Project: A healthy society - towards the optimal management of wind turbine noise

Norway grants

NCBR Narodowe Centrum Badań i Rozwoju

D1.5 Wind turbine noise – adaptation effect (M27)

Projekt: **Healthy society - towards optimal management of wind turbines' noise**

UAM AKUSTIX AGH SINTEF IOŚ-PIB

GIG Państwowy Instytut Badawczy Instytut Medycyny Pracy im. prof. J. Nofera PSEW

D1.5 Wind turbine noise – adaptation effect (M27)

Executive summary

Presented data explores wind turbine noise annoyance assessment, employing both field and laboratory conditions. The application of the *in-situ* methodology enables to capture a broad spectrum of annoyance influenced by visual and socio-economic factors, whereas laboratory measurements can isolate and characterise acoustic aspects.

Demonstrated research introduces a novel calibration method, enabling participants to develop a consistent internal criterion for annoyance assessment through exposure to pre-rated environmental sounds. Such an approach ensures more objective and reproducible evaluation.

Our findings indicate no significant differences between annoyance ratings in laboratory and field conditions after training, underscoring the reliability of controlled laboratory settings. Calibration signals were also utilized to determine if neural adaptation (i.e., habituation) to the sound of wind turbines occurred. The hypothesis was that the same individuals would rate the sounds as less annoying after the turbines were installed if habituation took place. However, the results did not support this hypothesis, indicating that habituation did not occur in the study group.

To know the subjective assessment of the people living, apart the quantitative evaluation, partakers described wind turbine noise using proposed adjectives. "Swishing" was the most frequently chosen descriptor, aligning with existing literature. However, inconsistencies in this qualitative assessment suggest a need for training in future research. This training could include samples of sounds with various acoustic characteristics and assigned attributes, enhancing the understanding of the proposed terms, particularly as they pertain to a relatively new sound source (in Poland).

Authors	Date of submission	Confidentiality level
Anna Pastusiak Robert Gogol Anna Preis Truls Gjestland	30.VI.2023	It can be made available on the project website: https://hetman-wind.ios.edu.pl

1. INTRODUCTION

Annoyance may be evaluated in two different ways. Firstly, during so called field (*in-situ*) studies – at the location of the noise source being assessed. The survey results describe the overall annoyance, which is largely made up of visual and socio-economic factors. However, such an evaluation does not take acoustic factors into account or is very general – it is not possible to determine what influence the individual parameters of this noise source have (Felcyn et al., 2022). The second approach to annoyance assessment is in laboratory conditions, where listeners are usually presented with pre-recorded samples (audio and/or audio-visual). The advantage of such a practice is that it is well controlled.

As one of the main parameters affecting overall annoyance remains noise, the specific influence of its level, length of exposure or acoustic characteristics (e.g. tonality of modulation presence) can be accurately determined knowing exactly what was presented in the experiment. On the other hand, laboratory settings are different from conditions experienced by people living in the vicinity of noise sources (Schreckenberg , & Schuemer, 2010; Bartels et al., 2015). Hermida Cadena et al. (2017) suggests, for instance, that the real environment allows an unmitigated contextualization as offers other accompanying stimuli.

Knowing the limitations and advantages of each method, we have developed and verified another approach. For the annoyance tests, both questionnaire and laboratory, we introduced an additional element, a kind of signal calibration, which was intended to give participants a practical introduction to “annoyance”. By familiarising themselves with exemplary samples and how they were assessed by a group of subjects, it was possible to create their own internal assessment criterion. This, in comparison with a reference, would allow for the most objective (despite the subjective nature of the experiment) and reproducible (within the individual participant) evaluation. The detailed procedure and validation results are presented below. The summary of the research implementation will be divided into three main parts: the methodology and process of implementing the "novel calibration" (sections 2 and 3), adaptation effect (section 4), and the subjective noise characteristics (section 5).

