at extremely high amplitudes, an interdisciplinary approach is mandatory, combining audiology with neuroscience and psychology. New methods for determining the effects of these sounds had to be developed. The other studies of this project are already making use of technologies such as EEG and fMRI in combination with traditional audiological methods.

1.3 Monaural versus binaural hearing

Recent studies in this field [11-14] administered the sound to test persons monaurally, via an insert earphone. While there is definitely a difference between the whole body and only ears being exposed to the sound pressure, studies suggest that ears are still the primary sensory organ for infrasound [2]. There is however no consensus when it comes to “binaural advantage”. The term refers to a common idea that binaural thresholds are slightly lower, typically around 3 dB. While it is widely accepted in terms of frequencies above 200 Hz, some studies have observed it in low-frequency and infrasound frequency range as well [15, 16], while others found no binaural advantage in this frequency range [13, 17].

1.4 The aim of this study

The goal of this study was to research the possibility of using objective physiological parameters to assess the psychological effects of infrasound on human subject. The level of psychological arousal, measured in form of activity of subject’s electrodermal activity (EDA) and heart rate (HR), was evaluated within two tasks: i) listening to infrasound by means of monaural and ii) by means of binaural hearing.

2 Measuring the effects of infrasound in monaural and binaural measuring systems

2.1 Measuring set-up

For the purpose of this experiment, an anechoic chamber (within Faculty of Electrical Engineering University of Ljubljana) was used [18]. The loudspeaker used for the experiment was custom made and constructed specifically for this project by Physikalisch-technische Bundesanstalt, Braunschweig, Germany [13]. The sound source produces very low harmonic distortion in 2-250 Hz range.
Atop the loudspeaker, a polyethylene hose is mounted to direct the flow of air pressure. After a few decimetres, the hose is split in two by a Y-splitter. The two tubes go through a valve each and are connected to the headset of a common stethoscope. The stethoscope had its tubing removed and is only used as a means to effectively connect the silicon hoses with the ear canal. The valves are manual and are controlled by an Arduino controlled servo motor, so they can be closed slowly. This prevents the problem of audible pops, that would otherwise occur when opening and shutting solenoid valves.

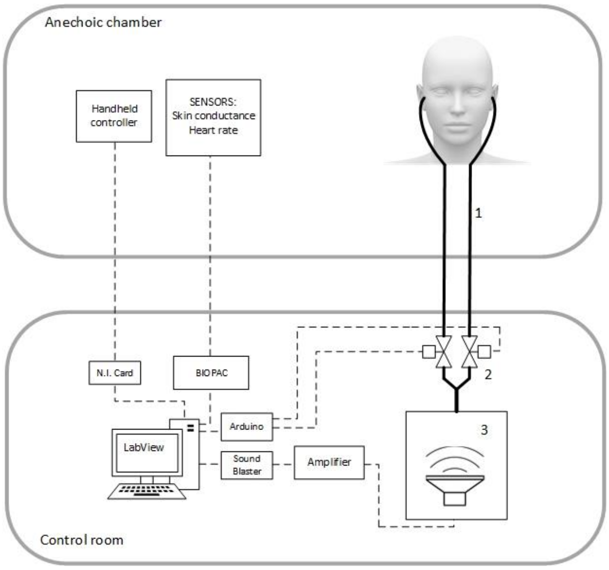

Figure 1. Measuring set-up: anechoic chamber, loudspeaker, stethoscope, valves, Biopac, computer, handheld controller

Prior the study hoses of different diameters, lengths and stiffness were tested. In the end a pair of harder hoses were chosen in order to conduct the least amount of noise from outside the anechoic chamber and overall best frequency response compared to the much softer silicone hose or the much wider polyvinyl chloride hose. The chosen hoses were about eight meters long with inner diameter of 4 mm and outer diameter of 6 mm.

To measure the physiological response of the research participants, Biopac MP150 module was used as a data acquisition device. Modules EDA100C and PPG100C were used to monitor skin conductance and heart-rate, respectively. Wet reusable Ag-AgCl electrodes for EDA and photoplethysmografic transducer were used as sensors. To ensure time synchronisation one of MP150 analogue channels was used as a triggering channel and was connected to the National Instruments DAQ 2344XX module, which was operated by the main computer.
The test person was given a handheld controller with a pushbutton and a potentiometer, to give them control over the amplitude in the first part of the experiment where the perceived threshold for each and both ears is found.

