Acta Scientiarum
http://periodicos.uem.br/ojs
ISSN on-line: 1807-8664
Doi: 10.4025/actascitechnol.v44i1.59025

CIVIL ENGINEERING

Subjective evaluation of floor impact noise using the tapping machine and a non-standardized source

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ABSTRACT. Assessing the acoustical performance of building floor systems relies on the impact source to be utilized and on the type of floor cover used. Besides that, a reliable assessment should consider the listeners' judgments of the sounds transmitted through floors or radiated by them. Objective ratings measured can help to foresee tenant satisfaction provided that they are well correlated with the listeners' judgments. The main objective of this study was to compare objective and subjective evaluations, using two types of impact sources and two types of floor covers, to try and determine which objective variables could be used to predict subject evaluation and to validate the use of an alternative impact source to be used in more realistic measurements. An objective evaluation was carried out employing impact noise insulation measurements according to ISO 10140:2010, evaluating different types of floors, resilient materials, and impact sound sources (a standardized tapping machine and a calibrated tire). In the analysis of the measured samples, several parameters were evaluated according to the sound source used. Simultaneously, "sound samples" were recorded to be used in a subjective evaluation based on the judgments of 29 listeners about the Noise Annoyance and the Loudness Sensation in response to the two impact sources. The magnitude estimation method was used. Results demonstrate that tapping machine measurements correlate very well with the subjective evaluation measurements and the calibrated tire presents well-correlated results in a specific measurement set-up. In addition, linear regression analysis of the objective and subjective variables shows alternative single number quantities for ratings of impact noise insulation.

Keywords: Building acoustics; impact noise insulation; noise control; impact source; subjective evaluation.

Received on May 1, 2021.
Accepted on October 11, 2021.

Introduction

Impact noise has been reported in the literature as the most relevant source of complaints amongst neighbors in multi-story buildings, (Rasmussen & Rindel, 2005; Niemann & Maschke, 2004), indicating that new regulations to control the impact noise should be established (Jeon, Jeong, & Ando, 2002). In that context, the disturbance caused by audio equipment with an improved low-frequency response, electrical devices, mechanical services, and mainly lightweight construction, results in the aggravation of impact noise in residential buildings (Araújo, Paul, & Vergara, 2016; Späh et al., 2013; Hagberg, 2010). Among all those noises, human walking noise is considered the most annoying in residential buildings (Jeon, Jeong, Vorlaender, & Thaden, 2004; Jeon, Ryu, & Lee, 2010; Hagberg, 2010; Park, Lee, & Yang, 2016).

Assessing the acoustical performance of building floor systems relies on the impact source to be utilized (Hopkins, 2007). Besides that, a reliable assessment should consider the listeners' judgments of the sounds transmitted through floors or radiated by them (Gover, Bradley, Schoenwald, & Zeitler, 2011). Objective ratings measured can help to foresee tenant satisfaction provided that they are well correlated with the listeners' judgments.

The International Organization for Standardization recommends that a standardized tapping machine should be used as part of floor impact insulation measurements. The tapping machine was initially developed in Germany and standardized in 1953, and is, until today, recommended by ISO 10140 and ISO 717 for field and laboratory measurements (Jeon et al., 2004). Since its standardization, various studies have been conducted trying to identify the most ideal approach to assess physical and auditory attributes of floor impact noise (Gerretsen, 1976), and it is assumed that using the tapping machine to assess impact noise, the acoustical performance of different types of floors is always the same, regardless of the source and the type of floor under test, yet, this approach is not accurate (Scholl, 2001).

Some studies concluded that the floor impact evaluation carried out using the tapping machine does not precisely emulate the acoustical attributes of human footsteps, or low-frequency impact noise, that is, the most annoying in residential buildings (Shi, Johansson, & Sundback, 1997; Warnock, 2000; Souza & Gibbs, 2001; Jeon, 2001; Scholl, 2001; Bradley, 2004; Jeon et al., 2004; Jeon & Sato, 2008; Kim, Jeong, Yang, & Sohn, 2009; Schoenwald, Zeitler, & Nightingale, 2010; Schoenwald, Nightingale, Zeitler, & King, 2010; Yoo, Lee, Lee, & Jeon, 2010). Shi et al. (1997) conveyed a study to decide the correlation between human footsteps and other standardized and non-standardized impact noise sources. They found that a sand ball dropped from a specific height shows more correlated results to human footsteps than the tapping machine.

ISO 717 presents a strategy to acquire a single number quantity to evaluate the performance of a specific floor system. The strategy presented in the standard is most appropriate for rating hard and heavy floor systems, however, Jeon et al. (2004) found that it produces uncertainties when the floors under examination are lightweight floor and soft floor covers, thereafter showing a gap in knowledge about various arrangements.

Research conducted by Scholl (2001) demonstrates that the assessment of floor impact noise depends both on the floor arrangement and on the kind of impact noise source utilized. This suggests a specific answer for lessening the impact noise level could work well when utilizing a tapping machine but less when utilizing an alternate impact source (Warnock, 2000).