2. CALIBRATION PROCEDURE

Prior to each study, both field and laboratory, 7 environmental sounds were presented to a group of 122 listeners (66 and 56 respectively). These had been recorded and described in detail in earlier studies (Preis et al., 2015). They were all recorded in various locations in Poznań (including a park, a street and a marketplace) using a TEDS 4101 binaural microphone together with the BK PULSE v.12.6.255 system. The samples were assigned average annoyance ratings expressed on a 11-point ICBEN scale in Polish translation (Fields et al., 2001; Preis et al., 2003 by the 17 participants of the aforementioned study. These ratings became the reference rating for participants taking part in the experiments conducted within the Hetman project. The detailed ratings are shown below - where a range of ratings is given, their mean falls roughly in the middle between the values. Subjects listened to the aforementioned sounds through Beyerdynamic DT-150 headphones and were informed what annoyance ratings were associated with these samples. The order of presentation was randomised, but each respondent heard all 7 examples.

After training, it was possible to proceed to the main part of the listening test. Listeners were presented with 5 other samples containing environmental sounds (described below) in a random order. The samples were recorded at one of the wind farms for the study by Felcyn et al. (2022). Each sample was time-clipped to 10s. Recordings contained a distinct amplitude modulation with a frequency of approximately 0.5 Hz and maximum energy in the 200 and 500 Hz band. The recordings varied in level (as they were registered at different distances from the sound source), which ranged from 45-65 dBA with a 5 dB step.

The subjects were not informed which sound sources were present in the recordings. Their task was to rate the annoyance of the recording using the Polish translation of the ICBEN scale by responding to a command: *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.*

Measurement set-up is presented in the Figure 1.

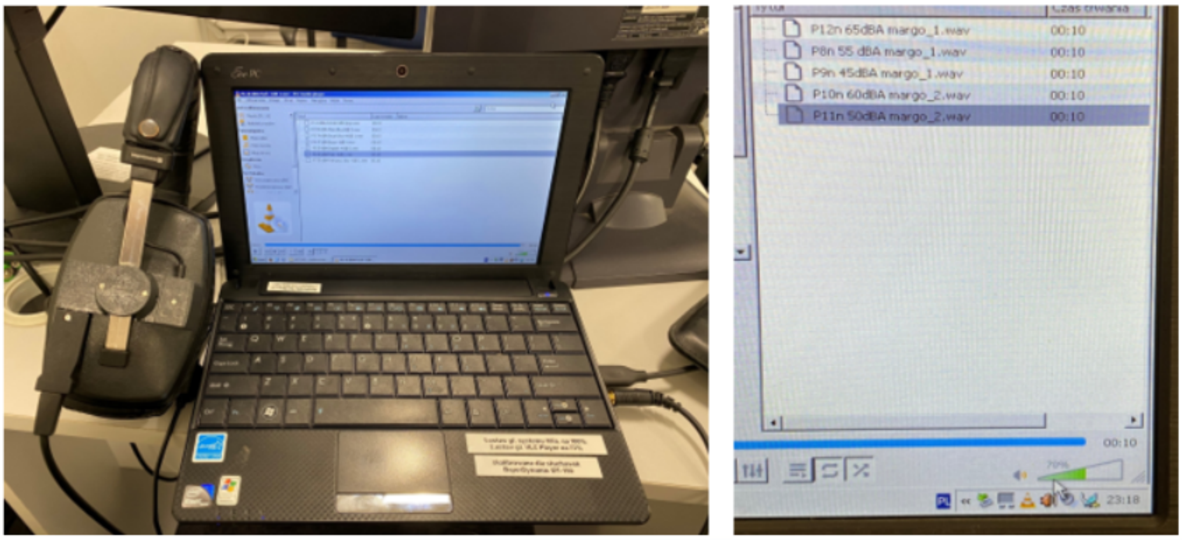

Fig 1. *Measurement set-up*

3. RESULTS

The ratings obtained for both groups (laboratory and field test) were analysed and compared with each other (Figure 2). As we found, there were no statistical differences between the annoyance ratings measured under laboratory conditions with listeners who had not previously experienced wind turbine noise and the field evaluation, which involved people living in close proximity to wind turbines (for 52 people, the WT is visible from at least one room in the house). The confidence intervals are not large, ranging between 1 and 1.5. This allows preliminary conclusions to be drawn indicating that the conditions for the presentation of the same signals are not significant after appropriate training to familiarise subjects with the concept of annoyance and its rating scale.