2.2 The test procedure

The experiment consists of three parts. The first part is finding the amplitude threshold at 125 Hz. This frequency was chosen, because it is a standard test frequency and accords to ISO 389-2 standard. The test subject is prompted to readjust the amplitude of the signal until they are certain that they have found their threshold. Test person is instructed to find their threshold for both ears once and then for each one ear once. Then the whole cycle is repeated two more times, resulting in three threshold measurements for each ear and both ears. Which ear the test person is having tested at the given time is predetermined in the program that shuts the correct valve, preventing the airflow from the loudspeaker and consequentially cutting of the stimuli for the respective ear. At the end of the first part of the test, a better ear is chosen, based on the criteria of having a lower average threshold at the given frequency. The third part is the same as the first. This allows us to observe any threshold shifts between the start and end of the experiment to ensure no hearing loss occurred during experiment.
The second part of the test consists of listening to a series of groups sounds. For the purpose of this paper, the term a “group of sounds” is used to refer to a specific composition of sound and silence that will be discussed further bellow.
In between the two parts, 90 seconds of inactivity was included to allow the test person’s physiology to stabilise and baseline physiology values to be acquired. 30 seconds before every group of test is played, a valve is turned, which causes a quiet humming noise. The humming noise only lasts a second, so the 30 second period is enough for physiology to stabilise again. This 30 seconds time period also serves as a divider between two groups of sounds, minimising the effect of the previous groups of sounds on the physiology when the next group of sounds is played.
Every test person is subjected to hearing sounds at the following frequencies: 8 Hz (infrasound, far from normal frequency range), 16 Hz (infrasound near normal frequency range) and 125 Hz (in normal

frequency range, clearly audible) (Figure 2). Groups of sounds of all frequencies are played twice: once both ears receive the stimuli and once only the better ear does. The sequence of frequencies and usage of both/better ears is not randomised; rather a balanced Latin square design is used. The same frequency is always played in pairs of monaural and binaural, but the order of frequencies and the order position within pairs changes with each test person.

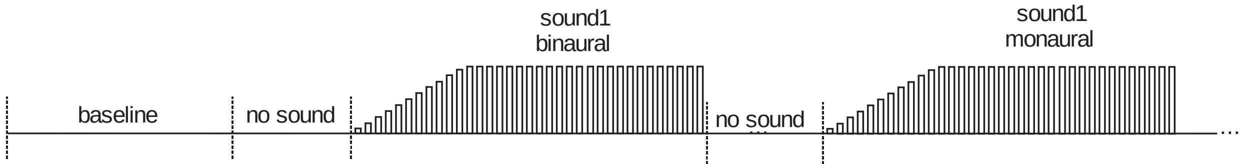

Figure 2. The measuring protocol (only first two played sounds are presented, in total every test subject listened to 6 sounds, i.e. 3 sounds (125 Hz, 16 Hz and 8 Hz), each twice (bi- and monaural)). Baseline period was 90 seconds, periods of silence 30 seconds and periods of played sounds 30 seconds long. In total, after 90 seconds of baseline relaxation period every subject was exposed to 6 randomized 30 seconds sessions of sounds (frequencies of 125 Hz, 16 Hz and 8 Hz).

The aforementioned groups of sounds consist of pure sinusoidal tones, which vary in amplitude following the envelope shown in Figure 2. We noted that raising the amplitude from zero to the desired value too fast could cause audible pops due to the rapid change in air pressure level in the tubes. Therefore, linear ramps were added to the begging and the end of the envelope of each pulse (Figure 2). The first few pulses in the series are also rising in amplitude. The middle part with the highest amplitude is the part that should be audible, while the other pulses provide smooth transition over the hearing threshold. This method was chosen because it allows us to monitor physiological parameters when the hearing threshold is crossed, while also minimizing the possibility of occurrence of physiology changes because of a shock due to suddenly hearing of a sound at a reasonably high amplitude.

After the experiment, the subjects were asked to describe their experiences, including possible discomfort caused by the anechoic chamber, boredom and any of the stimuli. This was done in a non-formal free interview.

2.3 Software implementation

The main program runs the National Instruments LabVIEW software. The program was designed in three parts, following the experiment protocol. At the start of the program, a trigger signal is sent to BIOPAC MP 150 to synchronise the two computers. LabVIEW is also used to control the Arduino, responsible for opening and closing of the valves. The first part of the program is designed to pick the test subject's better ear through comparing the thresholds that they set for themselves. The second part consists of playing groups of sounds as explained in the section 3.2. The start time of each group is recorded and written into a text file. All the start times, amplitudes and frequencies are set in advance, so there is no need to record this data.