The main objective of this study was to compare objective and subjective evaluations, using two types of impact sources and two types of floor covers, to try to determine which objective variables could be used to predict subject evaluation and to validate the use of an alternative impact source to be used in more realistic measurements. The results of the objective evaluation, using thirteen samples of resilient materials, were compared measuring their performance with the two impact sources, to understand the behavior of the heavy impact source (calibrated tire) (Panosso & Paul, 2020). Later on, a subjective evaluation was carried out, correlating its results with the objective ones thus determining its efficiency as a sound source to be used in real case simulations. The results of the subjective evaluation are presented in this article, along with the correlation between objective and subjective variables, and the prediction models of subjective evaluation calculated from the objective results.

In the analysis of the objective evaluation, several parameters were measured according to the sound source used. For the measurements made with the standardized tapping machine, the parameters Weighted Standardized Impact Sound Pressure Level ($\boldsymbol{L'_{nT,w}}$) and Global Impact SPL ($\boldsymbol{L'_{n100-3150\,Hz}}$) were analyzed. For measurements made with the non-standardized source, here called calibrated tire, the parameters evaluated were Average Maximum Impact SPL ($\boldsymbol{L_{i,Favg,Fmax}}$), Global Maximum Impact SPL ($\boldsymbol{L_{i,Fmax,50-630\,Hz}}$), and Percentile SPL ($\boldsymbol{L_{\mathrm{AF},5\%}}$ and $\boldsymbol{L_{AF10\%}}$).

The subjective evaluation carried out shows the judgments of 29 listeners about the dependent variables Noise Annoyance and the Loudness Sensation in response to the two impact sources.

Experimental method

Measurement and recording of sound samples

The measurements and recordings carried out for this work took place in the impact chamber of the acoustics laboratory of the Federal University of Santa Maria (Brazil). The bare slab floor structure of the impact chamber was covered with porcelain tile and wood laminate, both mounted over a mortar layer of 50 mm. Thirteen resilient layers were used, being placed between the concrete slab and the floor cover, working as a floating floor. Two types of sound sources were used, the tapping machine, standardized by ISO 10140 (International Organization for Standardization [ISO], 2010), and a calibrated tire as a representative source of heavyweight impact noise. This generated a total of 56 possible combinations, herein called samples.

Measurements were performed using a Brüel & Kjaer sound pressure level meter, model 2270. The complete list of equipment used in the measurements can be seen in Table 1.

The parameters evaluated with the heavyweight impact source were the Average Maximum Impact SPL ($\boldsymbol{L_{\mathrm{i},Favg,Fmax}}$), obtained from the Maximum Impact SPL $\boldsymbol{L_{i,Fmax}}$, weighted fast, for the 63, 125, 250, and 500 Hz octave bands, according to the recommendation of Ryu et al. (2011). Percentile SPL data was also measured, being the parameters of interest for the study $\boldsymbol{L_{AF5\%}}$ and $\boldsymbol{L_{AF10\%}}$, corresponding to the A-weighted SPL exceeded in 5% and 10% of the measurement time, respectively.

Table 1. Equipment used in measurements.

Equipment	Description
Standardized Tapping Machine	Brüel & Kjaer, model 3207
Calibrated tire	8 inches, calibrated with 9 [Psi]
Power amplifier	Brüel & Kjaer, model 2716
Omni power source	Brüel & Kjaer, model 4292
Temperature meter	CE, NF 171394-R, INSP 05/08
Handheld Analyzer	Brüel & Kjaer, model 2270
Prepolarized Free-field 1/2'' Microphone	Brüel & Kjaer, model 4189 (diffuse field)
Sound calibrator	Brüel & Kjaer, model 4231

In addition, the Global Impact SPL was also calculated from the third-octave bands analyzed according to each sound source (tapping machine: 100 to 3150 Hz, heavyweight impact source: 50 to 630 Hz), as recommended by ISO 10140 (ISO, 2010).

Also, following recommendations given in ISO 10140-4, background noise measurements and corrections were made when necessary. The components used to assemble the samples and parameters measured can be seen in Figure 1.

