DOI: 10.61782/fa.2023.0397

forum acusticum 2023

# ASPECTS OF QUANTIFYING IMPACT SOUND ANNOYANCE

**Martina Vrhovnik**[1*] **Urban Kavka**[1] **Rok Prislan**[1]

[1] InnoRenew CoE, Livade 6a in 6310 Izola, Slovenia

### ABSTRACT

The exposure to noise and its harmful effects on health have been a subject of scientific consideration for decades. Over time different psychophysical indicators for characterizing noise have been developed and some, such as the Zwicker loudness (ISO 532-1:2017), found its way even into standardization. Nevertheless, it is often challenging to establish a relationship between single-number (SNQs) quantities and annoyance ratings. This paper presents several trends in research that were found in scientific literature focusing on studies with a shorter listening test design, conducted under laboratory conditions. Moreover, the relation between psychophysical indicators and annoyance ratings is investigated. In addition, technical and practical constraints regarding the design of such experiments are presented.

**Keywords:** *impact noise, single-number quantities, annoyance ratings, subjective perception*

## 1. INTRODUCTION

Annoyance of impact noise within buildings can cause adverse health effects and disagreements between neighbors [1]. Psychoacoustic measures are intended to refer to the subjective auditory perception of noise quantified by single-number quantities (SNQs) [2]. These correlate better with our perception when spectrum adaptation terms are applied, taking into account the specific frequency characteristics of noise.

**Corresponding author*: *martina.vrhovnik@innorenew.eu.*


Rasmussen and Rindel [3] provided an overview of the historical development and increasing complexity of legal sound insulation requirements. They showed that differences between countries in the SNQs used can be large, making direct comparison between requirements difficult. Legal sound insulation requirements are "... thus representing a cataloguing of concepts rather than a harmonization"(Ramussen and Rindel [3], 2005).

In addition, there are several problems with relating subjective annoyance ratings to the developed SNQs, as they generally do not correlate well with each other. For example, the standardized SNQs predicted or determined by measurements do not appear to be appropriate when applied to timber buildings [4]. This raises questions according to different construction types and the relevant frequency spectra of the various standardized and real impact sound sources. In particular, the omission of low frequencies below 100 Hz in most standards potentially leads to a misrepresentation of how annoying impact sound is for people in the built environment [2].

To better understand this aspect, various listening tests were performed to assess people's response to impact noise [2]. Because of short auditory memory, in-situ comparisons within longer time intervals between listening are neither valid nor reliable. This was highlighted by Lokki in his study of perceptual preferences for concert halls [5]. Lokki reproduced acoustic environments of different halls under laboratory conditions and allowed participants to switch between them. Lokki argues that instantaneous switching between acoustic representations is essential for a reliable acquisition of subjective responses. Therefore, this review presents studies that evaluated subjective responses in shorter listening tests under laboratory conditions.

In 2018, Vardaxis and Bard published a review article on "...studies that approach acoustical comfort in living spaces by linking acoustical data and subjective responses in laboratory tests."(Vardaxis and Bard, 2018). Because this survey [2] focused on impact sound, it was taken as a starting point for further examination of studies investigating the relation between annoyance and impact sound in buildings.

## 2. METHOD

The databases Scopus, World of Science, and Researchgate were used to search for appropriate studies and conference proceedings. The keywords used were: *impact, noise, sound, annoyance, buildings, single number quantity*. Some literature was subsequently found on basis of the listed references in [2].

The studies considered conducted listening tests on subjectively rated impact noise annoyance under laboratory conditions. By laboratory conditions it is meant that the reproduced impact noise was recorded and reproduced through headphones or loudspeakers in a controlled environment. Another requirement for inclusion was that the studies examined correlations between at least one SNQ and the measured annoyance ratings.

For a definition of the quoted SNQs, sound qualities, and spectrum matching terms, please refer to [2] and [6]. The specifics of conducted listening tests and statistical methods applied in each individual study are not detailed and the interested reader should refer to the specific study.