In other words, well-controlled laboratory studies allow for the reliable measurement of annoyance caused by acoustic factors related to wind turbine noise. This has an important experimental relevance – acoustic annoyance (concerning sound only) can therefore be determined under laboratory conditions, which, often, are more accessible than field studies. Undoubtedly, this reduces the costs of testing and also allows the population that could potentially participate in listening tests to be expanded. One thing should be emphasised again: this concerns only acoustic annoyance, considering the sound characteristics of the source. The concept of annoyance itself is much broader and also includes visual or socio-economic factors, as described elsewhere in the project report.

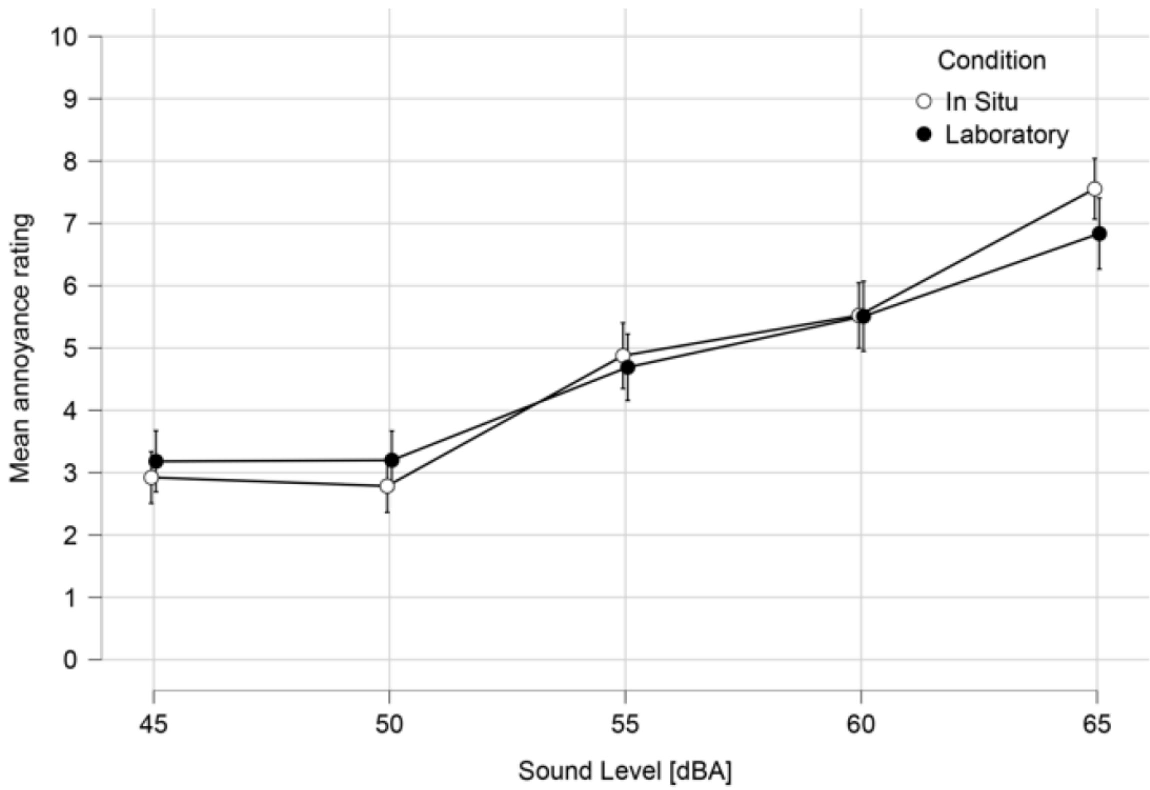

***Fig. 2** Mean acoustic annoyance ratings (with 95% confidence intervals) given by listeners to five different audio samples of wind turbine noise (in situ and laboratory conditions).*

Based on the results obtained in the laboratory tests, a trend can be seen indicating an increase in the annoyance rating expressed on a 0–10 scale with the level of the recording presented for both conditions (Figure 3 and 4).