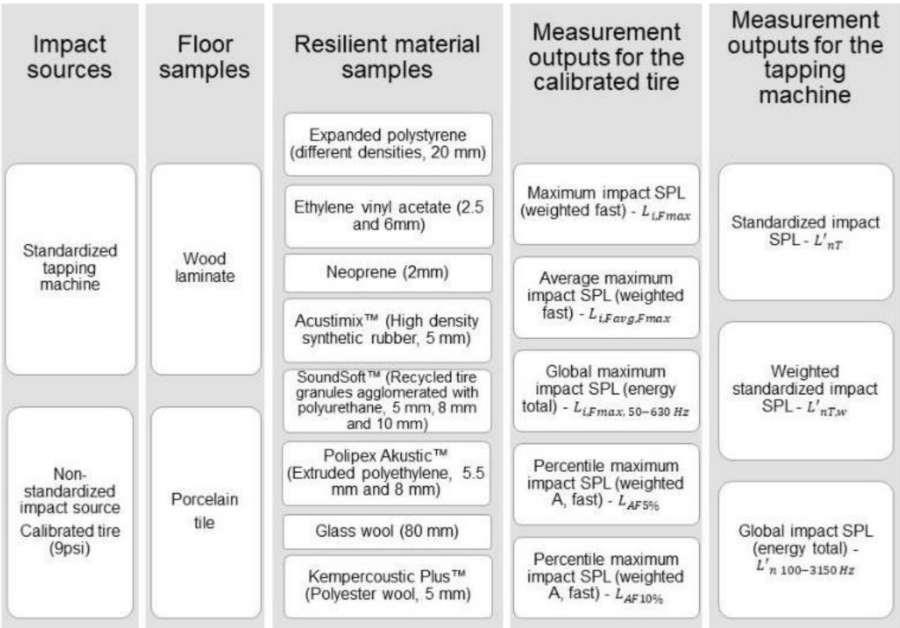

Figure 1. Sound sources, types of floors, types of resilient materials and parameters measured.

Fifty-six measured and recorded sound samples, including those assembled without any resilient layers, called anchors, were divided into four groups, each group having a different impact noise source and type of floor cover (Figure 2). The assembly of the floor samples for the measurements and recordings can be seen in Figure 3.

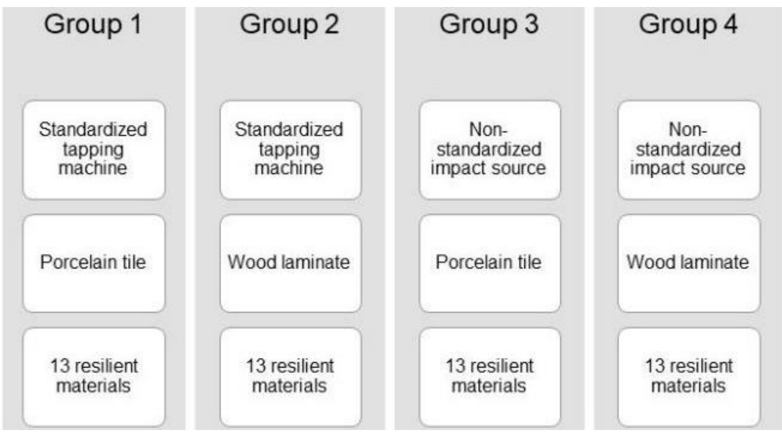

Figure 2. Arrangement of groups for measurements.

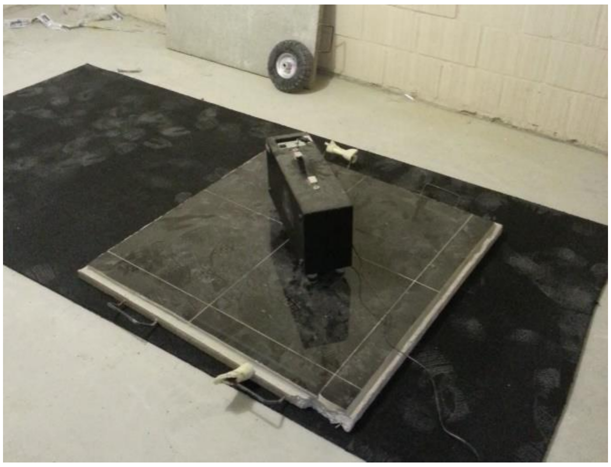

Figure 3. Assembly of the samples for the measurements and recordings in the impact chamber source room.

Recordings were made in an adapted receiving room to better approximate the results to a real living room situation (Klein, Panosso, & Paul, 2014). The reverberation time of the room was adjusted using different types of absorbent materials. A head and torso simulator were used to record sound samples, equipped with a Brüel & Kjaer binaural recording system as shown in Figure 4. Recordings were made in .hdf data format, allowing to store metadata about the system's calibration and dynamic range of the recordings.

According to measurement results, similarity criteria were used to determine which recorded samples were too similar and should not be used in the subjective evaluation.

Figure 4. Assembly of the recording equipment in the adapted receiving room of the impact chamber.

Set-up of the subjective evaluation protocol

A group of 29 listeners was selected to participate in the subjective evaluation of sound samples. To ensure subjects understood the task they participated in a prior training session using different common sounds samples.

Sound signals were presented to the subjects through a Presonus AD-DA converter and headphones (Seinnheiser open headphone, model HD650), seeking to account for better representation of the sound source localization, which is to be located outside the room. To make sure that the signals presented to subjects were as close as possible to a real situation, the Headphone's Frequency Response was measured using a head and torso simulator (Bruel & Kjaer, model 4128C). A digital filter was applied to the sound samples to compensate for the frequency response function. Also, through the same head and torso simulator, the reproduction system's gain was adjusted to reproduce the correct sound pressure levels of all sound samples.

The subjective measurement procedure used the method of magnitude estimation with anchor according to recommendations of Otto, Amman, Eaton, and Lake. (2001). A graphical user interface (Figure 5) was designed for this purpose. The subjective evaluation was composed of six blocks of sound samples, each featuring an anchor sound sample, which consisted of the recording made with the floor and the impact noise source without any resilient layer, and five other sound samples recorded with the resilient layers, totaling thirty sound samples to be evaluated per session.