## 3. RELEVANT LITERATURE

After reviewing the databases based on the previously stated requirements, ten studies were included in the literature review. The following review focuses on the results related to the correlation between the SNQs used and the reported annoyance ratings. The studies are grouped according to their focus of investigation.

### 3.1 Reproduction Condition

Jo and Jeon examined the influence of spatial and visual cues on ratings of annoyance in a virtual reality environment [7]. Recordings of a heavy impact noise (rubber ball) were played back through headphones as (1.) a mono sound source, (2.) binaurally, with an applied head-related transfer function (HRTF), (3.) in mono with visual information via a head-mounted display (HMD), and (4.) binaurally, with applied HRTF and with visual information via HMD [7]. The correlation between $L_{A,Fmax}$ and annoyance showed that annoyance ratings were significantly higher when the noise was reproduced binaurally or binaurally in combination with visual information via the HMD (cases 2 and 4) [7]. The allowance limit, measured in SPL dBA, at which half of the participants could no longer tolerate the noise, was significantly lower for the applied HRTF (cases 2 and 4) than for the presentation in mono (cases 1 and 3) [7]. The study concluded that noise sensitivity, and thus annoyance, was higher when directional and visual information was provided [7].

Another study on spatial effects, conducted by Frescura et al., focused on impact sound (walking) on the upper floor of wooden residential buildings [8]. The impact noise was characterized using the magnitude of the interaural cross-correlation function (IACC) and $L_{AFmax}$. Impact sound with a higher IACC also had a higher annoyance rating [8]. Similar to Jo and Jeon [7], the results showed that a clearer localization of the impact noise led to a higher annoyance rating [8].

### 3.2 Type of Construction

With regard to the comparison of different floor types, Hongisto investigated the perception of four real impact sound types (basketball bouncing, chair moving, walking with shoes, and walking with socks) elicited on six floor types [9]. The SNQ $L_{n,W}$ could not rank the six floating floors in the correct order to the four noise types [9]. In particular, walking with socks, a very common impact sound in the built environment, had no correlation to the SNQ [9].

Jeong et al. addressed the problem that heavy-weight impact sources, such as the tapping machine, walking or rubber ball, have not been subject of scientific research as often as their lightweight counterparts. Therefore, they conducted two listening tests on heavy-impact noise in which seven SNQs were evaluated in regard to their appropriateness. The SNQ $L_{iA,Fmax}$ had the highest correlation values. The SNQ $LL_z$, also known as Zwicker Loudness [10], had the lowest correlation value for the impact noise rubber ball. The study concludes that sound energy-based SNQs, especially $L_{iA,Fmax}$ have higher correlation values than loudness-based SNQs, such as $LL_z, N_5$ or $N_{max}$.

### 3.3 Impact Sources

The discussion about standardized impact noise sources such as the tapping machine or the impact ball, and its suitability to represent realistic sources is an ongoing topic

[3] [2]. For instance, in [2] results imply that the tapping machine does not represent walking sound as good the standardized rubber all. Frescura et al. come to the opposite conclusion that the spectrum of the impact noise source used for measurements is not relevant and the ISO tapping machine is a suitable noise source [11]. The discrepancy between conclusions in this regard underline the importance of further research in this area.

For impact sound that varies in duration, number or level the study conducted by Kim et al. indicate that SNQs which take into account the duration and energy level of the sound source are more explanatory then SNQs which measure the sound pressure level [12]. Reproduced children's running was used, because it needed to reflect irregular patterns of impact sound in an actual apartment [12]. The results show that $L_{eq}$ and $L_{AE}$ correlate better with the annoyance ratings than $L_{iA,Fmax}$ [12].

### 3.4 New Spectrum Adaptation Terms

A different approach to finding the most appropriate SNQ for annoyance ratings was taken by Kylliänen et al., who developed new SNQs for five real impact sounds [13]. The requirement was that the new SNQs could be composed as the sum of $L'_{nW}$ or $L'_{nT,W}$ and a new spectrum adaptation term [13]. Based on the measured reference spectra of each noise type and a psychoacoustic experiment, new spectrum adaptation terms were calculated [13]. The results of the listening test showed that each of the the new SNQs had a higher correlation with the annoyance ratings compared to the standardized SNQs from ISO 717-2 [13].

