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Evaluation of Annoyance Due to Wind Turbine Noise Based on Pre-learned Patterns

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Abstract. Annoyance due to wind turbine noise is usually assessed on the basis of surveys conducted among people living in the vicinity of turbines or in the laboratory conditions. Due to the fact that the latter are very different from natural conditions, we propose a solution to reduce this difference. Prior to the surveys, 50 participants were asked to familiarize themselves with 5 environmental signals. They were informed about the annoyance rating assigned to each signal (obtained earlier in laboratory conditions), expressed as a number between 0 (not annoying signal) and 10 (extremely annoying signal). Participants were then presented with new environmental sounds and asked to rate the annoyance caused by each sound, in accordance with the previously learned method. The analysis of our results shows that the variability of answers given by respondents at their homes is similar to those obtained earlier in laboratory conditions.

Keywords: survey, in situ study, laboratory experiment, calibration procedure.

1. Introduction

There are basically two methods for testing the annoyance due to the sound generated by a noise source. The first is to assess the annoyance resulting from the sound generated by a given noise source at the location where that source emits the noise. These are known as field studies. The second method, on the other hand, is related to playing a pre-recorded sound and assessing the annoyance associated with such a sound under laboratory conditions. It is clear that both methods have their advantages and disadvantages. The assessment of annoyance at the site of a noise source is usually carried out by means of questionnaires. On the basis of the information contained in the questionnaires, it is not possible to determine what influence the individual parameters of this noise source have on this assessment. Therefore, detailed studies on the effect on the human body of each of these individual parameters are carried out individually in the laboratory. These preliminary considerations apply to any noise source, including the noise generated by wind turbines. The annoyance due to wind turbine noise is usually assessed on the basis of surveys of people living in their vicinity. Such surveys provide information on the overall assessment of wind turbine noise annoyance. The main parameters affecting the emergence of an overall annoyance assessment are the noise level, its time course, the length of noise exposure, and the distance of the noise source from the listener. Under laboratory conditions, it is possible to determine the influence of each of these parameters on the overall annoyance rating.

However, it is known that laboratory conditions are markedly different from natural conditions [1-3], i.e. those experienced by people living near wind turbines. For this reason, we proposed a solution to reduce this difference. Our approach consisted of a kind of calibration of the signals presented to both survey participants and participants in the laboratory experiments which involved teaching them how to assess the annoyance associated with the reference noise samples. Prior to both the surveys and the laboratory experiments, participants were asked to listen to 5 environmental signals presented through headphones, and they were informed of the annoyance rating assigned to each signal, expressed as a number ranging from 0 (not annoying signal) to 10 (extremely annoying signal). Thus, it was a kind of training in which participants learned how to use numbers to assess the annoyance associated with a sound. Participants were then presented with new environmental sounds and asked to rate the annoyance caused by each according to a previously learned method. This arrangement at least makes it possible to assume that those participating in the survey assessing the annoyance generated by wind turbines use numbers in their assessment in the same way as those assessing wind turbine noise under laboratory conditions.

The experimental procedure described in this paper was approved by the university ethical commission of research conducted with people (resolution no. 15/2020/2021 from the 28th of September, 2021).

2. Method

At the current stage of the research (carried out under project NOR/POL/HETMAN/0073/2019), we have the results of 50 questionnaires (conducted *in situ*) in which participants were taught to use numbers to assess sound annoyance. We do not yet have the results of the experiments conducted in the laboratory.

Thus, a method will be presented for carrying out an annoyance assessment of selected environmental sounds after training on reference noise samples previously assessed in the laboratory (in older experiments, conducted by us in previous years). For this type of training, we used recordings of 7 reference noise samples, described in Tab. 1, which are sounds from an earlier publication [4]. Subjects listened to these sounds through headphones (Beyerdynamic DT-150) and were informed of the numbers assigned to the annoyance ratings associated with these sounds (see Tab. 1). The numbers shown in Tab.1 represent the annoyance ratings obtained by the 17 participants in this study.