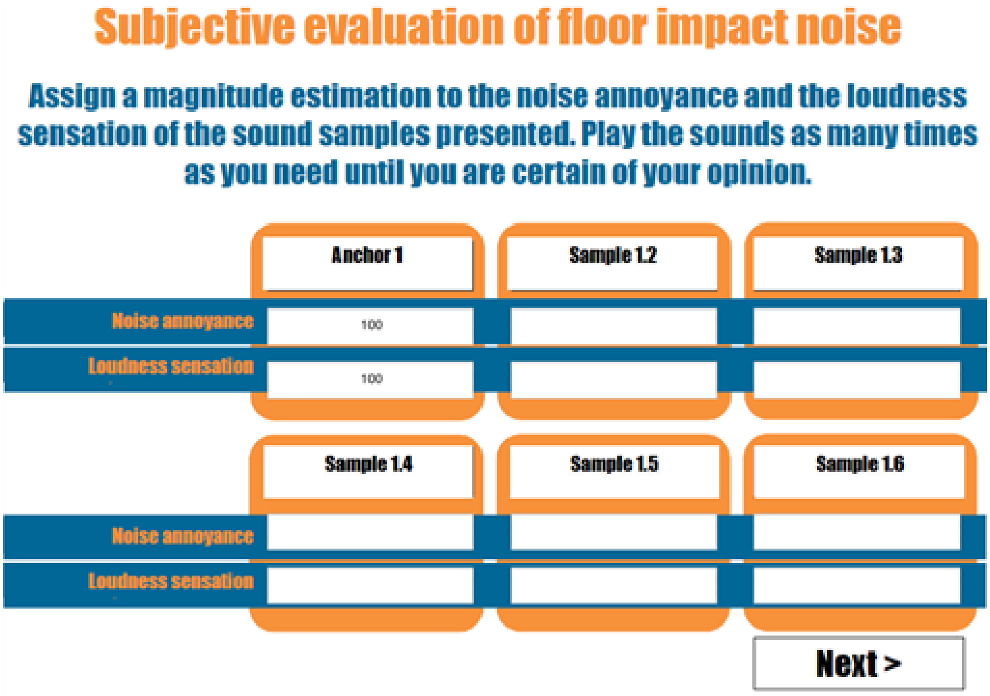

Figure 5. Interface used to evaluate the sound samples (translated).

Subjects were asked to estimate the magnitude of the noise annoyance and loudness sensation comparing it to the anchor sound sample (recorded with no resilient layer), which had a pre-assigned magnitude of 100. There were no limits to the magnitude the subjects could assign to the noise annoyance and loudness of each sound sample.

Subjects

Twenty-nine subjects participated in the tests, at two different moments, each time judging thirty different sound samples. Most of them were university students (undergraduate and graduate) and researchers. Both males and females participated equally, aged between 20 and 33 years. 69% of the subjects responded they are living in multi-story residential buildings and 65.5% had already engaged in some activity regarding acoustic evaluations.

Statistical analysis of objective and subjective data

Data obtained in the objective and subjective evaluations were statistically analyzed.

For measured samples combining the type of floor, resilient material, and the standard tapping machine in each measurement set up, eight values for the SPL (L_2) and background SPL (B_2) were obtained, both in third-octave bands. A comparison was then made to determine whether SPL needed to be corrected.

The corrected sound pressure levels were then converted to effective sound pressure p_{ef}^2 and a descriptive statistical analysis was performed on the data. Using the Kolmogorov-Smirnov test each data set was tested for normal distribution. Based on this, a single number impact SPL was determined from the mean (for data with normal distribution) or the median (for data with non-normal distribution) of the effective sound pressure. The same descriptive analysis was performed for the reverberation time data.

From the mean or median of the effective third-octave sound pressures, the Average Impact Sound Pressure Level L_i was calculated. Using the equivalent sound absorption area, obtained from the reverberation time, the one-third octave band Normalized Impact Sound Pressure Levels, L'_n, were calculated. Using the reverberation time data directly, the Normalized one-third octave band Impact Sound Pressure Levels, L'_{nT}, were calculated.

To obtain the single number that describes the performance of the analyzed system, the Weighted Standardized SPL, $L'_{nT,w}$, was determined as described by ISO 717 (International Organization for Standardization [ISO], 2013).

The Global Impact SPL, $L'_{n100-3150Hz}$ were calculated from the energetic sum of the Standardized Impact SPL (L'_{nT}) for one-third octave bands between 100 and 3150 Hz, through Equation 1.

$$\mathbf{L'_{n100-3150\text{Hz}}} = \mathbf{10log}\left(\sum \mathbf{10}^{L'_{\text{n},j}/_{10}}\right) \qquad \text{Equation (1)}$$

being:

$\boldsymbol{L'_{\text{n},j}}$ the Normalized Impact SPL for the one-third octave bands $\boldsymbol{j}$ ($\boldsymbol{j} = \mathbf{100, 125}\ \dots\ \mathbf{3150}$).

For floor and resilient material measured samples produced with the heavyweight impact source, the resulting variables were the Maximum Impact SPL, $\boldsymbol{L_{i,\text{Fmax}}}$, measured with Fast time weighting, given the type of impact.

