PILOT STUDY ON THE INFLUENCE OF TONAL NOISE ANNOYANCE ON WORK PERFORMANCE

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The tonal noises can cause unpleasant evaluation of spaces and potentially increased complaints by mental workers. So far, however, there has been limited research on the effects of tones on human annoyance that can be used to set objective guidelines or limits on tones in noise. Current indoor noise evaluation methods do not directly account for tonal characteristics of noise. Thus, this paper addresses the relationship between human perception and noise with tonal components in the working environment. To determine relations between noise metrics (tone-to-noise ratio TNR and prominence ratio PR) and work performance the author applied psychological tests from the Vienna Test System with exposure to four test signals at the same sound pressure level with different tonal components. Results showed that noise with medium and high frequencies of tonal components were evaluated as more annoying. However lack of significant variation of psychological test results between individual signals do not give reasons for using the correction of the noise measurement result due to the tonality as for example in the ISO 1996-2.

Keywords: noise, tonality, annoyance, workplace

1. Introduction

Noise is any undesirable sound which can be burdensome or harmful to health, or which can increase the risk of an accident at work [17]. Tonal noise can be defined as noise with tonal frequency components in its spectrum. In addition to damaging the hearing organ, as a stressor, noise can contribute to the development of various types of illnesses (e.g. hypertension, peptic ulcers, neurosis), cause distraction, hinder work and reduce staff performance [19]. According to the ISO/TS 15666 definition [6] annoyance resulting from exposure to noise is an individual, adverse reaction of a person causing dissatisfaction, anxiety, irritation, or disturbance. The World Health Organisation associates noise annoyance with an adverse effect on health and defines it as the experiencing of many different reactions such as anger, disappointment, dissatisfaction, withdrawal, helplessness, depression, fears, distraction, or fatigue [23]. Loudness seems to be the most significant noise characteristic associated with the perception of annoyance. Loudness is commonly evaluated by using the following parameters: equivalent sound pressure level corrected by the frequency characteristics A ($L_{Aeq}$), loudness levels as per ISO 532 [5] and ANSI 3.4-2007 [1] and even the perceived noise level ($PNL$) [7]. However, many studies indicate that only a fraction of the perception of annoyance can be predicted by loudness. Brocolini [3] suggested that only approx. 30% of annoyance results from loudness, owing to other sound characteristics and non-acoustic factors. Relevant literature clearly indicates that the tonality of noise is one of the most important remaining noise characteristics which should be taken into account when evaluating annoyance [10].

Components for building technical equipment, such as heating, ventilation or air-conditioning are increasingly energy efficient; however, less attention is given to their acoustic quality [16]. A large part of this equipment emits clear tonal sounds as a result of rotating parts such as fans, or pumps,
etc. Tonal sound may be also emitted by office equipment – computers, printers, and telecommunications equipment [22]. In the domestic market, the widespread presence of these devices in the working environment can be observed at perhaps several hundred thousand indoor workstations such as administrative workstations, design offices, rooms for theoretical work and data development, as well as rooms with other similar intended uses to which these issues may apply. Tonal noise may be also occur at workstations located near wind power plants [11].

Literature on the subject reveals many results of research on the effect of different types of sound signals on the performance of the subjects, including the efficiency of the tasks performed. These tasks mainly include memorising numbers and words, crosswords, mathematical operations, or puzzles such as Sudoku, etc. [8, 9, 10, 19, 20]. Even though some research indicates that there is a relationship between the incidence of tones in noise and the efficiency or accuracy of tasks performed, this research is usually limited, both with regard to test samples and the range of sound stimuli applied. There are also no literature reports on the effect of tonal noise on the results of standardised psychological tests.

With regard to measurement methods and permissible noise levels at workstations, the regulations and standards currently in force in Poland [11, 14, 17, 18] do not take tonal noise into account. There is also a lack of information on permissible noise levels in rooms intended for human occupancy [13]. Recent literature reports [8] indicate that there is a need to develop criteria for tonal noise annoyance; however, the results of recent research are not sufficient to establish such criteria.

The main objective of the pilot studies presented in this document was to verify the research method by which it would be possible to establish criteria for assessing tonal noise annoyance in the working environment.

2. Material and methods

In the pilot studies, random sampling was used to select the sample since the main purpose of the pilot studies was to verify the research method by means of a test-retest approach. Eleven people participated in the pilot studies (6 men and 5 women). The average age was 30.3 years.

At the beginning, every subject underwent tonal audiometry at the following frequencies: 125 Hz, 1500 Hz and 8000 Hz. The tonal audiometry frequencies were selected so as to correspond to the tonal signals generated during the tests. The range of 0–20 dB HL was considered to be the eligibility threshold for the tests. Each subject was acquainted with the test procedures, received proper instruction on how to perform the tasks, and had to sign an informed consent form to participate in the tests.