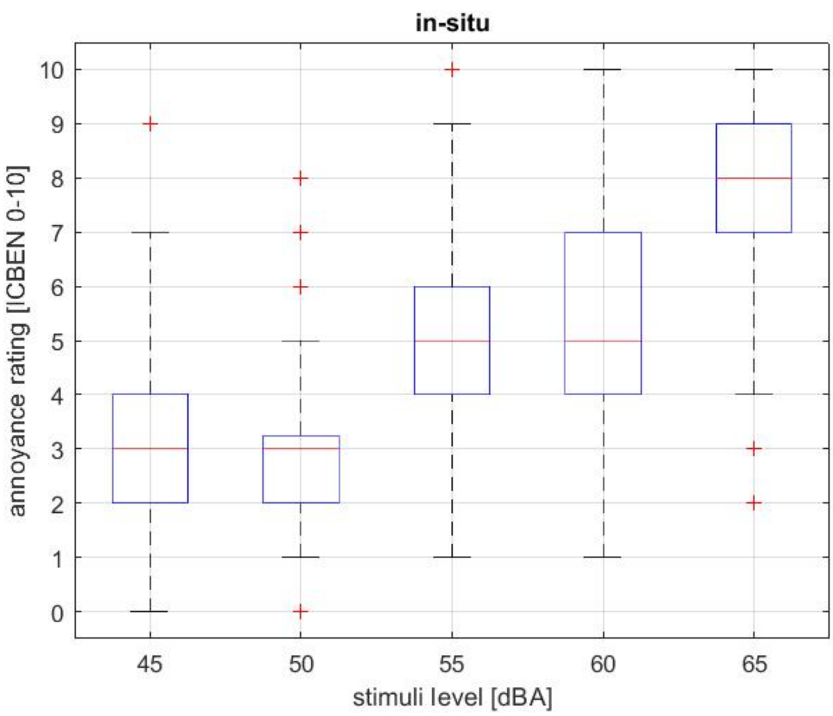

***Fig. 3** Mean annoyance rating in ICBEN scale – in-situ*

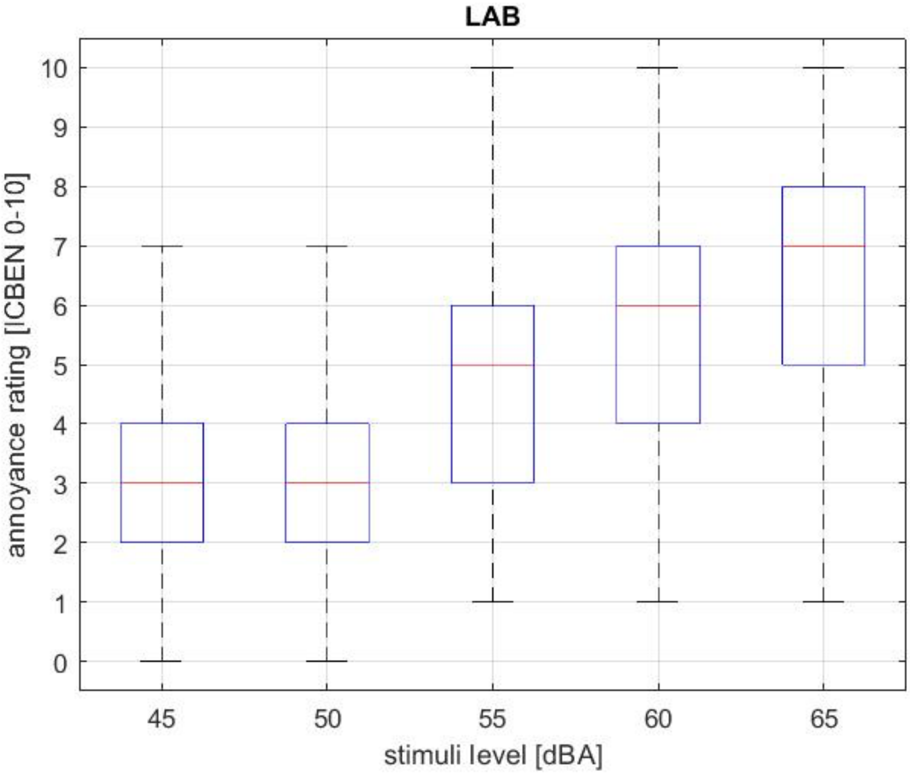

Fig. 4 *Mean annoyance rating in ICBEN scale – laboratory*

However, no statistically significant differences were found between 45 and 50 dBA and 55 and 60 dBA. All other differences between the various signal levels are statistically significant. Exactly the same relationships were found in the field measurements.