The corrected Maximum Impact SPL, $\boldsymbol{L_{i,\text{Fmax}}}$, were converted to effective sound pressure, $\boldsymbol{p^2_{\text{ef}}}$, and the data were also subjected to descriptive statistical analysis. From the results of normality tests performed on the data, the mean was determined to be the appropriate measure of central tendency for the data sets that presented normal distribution and the median for those that presented a non-normal distribution.

Measured samples performance were expressed as a single number quantity, the arithmetic Average Maximum Impact SPL values, denoted by $\boldsymbol{L_{i,\text{Favg,Fmax}}}$ (Ryu et al., 2011). The procedure for obtaining the single number quantity involved converting the data given in one-third octave bands into octave bands and calculating the arithmetic average of the maximum impact SPL, $\boldsymbol{L_{i,\text{Fmax}}}$, of the 63, 125, 250, and 500 Hz octave bands using Equation 2. It was considered that the smaller the single number, the better the performance of the sample.

$$\boldsymbol{L_{i,\text{Favg, Fmax}}} = \boldsymbol{10log}\left(\frac{\mathbf{1}}{\boldsymbol{m}}\sum \mathbf{10}^{L_{i,\text{Fmax},j}/_{10}}\right) \qquad \text{Equation (2)}$$

being:

$\boldsymbol{m}$ the number of octave bands considered and $\boldsymbol{L_{i,\text{Fmax},j}}$ the Maximum Impact SPL for the octave band $\boldsymbol{j}$ ($\boldsymbol{j} = \mathbf{63, 125, 250}$ e $\mathbf{500}$).

The Global Impact SPL, $\boldsymbol{L_{\text{Fmax}\,\mathbf{50-630}\,\text{Hz}}}$, was calculated from the energetic sum of the Maximum Impact SPL, $\boldsymbol{L_{i,\text{Fmax}}}$, for the one-third octave bands between 50 and 630 Hz through Equation 3.

$$\boldsymbol{L_{i,\text{Fmax}\,\mathbf{50-630}\text{Hz}}} = \boldsymbol{10log}\left(\sum \mathbf{10}^{L_{i,\text{Fmax},j}/_{10}}\right) \qquad \text{Equation (3)}$$

being:

$\boldsymbol{L_{i,\text{Fmax},\,j}}$ the Maximum Impact SPL for the one-third octave band $\boldsymbol{j}$ ($\boldsymbol{j} = \mathbf{50, 63}\ \dots\ \mathbf{630}$).

Percentile SPL, $\boldsymbol{L_{\text{AF},\mathbf{5\%}}}$, and $\boldsymbol{L_{\text{AF},\mathbf{10\%}}}$, were also calculated for comparison purposes.

Results and discussion

The subjective evaluation of Noise Annoyance and Loudness Sensation generated interval type data. A descriptive statistical analysis of each of the two variables were performed. Normality tests were undertaken and discrepant values were identified to determine if the central tendency measure that would describe the data set would be the mean, if they had a normal distribution or median, otherwise.

The results of the descriptive statistical analysis of the objective and subjective data were submitted to linear regression analysis and Pearson's coefficient calculation to determine if there was a correlation and how strong it was (Figueiredo Filho & Silva Júnior, 2009). The linear regression analysis was carried considering the subjective variables dependent as a response of objective independent predictors.

The Noise Annoyance and Loudness Sensation of 56 sound samples were assessed using the magnitude estimation method. Outcomes are presented in Figure 6, where each of the bar plots shows the mean or median (depending on the distribution of data) of Noise Annoyance and Loudness Sensation rating given for the test sound samples. The blank spaces show samples that were too similar and were eliminated from the evaluation by the similarity criteria (from a total of 66 samples).

It can be seen that most sound samples were evaluated with the magnitude estimation lower than the reference of 100, indicating that there is a relation between sound pressure level and Loudness Sensation and Noise Annoyance.

The Pearson coefficient is a measure of bi-variate association that indicates the strength and direction of the linear relationship between two variables. It is considered that the relationship between variables is strong if the Pearson coefficient is higher than 0,6 (Dancey & Reidy, 2018). Table 2 shows that all subjective and objective variables have a strong relation in groups 1 and 2 (measurements and recordings made with the tapping machine), although there is a slightly stronger correlation between the subjective variables and $\boldsymbol{L'_{n100-3150\,Hz}}$ than with the variable standardized by ISO 717-2, $\boldsymbol{L'_{nT,w}}$, indicating that the variable Global SPL $\boldsymbol{L'_{n100-3150\,Hz}}$ can be a reliable predictor of subjective evaluation, in addition to the one standardized.