To gather data from BIOPAC MP 150, AcqKnowledge 4.1 was used, where the bulk of data analysis also took place. Using the built-in functions the skin conductance responses (SCR) were identified, counted and their amplitudes measured. In addition, skin conductance level (SCL) within the baseline period and each interval was calculated. Average heart rate and its standard deviation was calculated.

2.4 Test persons

Fifteen healthy volunteers (students, 5 women and 10 men) participated in the study. Before the experiment, the protocol was briefly explained to them and they signed the written consent to participate in the study allowing them to leave the experiment if chosen.

2.5 Data analysis

Acquired physiological parameters were pre-processed by removing the outliers and filtering for the moving artefacts, which were manually identified. Descriptive statistics (mean value and standard deviation) od skin conductance level (SCL) and heart rate (HR) and number and amplitude of skin conductance responses (SCR) for the 90 seconds baseline and duration of each sound exposure were calculated. Number of SCR pulses (pulses in skin conductance signal, with amplitudes exceeding 0.02 uS and representing a measure of subject's momentary arousal) and sum of the mean SCR pulse amplitudes were calculated.

Normality was checked using Shapiro-Wilk test and the independent samples equal variances T test was used to compare effects of the monaural and binaural hearing to the subject's physiology. Statistical significance was assumed at $p \leq 0.05$.

3 Results

The physiological data of the subject was collected. In 30 % of the signals the heart rate values and especially heart rate variability parameters, such as standard deviation of heart rate, was corrupted and discarded from the following processing due to high content of moving artefacts caused by moving the hands when operating the handheld controller.

In general, the following was expected. An increase in SCL values and standard deviation of SCL is associated with increase in psychological arousal of the subject. I.e. larger SCL values with monaural hearing would indicate higher annoyance/discomfort level as compared to binaural hearing of the same frequency sound. Similarly, the number and amplitude of SCR pulses increases with arousal. An increase in value of HR and standard deviation of HR (i.e. heart rate variability) would indicate the arousal and hence higher annoyance level of the subject.

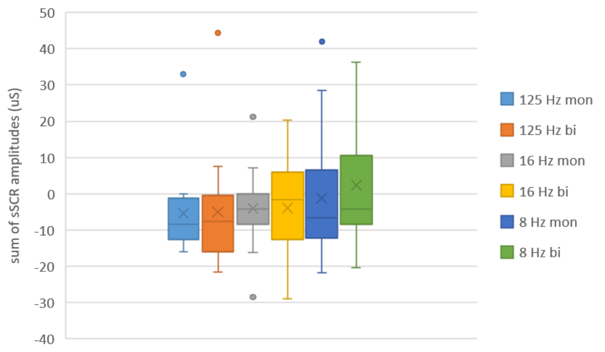

Figure 3. Comparison of sums of SCR amplitudes for different frequencies of sounds and different types of hearning (monaural, binaural).

Table 1. Comparison of physiology during binaural and monaural hearing

Physiology	Sound frequency	t value	df	p
SCL	125 Hz	1,186038	28	0,245574
	16 Hz	0,187703	28	0,852463
	8 Hz	0,991527	28	0,32992
stdSCl	125 Hz	0,830926	28	0,413045
	16 Hz	1,189663	28	0,244169
	8 Hz	1,237406	28	0,226213
SCR	125 Hz	0,213857	28	0,832208
	16 Hz	1,187777	28	0,444169
	8 Hz	0,855287	28	0,399652
SCRampl	125 Hz	0,080528	28	0,93639
	16 Hz	0,023826	28	0,98116
	8 Hz	0,586761	28	0,562066
avgHR	125 Hz	0,479043	26	0,635913
	16 Hz	0,159985	26	0,874129
	8 Hz	0,4146	26	0,681835
stdHR	125 Hz	0,084415	28	0,933327
	16 Hz	0,530837	28	0,599718
	8 Hz	0,133207	28	0,894983

In table 1 the comparison of physiology during binaural and monaural hearing of 30 seconds sounds of different frequencies (below infrasound threshold (8 Hz), threshold (16 Hz), audio range (125 Hz)). No statistically significant differences were found for any of the physiology parameters.

4 Discussion

This study investigated whether simple physiology, electrodermal activity (SCL, SCR) and heart activity (heart rate), could be suitable measures for assessing the physiological effects of infrasound on human subjects. We compared binaural and monaural hearing of sounds near infrasound hearing thresholds (well above (125 Hz), approximately at (16 Hz) and below (8 Hz) threshold). Our results showed no difference between monaural and binaural hearing of these sounds.

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