Table 1. Annoyance ratings (on a scale of 0-10) of the presented reference noise samples in the survey. The ratings were for noise samples of 10 s duration.

Noise source description	Annoyance rating
P1 Traffic circle	7
P2 Street with light traffic	4-5
P3 Street with heavey traffic	9
P4 Market square	3-4
P5 Pedestrian zone	5-6
P6 Park close to the lake Malta	0-1
P7 Park near the street with heavy traffic	4-5

Note: If a range of numbers is given, it means that the average annoyance was more or less the average of the range given. However, as an individual respondent can only tick an integer value, it is recommended to give a range of both numbers ('rated 4 to 5', 'some rated 4, some rated 5') rather than an average value.

All questionnaires were filled in by participants in their houses or local community centers. We presented them the concept of the annoyance scale and all seven recordings mentioned above (using headphones). After this training, the interviewees were asked to rate 5 other environmental sounds with numbers (these were sounds generated by wind turbines) of the same duration. Wind turbines recordings had noticeable amplitude modulation with the frequency around 0.5 Hz. Maximum energy lied in the band between 200 and 500 Hz. The instructions to the interviewees were as follows:

You have just been presented with the recordings along with their average annoyance rating. We will now present five more recordings, but this time we ask you to rate the annoyance yourself. Please rate on a scale from 0 to 10 how annoying or disturbing the sound was. If it did not annoy you at all, please choose 0, if it annoyed you extremely, please choose 10, if it annoyed you 'in between', please choose a number between 0 and 10.

According to these instructions, the people surveyed were to rate the annoyance of these 5 sounds on a numerical ICBEN scale of 0 to 10 [5] in its Polish translation [6]. The annoyance ratings made by the survey participants were evaluated and analyzed. The scatter of the ratings of the survey participants was compared with the scatter of annoyance ratings obtained in the paper [4] from where the training sounds originated. This whole procedure was devised so that when answering the questions in the survey (without the headphones) about the annoyance ratings of the selected noise sources, the person surveyed could use the knowledge they had learned in training. The questions in the survey in which this knowledge was used are not the subject of this paper, however we applied both semantic and numerical version of ICBEN scales.

3. Results – Annoyance ratings of 5 environmental sounds

Based on the answers given by 50 people (28 men and 22 women, mean age = 55.2, SD = 15.1) we can say that the overall annoyance rating of an audio sample increases with the sound level value (see Fig. 1). However, there is no statistically significant difference between 45 and 50 dBA. All the other differences between various sound level values are indeed statistically significant.

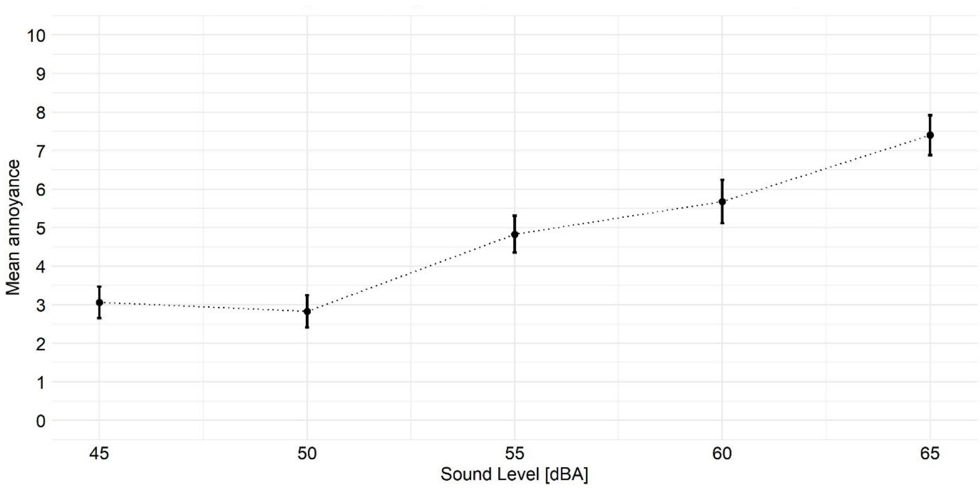

Figure 1. Mean annoyance ratings (with 95% confidence intervals) given by listeners to five different audio samples of wind turbine noise.