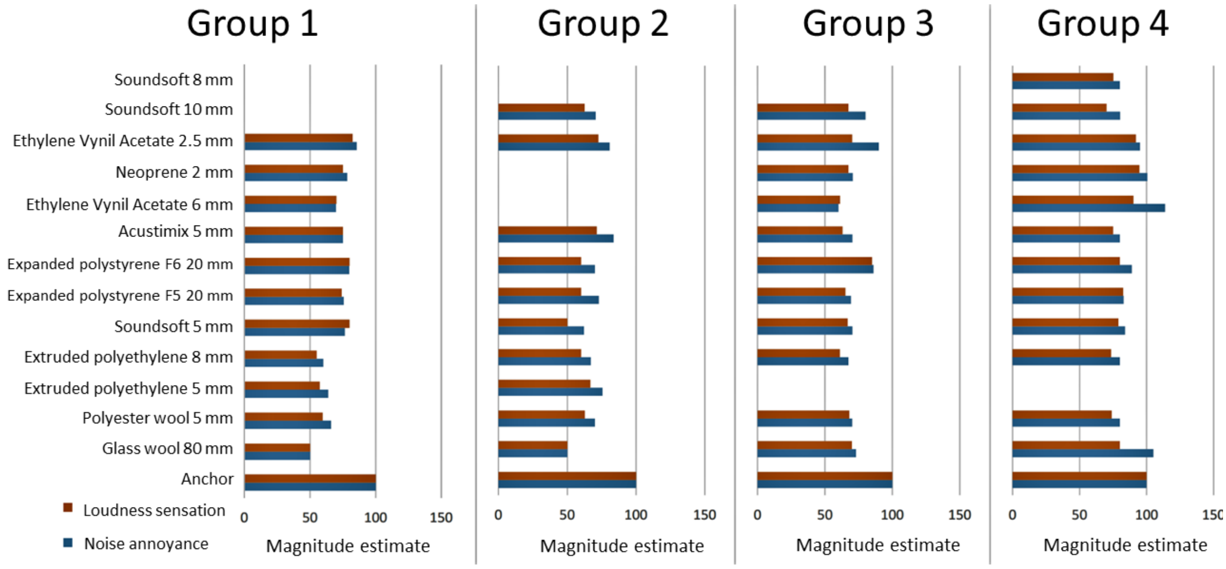

Figure 6. Results (mean or median) for the Noise Annoyance and Loudness Sensation of 56 sound samples from 29 subjects.

Table 2. Pearson coefficients calculated for all related subjective and objective variables.

Pearson Coefficient	$L'_{nT,w}$	$L'_{n100-3150\,Hz}$	$L_{i,Favg,Fmax}$	$L_{i,Fmax,50-630\,Hz}$	$L_{AF5\%}$	$L_{AF10\%}$
Noise annoyance G1	0.92	0.93	-	-	-	-
Loudness sensation G1	0.90	0.91	-	-	-	-
Noise annoyance G2	0.85	0.86	-	-	-	-
Loudness sensation G2	0.75	0.75	-	-	-	-
Noise annoyance G3	-	-	0.89	0.86	0.76	0.66
Loudness sensation G3	-	-	0.86	0.81	0.88	0.83
Noise annoyance G4	-	-	0.11	negligible value	0.24	0.34
Loudness sensation G4	-	-	0.38	0.37	0.71	0.76

Pearson's coefficient is quite similar and strong in Groups 1 and 2, indicating that the tapping machine correlates very well with the subjective variables and indicating it can be used to predict tenant satisfaction, as indicated by Gover et al. (2011).

Table 2 shows that results from groups using the tapping machine and the calibrated tire differ, confirming the findings of Warnock (2000), which states that the type of impact source plays an important role in the evaluation of performance ratings.

Table 2 also shows that all objective variables calculated for Group 3 samples (measured and recorded with the heavyweight impact source and porcelain tile flooring) also correlate well with noise annoyance and loudness sensation, confirming the findings of Ryu et al. (2011).

On the other hand, Group 4 samples (measured and recorded with the heavyweight impact source and wood laminate flooring) show that a strong correlation is found only between the subjective Loudness Sensation and the Percentile SPL $\boldsymbol{L_{AF5\%}}$ and $\boldsymbol{L_{AF10\%}}$, indicating that the type of floor cover plays an important role in the subjective evaluation of listeners, confirming Scholl's (2001) findings.

The fit of the different linear regression models was assessed by the Coefficient of Determination, $\boldsymbol{R^2}$, given in Table 3. The value of $\boldsymbol{R^2}$ indicates the percentage of the variation on the subjective variables that can be explained by the regression models.

The linear regression analysis for the dependent subjective variables as a response of an independent objective variable (predictor) indicated that, for Group 1 and 2 (samples measured and recorded with the tapping machine) models with higher $\boldsymbol{R^2}$ better relate the subjective variables with the $\boldsymbol{L'_{n100-3150\,Hz}}$, even though that the difference is very small. The models that predict noise annoyance and loudness sensation from the $\boldsymbol{L'_{n100-3150\,Hz}}$ can be seen in Figure 7 and Figure 8.

Table 3. $\boldsymbol{R}^2$ obtained in the linear regression analysis correlating objective and subjective ratings.