### 3.5 Low Frequencies

Panosso and Paul made comparisons between objective and subjective ratings of two impact sounds (tapping machine and calibrated tire) and two types of floor covers [14]. One of the SNQs used to evaluate the ratings of impact noise produced by the calibrated tire was $L'_{i,Fmax,50-630}$ [14]. The results of the listening test showed a higher correlation for $L'_{i,Fmax,50-630}$ than for the standardized SNQ $L_{nT,W}$. [14].

Also, the new spectrum adaptation for the frequency range between 50-2500 Hz in the previously mentioned study of Kylliäinen, had a higher correlation to annoyance in comparison to the standardized SNQs $L'_{nW}$ and $L'_{nT,W}$ [13].

In the above-mentioned work by Jeong et al. [15] using multiple SNQs, opposite results were found. In addition to $L_{iAvg,Fmax(63-500)}$, $L_{i,Fmax}$ was also used and showed a higher correlation with annoyance. [15].

Amiryarahmadi and Kropp developed a virtual design studio for low-frequency noise analysis [16]. They conducted a listening test to evaluate heavy-weight impact noise (walking) on different floor designs. They used $L'_{nT,w}$ and additionally two spectrum adaptation terms, namely $C_{I,50-2500}$ and $C_{I,20-2500}$ [16]. For about half of the wooden floors studied, none of these three SNQ variations could predict the perceived annoyance [16]. They conclude that the lack of correlation needs further investigation and that the perceptual evaluation of impact sound is of great importance [16].

### 3.6 Physiological Aspects

A study conducted by Sang Hee Park et al., which simultaniously measured annoyance, heart rate, electrodermal activity, and respiratory rate in relation to floor impact noise showed that human hearing is more sensitive than the aforementioned physiological responses [17]. Participants were divided into high and low sensitivity groups and exposed to the impact noise of footsteps and an impact ball. A correlation to $L_{A,Fmax}$ showed that annoyance increased with increasing SPL. The high sensitivity group had significantly higher annoyance values than the low sensitivity group [17].

## 4. DISCUSSION AND CONCLUSION

The purpose of this literature review was to provide a brief overview about the research on the prediction of subjective annoyance using single number quantities, spectrum adaptation terms, and sound quality descriptors. The field of research encompasses a wide range of different topics with overlapping research questions and approaches.

The multiplicity of SNQs and spectrum adaptation terms used displays the inconsistency mentioned over the years by Rasmussen and Rindel in 2005 and Rasmussen in 2022 [3] [6]. The results described regarding the utility of particular SNQs for a specific research question and/or procedure are not consistent. In some studies, such as in [15], standardized SNQs correlate very well with annoyance ratings, whereas in others, such as in [9], [13], and [16], the correlation is limited.

Another topic is the reproduction environment itself. Using the interaural cross-correlation function to implement spatial cues makes the reproduced noise more realistic, which consequently leads to more reliable test results. In addition to playback with headphones, a virtual studio as described in [16], are another step towards a higher ecological validity of listening tests under laboratory conditions.

Several studies have examined SNQs with extended frequency ranges down to 50 Hz and 20 Hz with mixed results. While in [13] and [14] the inclusion of low frequencies lead to a higher correlation, SNQs without this inclusion were more effective in [15] and [16].

Overall, the examined investigations expose that future research is needed. In this regard, several important aspects have been identified whose better understanding would lead to a higher efficiency of SNQs.

## 5. ACKNOWLEDGEMENTS

The authors gratefully acknowledges the European Commission for funding the InnoRenew project (grant agreement 739574) under the Horizon2020 Widespread-Teaming program and the Republic of Slovenia (investment funding from the Republic of Slovenia and the European Union from the European Regional Development Fund). The authors acknowledge the financial support from the Slovenian Research Agency (funding no. J4-3087, Engineered wood composites with enhanced impact sound insulation performance to improve human well being and funding no. Z1-4388, Toward better understanding the diffuse sound field).