The main part of the test consisted of four parts broken down by the test signal generated. In each part, the subjects performed specific tasks on a computer (psychological tests), and then they assessed the test signals by using the questionnaire which included:

- the assessment of the annoyance of the signal generated (verbal scale as per ISO 15666 [6]),
- the assessment of the difficulty and load during the performance of tasks (abridged NASA questionnaire Task Load Index [4]).

The Vienna Test System was used during the studies and three types of psychological tests were selected to assess the performance of the subjects while exposed to the test signals generated:

- Assessment of attention and concentration (COG),
- Assessment of memory span (CORSI),
- Assessment of performance (ALS).

The test scenario included four types of test signals:

- Signal A – filtered pink noise,
- Signal B – filtered pink noise with the tone at a frequency of 125 Hz,
- Signal C – filtered pink noise with the tone at a frequency of 1600 Hz,
- Signal D – filtered pink noise with the tone at a frequency of 8000 Hz

Parameters of the signals developed are provided in Table 1.
### Table 1: Parameters of the signals used in the pilot studies

<table>
<thead>
<tr>
<th>Signal</th>
<th>TNR</th>
<th>PR</th>
<th>$L_{Aeq}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>-</td>
<td>-</td>
<td>55 dB</td>
</tr>
<tr>
<td>B</td>
<td>16.1</td>
<td>17.6</td>
<td>55 dB</td>
</tr>
<tr>
<td>C</td>
<td>7.53</td>
<td>8.87</td>
<td>55 dB</td>
</tr>
<tr>
<td>D</td>
<td>8.23</td>
<td>8.58</td>
<td>55 dB</td>
</tr>
</tbody>
</table>

* $TNR$ – tone-to-noise ratio  
* $PR$ – prominence ratio  
* $L_{Aeq}$ – $A$-weighted equivalent sound pressure level

The first assumption of the measuring signals developed was to ensure that each of them had the equivalent sound pressure level $A$ of 55 dB (the criterion for noise annoyance at the workstation as per PN-EN-01307:1994 [12]). The second assumption was that for signals with tonal components the TNR and PR parameters should be at the limits of criterion curves which would prove that the tonal components in the spectrum are significant.

The signal without any tonal components (filtered pink noise) had its frequency corrected in such a manner as to ensure that the spectrum shape corresponded to NC curves (noise criterion – the criterion curves introduced in the United States to be used during indoor noise assessment [2]). Following this correction, the NC value calculated for signal A was 46 (for $L_{Aeq}$=55 dB). The remaining signals were generated by adding tonal components to the signal A, and adjusting the proportions accordingly to the assumed overall signal loudness.

During exposure to each of the test signals the subjects performed three psychological tests (COG, CORSI and ALS) and then they assessed a given signal with the use of the questionnaire.

The sequence of signal presentation was based on the Latin square design to exclude the effect of the sequence of the signals on the assessment results. The time of a full test for one participant was approx. 2 hours.

### Table 2: Test scenario diagram.

|----------------------------|----------|-------------------|--------------------|------------------|------------------------------------|

The test-retest method was used to assess the reliability of the research method. The interval between subsequent tests for each of the participants was at least two weeks. The tests were carried out in the same laboratory conditions and on the same study group.

The results of the tests were analysed using the following statistical tests: Shapiro-Wilk test for assessment of the normality of variable distribution, Brown-Forsythe test for assessment of the equality of variances, Friedman test for assessment of the significance of variation (ordinal variable) and...
the variance analysis test for assessment of the significance of variation (quantitative variable). Statistica 10 and PQStat software were used during the statistical analysis. A significance level of 0.05 was adopted in the analysis.

3. Results

The results of the subjective assessment of the annoyance of the signals under consideration are presented in the figure below (Fig. 1). The signals examined were evaluated within the range from slightly cumbersome to extremely troublesome. On average, signals A and B were rated moderately cumbersome, while signals C and D were rated very troublesome. The average results of the annoyance assessment for test 1 and re-test 2 did not show any discrepancies.

![Figure 1: Results of the subjective evaluation of the annoyance of signals (0 – not at all; 1 – slightly; 2 – moderately; 3 – very; 4 – extremely); medians, boxes: the range from 25% to 75% and whiskers: minimum and maximum values.](image1)

The results of the subjective assessment of signal loudness are presented in Fig. 2. A large span of individual ratings was observed (from 1 to 9 in the rating scale of 0 to 10) However, the average values of the rating indicate the moderate loudness of the signals examined (the rating of 3–4 for signals A, B and C and 4–6 for signals C and D). The average values of the rating between test No 1 and test No 2 did not differ by more than 1 point on the rating scale (signals A, B and D) or by 2 points on the rating scale (signal C).

![Figure 2: The subjective assessment of the signal loudness; medians, boxes: the range from 25% to 75% and whiskers: minimum and maximum values.](image2)
The results of the longest sequence in the CORSI test are presented in Fig. 3. The values obtained ranged from 3 to 9. The average values ranged from 5 to 6 for all the signals and did not differ by more than 1 point between test No 1 and test No 2.