R^2	$L'_{nT,w}$	$L'_{n100-3150\,Hz}$	$L_{i,Favg,Fmax}$	$L_{i,Fmax,50-630\,Hz}$	$L_{AF5\%}$	$L_{AF10\%}$
Noise annoyance G1	0.86	0.87	-	-	-	-
Loudness sensation G1	0.81	0.83	-	-	-	-
Noise annoyance G2	0.72	0.74	-	-	-	-
Loudness sensation G2	0.56	0.56	-	-	-	-
Noise annoyance G3	-	-	0.79	0.73	0.58	0.44
Loudness sensation G3	-	-	0.74	0.66	0.77	0.69
Noise annoyance G4	-	-	0.01	negligible value	0.06	0.12
Loudness sensation G4	-	-	0.14	0.14	0.50	0.58

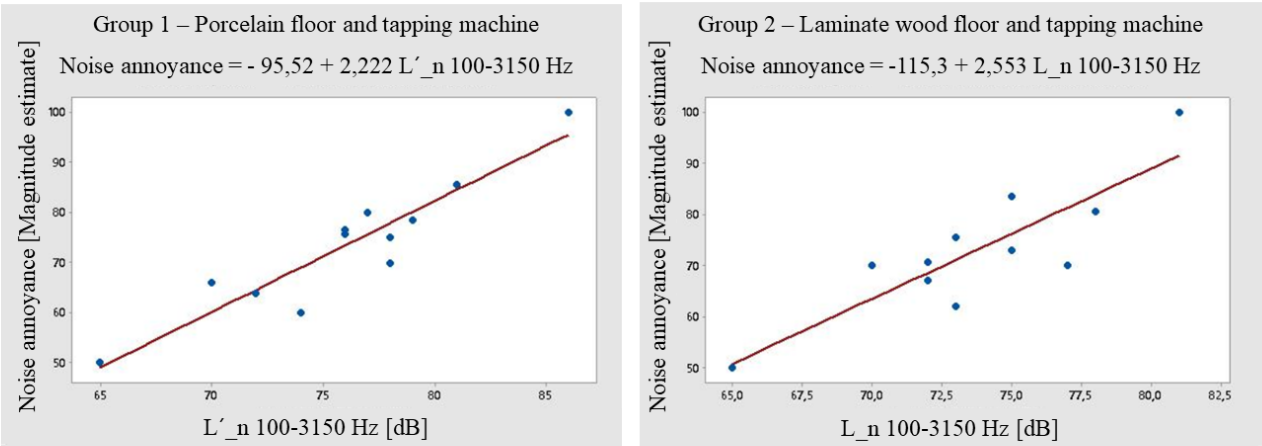

Figure 7. Fitted regression model of the better correlated subjective (Noise annoyance) and objective variables for Groups 1 and 2.

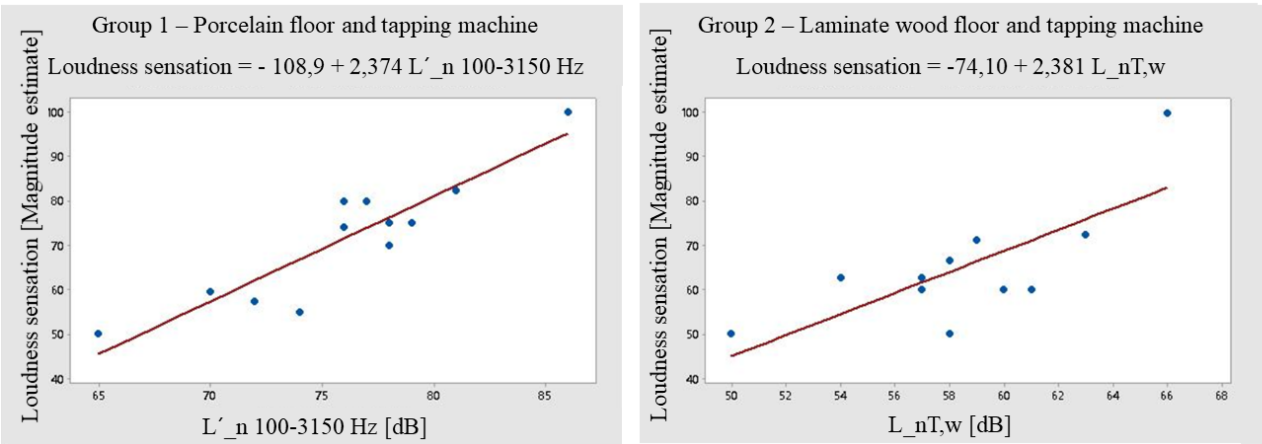

Figure 8. Fitted regression model of the better correlated subjective (Loudness sensation) and objective variables for Groups 1 and 2.

The linear regression analysis for Group 3 (samples measured and recorded with the heavyweight impact source and porcelain floor) returned the best regression models that relate the subjective variable Noise Annoyance with the $\boldsymbol{L_{i,Favg,Fmax}}$ and the Loudness Sensation with the $\boldsymbol{L_{AF5\%}}$, as seen in Figure 9. This confirms the findings of Ryu et al. (2011).

The linear regression analysis of the variables for the Group 4 samples demonstrated a very poor relationship, as seen in Table 2 and Table 3.