Preliminary findings suggest that laboratory-based results align closely with in-situ observations post-training, with no statistically significant disparities noted. However, it is evident that non-acoustic determinants exert a notable influence on the assessment of annoyance. To gain insights into these factors, conducting audio-visual experiments, preferably leveraging virtual reality (VR) technology, is imperative. Notably, while respondents often draw analogies between turbine noise and ambient sounds such as ocean waves or aircraft engines, articulating precise descriptions poses challenges, necessitating structured training interventions.

4. ADAPTATION EFFECT

Habituation (understood as decrease in response to repeated stimuli) and neural adaptation (changes in neuron responses to constant or recurring stimuli) are concepts that are relatively underexplored in hearing-related scientific literature, particularly compared to studies on vision. This is especially true when it comes to adaptation to sound sources in the acoustic environment over long-term assessments, as opposed to brief samples like short-term adaptation evaluated with pre- and post-exposure questionnaires. Quantifying this effect is challenging.

The analyses conducted as part of the Hetman project aimed to assess the degree of habituation by comparing annoyance ratings of all sound sources over 12 months, collected before and several months after the wind farm was commissioned. It was assumed that over this period, the only changing sound source was the wind turbine noise (which was not directly assessed in the surveys but was present in the acoustic environment during the second survey at the same location). ANOVA analysis of the results from the 15 participants surveyed on two occasions showed no statistical differences between the 'before' and 'after' questionnaires regarding the wind farm start-up (the f-ratio value is 0.77; p-value is 0.39). Several months after the wind farm becomes operational, residents of neighboring areas do not perceive the acoustic environment as worse. The acoustic environment is understood here as a combination of all sound sources to which the test subjects are exposed, taken together (their annoyance was the subject of a question from the survey quoted in chapter 2). On a perceptual level, the introduction of a new sound source and the passage of time do not increase annoyance. However, it cannot be concluded that habituation has occurred.

Studies show that people may become accustomed to certain sounds over time, thereby reducing their annoyance (e.g. Leventhall, 2004). In this case such reduction was not observed and it seems to be confirmed by subsequent analyses.

The table below (Table 1) shows the average annoyance rating on a 11-degree ICBEN scale measured before and after the commissioning of a wind farm close to the respondents' dwelling places. These ratings provide a clear indication that the overall annoyance (combination of all sound sources) remained consistent with the introduction of the wind farm (and enhanced familiarity with this sound source), but did not decrease, as would have been the case with habituation.

Table 1 *Mean annoyance rating before and after the commissioning of a wind farm*

sample level	before	after	F-score
45 dBA	3.60	3.06	1.09
50 dBA	3.53	3.00	1.20
55 dBA	4.86	4.46	0.51
60 dBA	5.86	5.73	0.05
65 dBA	7.53	7.66	0.06

While habituation is possible with many stimuli, including auditory ones, wind turbines seem to be a particular source. Perhaps this is due to their unsteady acoustic characteristics and the strong influence of other factors, not only physical (e.g. the visual aspect), but also psychological or socio-economic. It remains in line with the literature – Pedersen and Waye (2007) found that residents living in the vicinity of wind turbines do not always exhibit habituation to the noise, and its annoyance can remain high even after prolonged exposure.

5. NOISE CHARACTERISTICS

One of the respondents' tasks was to select adjectives they most associated with wind turbine noise. They made this selection while the turbines near their residences were already in operation, meaning they, in theory, were familiar with the nature of the sound. Additionally, they were introduced to examples containing the sound of wind turbines, although these samples were presented without prior description (the investigator(s) did not inform in advance of what the recordings contained).

As can be seen, the most common term respondents used to characterise the sound generated by wind turbines is 'swishing' which aligns with the literature (e.g. Pedersen, 2004, 2008) – see Figure 5.