Figure 3: The results of the assessment of memory span (CORSI) – the longest sequence that has been reproduced at least 2 times (immediate block span); medians, boxes: the range from 25% to 75% and whiskers: minimum and maximum values.

The results of the assessment of concentration and attention (COG) are presented in Fig. 4. The average values of the results obtained ranged from 0.85 to 1.05 s for test No 1 and from 0.85 to 1.25 s for test No 2. One extreme value for signal A was observed during test No 2. The average values of time periods for individual signals in test No 1 did not differ by more than 19% and the longest time period was observed for signal A. During test No 2 the average values of time periods did not differ by more than 30% (with the extreme value observed) or 12% (without any extreme value observed). As in test 1, the longest time periods were observed for signal A (both with the extreme value observed and without any such value observed). The difference between average time periods for individual signals between test No 1 and test No 2 did not exceed 19% (with the extreme value observed) or 10% (without any extreme value observed).

Figure 4: The results of the assessment of concentration and attention (COG): medians, boxes: the range from 25% to 75% and whiskers: minimum and maximum values.

The range of quantities of the tasks performed in the ALS test for all the signals was from 203 to 614. The average quantities ranged from 353 to 395 (Fig. 5). The difference in the average quantities between individual signals did not exceed 8% for test No 1 and 5% for test No 2. The smallest average
quantity of tasks performed was observed for signal A, both in test No 1 and in test No 2. The difference in the average quantity of tasks performed between test No 1 and test No 2 did not exceed 6% for individual signals.

![Figure 5: The results of the performance test (ALS) – the quantity of the tasks performed; medians, boxes: the range from 25% to 75% and whiskers: minimum and maximum values.](image)

During the assessment of the annoyance of the signals a statistically significant variation was demonstrated in test No 1 (p=0.0034; T1=11.9), whereas no statistically significant variation was demonstrated in test No 2 (p=0.052; T1=7.73). The results of statistical analysis did not show a statistically significant variation between individual signals both for the remaining questionnaire research, and for the psychological tests. Results of the variance analysis are provided in Table 3 and Table 4 for test No 1 and test No 2 respectively. Results of the interclass correlation (ICC) for test 1 and test 2 are presented in Table 5.

<table>
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<tr>
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<th>p</th>
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<tr>
<td>COG</td>
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<tr>
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<td>1.00</td>
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<td>CORSI</td>
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<tr>
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<td>ALS</td>
<td>0.30</td>
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<table>
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<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
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<td></td>
<td>0.89</td>
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<tr>
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<td>-0.11</td>
<td>0.89</td>
<td>0.76</td>
<td>-0.23</td>
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<tr>
<td></td>
<td>0.54</td>
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<td>0.92</td>
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</table>
4. Conclusions

The lack of variation in test results between the individual signals presented in the statistical analysis does not give any reasons to correct the measurement result due to tonality according to ISO 1996-2. [14]. However, the primary object of the pilot studies was to verify the research method; therefore, care should be taken when interpreting the results of the tests due to the number of subjects in the study group.

From among the possible comparisons of tests between two studies (test-retest), the value of less than 0.5 (the value demonstrating non-conformity) was obtained in 3 tests. In these cases, the prominent and extreme observations seem to be of key importance, as with such a small study group they may significantly affect the results of the analysis. The results of pilot studies form the basis for research aimed at establishing criteria for annoyance in the working environment. The use of the test-retest method to assess the reliability of the research method indicates the possibility of using the method developed, assuming that the study group is larger.

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REFERENCES

1 ANSI, ANSI S3.4-2007, Procedure for the Computation of Loudness of Steady Sounds, (2007)
13 PKN, PN-B-02151-02:1987 Building acoustics - Protection against noise in buildings - Permissible sound levels in rooms [in Polish: Akustyka budowlana - Ochrona przed hałasem pomieszczeń w budynkach --Dopuszczalne wartości poziomu dźwięku w pomieszczeniach], (1987)


17 Regulation of the Minister of Economy and Labor of August 5, 2005 on health and safety at work related to noise exposure or mechanical vibrations [in Polish: Rozporządzenie Ministra Gospodarki i Pracy z dnia 5 sierpnia 2005 r. w sprawie bezpieczeństwa i higieny pracy przy pracach związanych z narażeniem na hałas lub drgania mechaniczne], Dz.U.2005.157.1318, (2005)

18 Regulation of the Minister of Labor and Social Policy of June 6, 2014 on the highest permissible concentrations and intensities of factors harmful to health in the work environment [in Polish: Rozporządzenie Ministra Pracy i Polityki Społecznej z dnia 6 czerwca 2014 r. w sprawie najwyższych dopuszczalnych stężeń i natężeń czynników szkodliwych dla zdrowia w środowisku pracy], Dz.U. 2014 poz. 817, (2014)


23 World Health Organization, Burden of disease from environmental noise. Quantification of healthy life years lost in Europe, (2011)