As one can see, the confidence intervals around the mean values are not large, typically around 1. We have mentioned before that these results are obtained *in situ,* during the initial procedure of our survey research. So the main question is: are these results and their variability similar to laboratory conditions?

To answer this question, we compared the results from Fig. 1 with our previous studies. The first reference study was the study from which we took the teaching audio samples [4]. In this study, the duration of samples was the same (10 seconds), however the sound level values were different, so we cannot compare stimuli one-to-another per se. Thus, we also checked another study [7] in which the sound level values were almost the same (without 45 dBA), but the stimuli duration was 5 minutes.

The comparison procedure was simple. We computed some variability metrics – including the confidence interval range, standard deviation, variance and range of given answers – and compared them with the same metrics from both reference studies. The results are presented in Tabs. 2 and 3, respectively. In both tables, 'metric' is the confidence interval range (CI), standard deviation (sd), variance (var) and the range of answers (range). The column 'MetricLower' shows in how many cases a given metric was lower in our study than in the reference one; the opposite calculation is in the column 'MetricHigher'; the column 'SL' is the sound level value.

Table 2. Comparison between results of our study and the first reference study [4].

SL	Metric	MetricLower	MetricHigher
45	CI	5	2
45	sd	5	2
45	var	5	2
45	range	4	2
50	CI	5	2
50	sd	5	2
50	var	5	2
50	range	4	3
55	CI	4	3
55	sd	4	3
55	var	4	3
55	range	3	3
60	CI	2	5
60	sd	2	5
60	var	2	5
60	range	3	3
65	CI	2	5
65	sd	3	4
65	var	3	4
65	range	3	3

In Tab. 2, 'SL' shows only the sound level values of a stimuli from our study. Because in the reference research there were no such sound level values, we simply compared each stimulus with all the teaching stimuli – taken from [4]. As one can see, the results are almost symmetrical, with more lower metrics for low SL values and more higher ones for large SL values. Overall, in 73 cases the metric values in our study were lower and in 63 – higher than in the reference study. So it seems that our results have almost the same variability as was observed in [4].

Table 3. Comparison between results of our study and the second reference study [7].

SL	Metric	MetricLower	MetricHigher
50	CI	6	8
50	sd	9	5
50	var	9	5
50	range	6	5
55	CI	4	10
55	sd	12	2
55	var	12	2
55	range	2	8
60	CI	2	12
60	sd	8	6
60	var	8	6
60	range	6	1
65	CI	11	3
65	sd	14	0
65	var	14	0
65	range	13	0

Another situation could be observed for the second comparison (Tab. 3). This time it can be clearly seen that there are more cases in which our study has lower metric values than the reference one. There are some exceptions to this pattern (mainly for CI for SL = 55 and for CI for Sl = 60), however, overall in 136 cases the metric values in our study are lower and only in 73 they are higher. These results suggest that for this comparison our study had generally lower variability than the reference study (which was, to repeat, a laboratory one).

4. Conclusions

One of the issues encountered in field studies on noise annoyance is large variance in the answers. This problem was reported several times in the literature [8]. When one wants to compare field studies with laboratory ones, this could be a problem. As we want to analyze the noise of wind turbines in both conditions, our aim was to teach people the concept of annoyance and gather reliable data from them. As can be seen from results, this goal was met – overall, the variability of answers given by respondents at their homes is similar to those obtained in earlier experiments in laboratory conditions. Thus, it is possible that a future comparison will not be biased by variability in the answers. On the other hand, it could be stated that in laboratory conditions there are far less distracting factors but the situation is also more 'artificial' for participants (an anechoic chamber is not a living room) and this could be a problem which should be properly addressed.

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Additional information

The author(s) declare: no competing financial interests and that all material taken from other sources (including their own published works) is clearly cited and that appropriate permits are obtained.

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