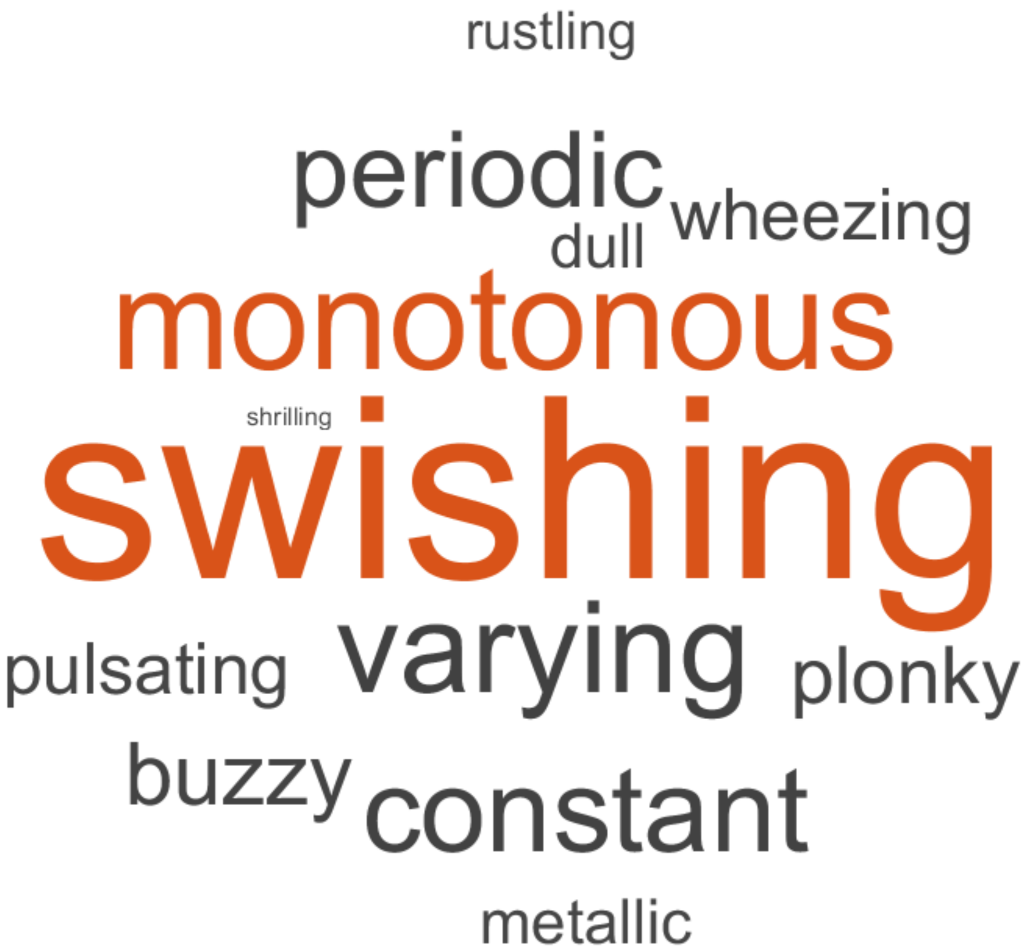

Fig 5. *Most commonly used wind turbine noise subjective characteristics*

The sound of a turbine is often compared to a "plane flying at high altitude", the sound of the sea, or the rustling of trees. However, there is some inconsistency in the following terms. While characteristics related to the modulation or variability of sound are consistent with

scientific reports (Pedersen, 2004; *modulation/variability* in Yoon, 2016; Large, 2014; Hayes, 2006), surprisingly, the opposite terms – "constant" and "monotonous" – are just as frequent. Moreover, there were instances where respondents simultaneously chose opposing terms.

Several possible explanations exist for this phenomenon. Firstly, although the respondents live near the wind turbines, they may have never actually heard the turbines or only heard them extremely rarely (e.g., when walking in their immediate vicinity). In interviews conducted after the main part of the questionnaire, some partakers claimed they were not aware that the turbine could generate any sound. In addition, at the location where a significant part of the surveys were conducted, other dominant sound sources within a short distance of the measurement site effectively masked the wind turbine noise, regardless of the time of day or year (e.g. highway). The use of inconsistent terms might be attributed to unfamiliarity with the characteristics of wind turbine sound - after all, turbines in Poland are a relatively new and less well-known source of environmental noise compared to more familiar sources like aviation or car noise. It is also likely that respondents did not fully understand the proposed terms. It should be noted that the listeners were not individuals with experience in acoustic experiments. Therefore, it might have been challenging for them to relate the perceived nature of the sound to the given terms. It is possible that their cognitive evaluation was accurate (i.e., corresponding to the psychoacoustic characteristics described in the literature) but incorrectly named. A potential solution for future research could involve training similar to that on annoyance. Test subjects could be presented with samples containing sounds of different acoustic characteristics (not necessarily from wind turbines), along with the assigned characteristics. It is important that these are real recordings, not synthetic samples.