Analyzing Table 3 and the fitted regression models, it can be seen that the relationship between variables is strong and the dependent variables can be predicted by the objective ones, however, it can also be seen that the variables in groups 2 and 4 (those with wood laminate flooring) have a weaker relation, indicating the role that the floor covering plays in the relation. This is a very important thing to be considered, as it is assumed that the performance ratings of floating floors are always the same, regardless of the floor cover and the impact source, the results show the exact opposite.

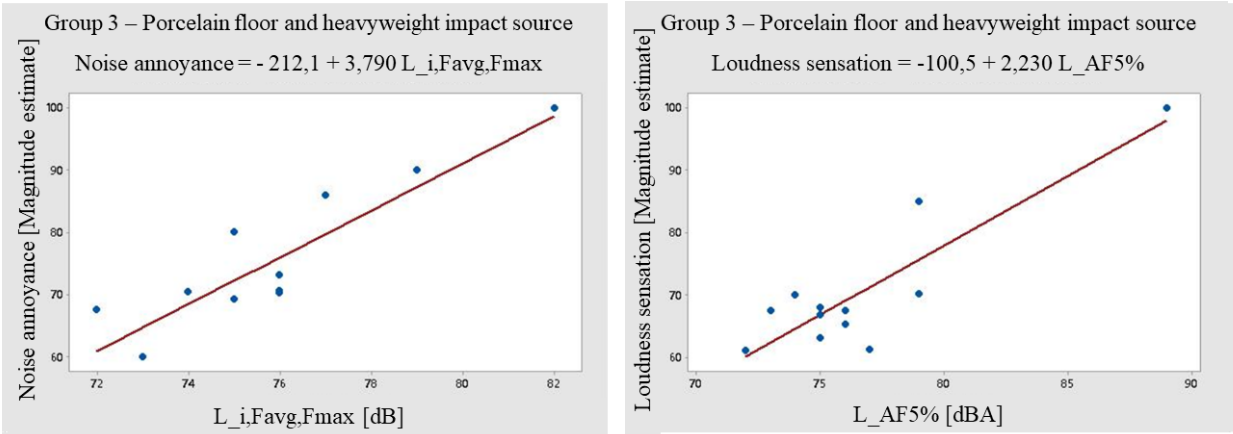

Figure 9. Fitted regression model of the better correlated subjective and objective variables for Group 3.

Conclusion

In this paper, the relationships between subjective and objective variables for the performance of different floor systems were described. The floor systems were evaluated using two measurement protocols. One called objective, using standardized procedures (ISO, 2010, 2013) and one called subjective using a procedure developed based on literature (Otto et al., 2001; Jeon, Jeong, & Ando, 2002; Ryu et al., 2011; GOVER et al., 2011).

Analyzing and comparing the subjective and objective ratings, it was found that when using the tapping machine, the type of floor is irrelevant and the objective and subjective results correlate very well. The Pearson Coefficient calculated for related subjective and objective variables showed results between 0.75 and 0.95 for the samples assembled with the tapping machine, which is a very strong correlation. In addition to that, the regression models showed that the independent objective variables Standardized Impact SPL ($\boldsymbol{L'_{nT,w}}$) and Global Impact SPL ($\boldsymbol{L'_{n100-3150\,Hz}}$) are good predictors of noise annoyance and loudness sensation, indicating that there is an additional objective variable that could be used to predict tenant satisfaction.

When using the calibrated tire, it was showed that the type of flooring is very relevant and the subjective and objective variables correlate well if the floor under test is the porcelain tile, indicating that the heavyweight impact source can be used to simulate real cases, within this specific measurement set-up. The use of the independent variable Average Maximum Impact SPL (weighted fast - $\boldsymbol{L_{i,Favg,Fmax}}$) was confirmed as a good predictor of subjective evaluation of Loudness Sensation and Noise Annoyance, showing a determination coefficient of 0.79 and 0.74, respectively. In addition, the variable Global Maximum Impact SPL ($\boldsymbol{L_{i,Fmax,50-630\,Hz}}$) showed that 73% and 66% of the Noise Annoyance and Loudness Sensation evaluation can be explained by the regression models, also indicating good predictors of subjective evaluation. Percentile SPL better correlated to the Loudness Sensation, where 77% ($\boldsymbol{L_{AF5\%}}$) and 69% ($\boldsymbol{L_{AF10\%}}$) of the subjective evaluation could be explained by the regression models. On the other hand, Noise Annoyance showed a lower correlation, 58%, and 44%, for the $\boldsymbol{L_{AF5\%}}$ and $\boldsymbol{L_{AF10\%}}$, respectively.

Objective results for the heavyweight impact source and the wood laminate floor, in general, do not correlate well with the Noise Annoyance showing results between 0.01 and 0.12. The Loudness Sensation showed better R^2 with the Percentile SPL ($\boldsymbol{L_{AF5\%}}$ **and** $\boldsymbol{L_{AF10\%}}$), between 0.50 and 0.58.

It can be concluded that the variables measured with the tapping machine present a much better connection with the subjective response of listeners, while the heavyweight impact source comes as a valid source but in a specific measurement set-up. This confirms Scholl's (2001) and Panosso and Paul (2020) findings and shows that the calibrated tire could be used as a valid heavyweight impact source but isn't still a reliable impact sound source to test all kinds of impact noise.

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