## 6. REFERENCES

[1] World Health Organization. Regional Office for Europe, *Environmental noise guidelines for the European Region*. Pages: xviii + 160 p. Type: Publications.

[2] N.-G. Vardaxis and D. Bard, "Review of acoustic comfort evaluation in dwellings: part ii—impact sound data associated with subjective responses in laboratory tests," *Building Acoustics*, vol. 25, pp. 171–192, 05 2018.

[3] B. Rasmussen and J. Rindel, "Concepts for evaluation of sound insulation of dwellings - from chaos to consensus?," *Forum Acusticum Budapest 2005: 4th European Congress on Acustics*, 01 2005.

[4] K. Bard Hagberg, *Management of acoustics in lightweight structures*. PhD thesis, Department of Construction Sciences, Apr. 2018. Defence details Date: 2018-05-18 Time: 10:15 Place: V:B, V-building, John Ericssons väg 1, Lund University, Faculty of Engineering LTH. External reviewer(s) Name: Zeitler, Berndt Title: Professor Affiliation: Hochschule für Technik, Stuttgart, Germany —.

[5] T. Lokki, "Sensory evaluation of concert hall acoustics," *Proc. of Meetings on Acoustics*, vol. 19, 06 2013.

[6] B. Rasmussen, "Acoustic classification of dwellings - a growing diversity of sound insulation descriptors in national schemes in europe," in *ICA 2022 Proc. of the 24th International Congress on Acoustics*, (Aalborg, Denmark), pp. 199–206, 2022.

[7] H. I. Jo and J. Y. Jeon, "Downstairs resident classification characteristics for upstairs walking vibration noise in an apartment building under virtual reality environment," *Building and Environment*, vol. 150, pp. 21–32, 2019.

[8] A. Frescura, P. J. Lee, Y. Soeta, and A. Ariki, "Effects of spatial characteristics of footsteps sounds and non-acoustic factors on annoyance in lightweight timber buildings," *Building and Environment*, vol. 222, p. 109405, 2022.

[9] V. Hongisto, P. Virjonen, H. Maula, P. Saarinen, and J. Radun, "Impact sound insulation of floating floors: A psychoacoustic experiment linking standard objective rating and subjective perception," *Building and Environment*, vol. 184, p. 107225, 2020.

[10] International Organisation for Standardization, *ISO-532:2017 Acoustics - Methods for calculating loudness - Part 1: Zwicker method*. Geneva: International Organisation for Standardization, 2017.

[11] A. Frescura, P. J. Lee, F. Schöpfer, and U. Schanda, "Correlations between standardised and real impact sound sources in lightweight wooden structures," *Applied Acoustics*, vol. 173, p. 107690, 2021.

[12] S. Kim, J. Kim, S. Lee, H. Song, M. Song, and J. Ryu, "Effect of temporal pattern of impact sound on annoyance: Children's impact sounds on the floor," *Building and Environment*, vol. 208, p. 108609, 2022.

[13] M. Kylliäinen, P. Virjonen, and V. Hongisto, "Optimized reference spectrum for rating the impact sound insulation of concrete floors," *The Journal of the Acoustical Society of America*, vol. 145, no. 1, pp. 407–416, 2019.

[14] A. D. S. Panosso and S. Paul, "Subjective evaluation of floor impact noise using the tapping machine and a non-standardized source," *Acta Scientiarum. Technology*, vol. 44, p. e59025, 2022.

[15] J. H. Jeong, S. H. Park, and P. J. Lee, "Single-Number Quantities of Heavyweight Impact Sound Insulation," *Acta Acustica united with Acustica*, vol. 105, no. 1, pp. 5–8, 2019.

[16] N. Amiryarahmadi and W. Kropp, "A virtual design studio for low frequency impact sound from walking," *Acta Acustica*, vol. 5, no. 40, 2021.

[17] S. H. Park, P. J. Lee, and J. H. Jeong, "Effects of noise sensitivity on psychophysiological responses to building noise," *Building and Environment*, vol. 136, pp. 302–311, 2018.