6. SUMMARY

Preliminary findings of our research suggest that:

1) Laboratory-based results of acoustic annoyance measurements align closely with in-situ observations post-training, with no statistically significant disparities noted.

2) It is evident that non-acoustic determinants exert a notable influence on the assessment of annoyance. To gain insights into these factors, conducting audio-visual experiments, preferably leveraging virtual reality (VR) technology, is imperative.

3) The comparison of annoyance levels over the past 12 months, both before and after the commencement of operations at the wind farm, indicates no statistically significant variances in mean scores. Given that the wind turbine represents the sole source of sound altering the acoustic landscape within which respondents reside daily, it can be inferred that, on the whole, the turbine's presence does not exacerbate the overall evaluation of the environment several months post-commissioning. However, it cannot be concluded that habituation has occurred, as the expected and literature-reported decrease in annoyance ratings was not observed.

4) While respondents often draw analogies between turbine noise and ambient sounds such as ocean waves or aircraft engines, articulating precise descriptions poses challenges, necessitating structured training interventions.

Undoubtedly, mentioned issues warrant further in-depth research; however, the findings gleaned from this study offer fresh insights into the matter at hand. Moreover, the question concerning the qualitative assessment of the source appears to remain open, suggesting avenues for continued investigation and exploration.

REFERENCES

Bartels S., Márki F., Müller U. (2015), The influence of acoustical and non-acoustical factors on short-term annoyance due to aircraft noise in the field - The COSMA study, Science of The Total Environment, 538: 834–843.

Felcyn J., Preis A., Gogol R. (2022), Evaluation of Annoyance Due to Wind Turbine Noise Based on Pre-learned Patterns, *Vibrations in Physical Systems*, 33(1): 1–5.

Fields et al. (2001), Standardized general-purpose noise reaction questions for community noise surveys: Research and a recommendation, *J Sound Vib*, 242(4): 641–679.

Hayes M. (2006), The measurement of low frequency noise at three UK wind farms, Contract Number W/45/00656/00/00, URN 6, 1412.

Hermida Cadena A.C. et al. (2017), Assessing soundscape: Comparison between in situ and laboratory methodologies, *Noise Mapping*, 4(1): 57–66.

Large S., Stigwood M. (2014), The noise characteristics of compliant wind farms that adversely affect its neighbours, [in:] INTER-NOISE and NOISE-CON Congress and Conference Proceedings, 249(1), pp. 6269–6288.

Leventhall H.G. (2004), Low frequency noise and annoyance, *Noise Health*, 6(23): 59–72.

Pedersen E., Waye K.P. (2004), Perception and annoyance due to wind turbine noise--a dose-response relationship*, J Acoust Soc Am*, 116(6): 3460–2470.

Pedersen E., Waye K.P. (2007), Wind turbine noise, annoyance and self-reported health and well-being in different living environments, *Occupational and Environmental Medicine*, 64(7): 480-486.

Pedersen E., Larsman P. (2008) ,The impact of visual factors on noise annoyance among people living in the vicinity of wind turbines, *J Environ Psychol*, 28: 379–389.

Preis A. et al. (2003), Polish version of standardized noise reaction questions for community noise surveys, *Int J Occup Med Environ Health*, 16(2): 155–159.

Preis A. et al. (2015), Audio-visual interactions in environment assessment, *Science of the Total Environment*, 523: 191–200.

Schreckenberg D., Schuemer R. (2010), The impact of acoustical, operational and non-auditory factors on short-term annoyance due to aircraft noise, Proceedings of Inter Noise 39th International Congress on Noise Control Engineering, 13–16 June 2010, Lisbon, Portugal.

Yoon K. et al. (2016), Effects of amplitude modulation on perception of wind turbine noise, *J. Mech. Sci. Technol*, 30(10): 4503–4509.