Walking Noise: Physics and Perception

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Introduction

Hard floors such as laminate became increasingly popular in the last years. As a consequence, the annoyance by the noise from walking over such floors became a problem. This problem was addressed by various efforts to manufacture less annoying floorings. In order to assess the quality of each solution, a rating method is required.

Such a rating method has to fulfill two basic requirements. It must give a practical and correct representation of the human perception of the walking noise. Further, the reproducibility of its results have to be sufficient. A number of different rating methods were developed that use either the standard tapping machine or a human walker. Different quantities such as sound pressure level, sound pressure level spectra and loudness are measured in semi-anechoic or in nearly diffuse-field environments. As a consequence, the results of the methods are not comparable (Fig. 2).

One main reason for the different procedures is a lack of knowledge regarding the physical mechanism of walking noise production. Another reason is that there is not much known about the perception of walking noise. These two questions shall be addressed below.

Physics: mechanisms of sound generation

A good model for a hard flooring is a (multilayer) plate on an elastic bedding[1]. If a person is walking on the flooring, each step can be seen as an impact of the shoe. This impact happens at a certain impact speed v_0. The impacting body (the shoe) will be suddenly stopped and an impulsive force will act on the flooring.

Several simultaneous mechanisms of sound generation are in effect in this process (Fig. 3): First, the sudden stop of the impacting body will cause acceleration sound. Acceleration sound is air-borne sound that is produced because of the fluid that surrounds the body (the hydrodynamic mass) must accelerated if the body is undergoing a (positive or negative) acceleration. Under certain circumstances, the sound energy emitted by this process is the same as the kinetic energy of the hydrodynamic mass[2]. The hydrodynamic mass is the imaginary part of the sound radiation impedance which can be estimated from the shape of the body. For the impact of a circular disk of radius a and thickness h the energy W is:

$$W = \rho_0 \frac{4}{3} a^3 \left(1 - (4-\pi)\frac{h}{8a}\right) v_0^2 \qquad (1)$$

For the impact of a shoe ($a = h = 2$ cm) at $v_0 = 1$ m/s this yields a mean sound power level of approx. 73 dB

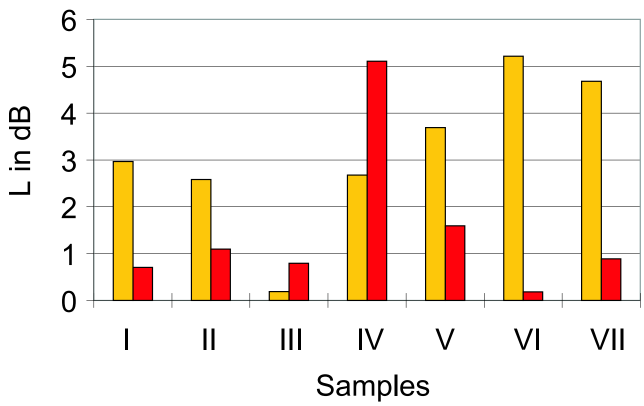

Figure 2: Decrease in A-weighted sound pressure level compared to a reference sample for seven different floorings, yellow (left columns): tapping machine, red (right columns): female walker, both measured in a reverberation room. The results are not comparable.

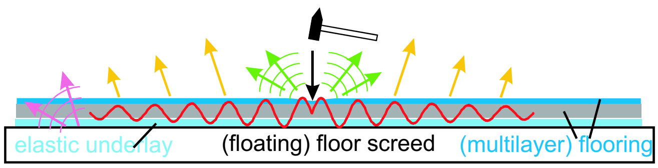

Figure 3: Mechanisms of walking noise sound generation, green: acceleration sound (air-borne), red: impact-excited structure-borne sound, yellow: radiation from structure-borne sound (secondary air-borne), magenta: excitation of secondary structure-borne sound due to the flooring panel hitting the floor at uneven surface

for two steps per second. For the tapping machine with the standard parameters applied the result is only 70 dB for 10 hits per second.

The second sound generation mechanism is the excitation of structure borne sound in the flooring plate due to the impact forces. Here, the hardness of the flooring and the impacting body has an influence as well as the stiffness of the bedding. The structure borne sound will propagate in the flooring plate, so the bending wave speed and damping of the plate is important. The radiation of this structure-borne sound is a secondary source of air-borne sound.

Further, an unevenness of the base floor may lead to the excitation of secondary structure-borne sound in the flooring plate when the vibrating plate hits the floor at exposed points.

From this analysis it is possible to conclude the influence factors:

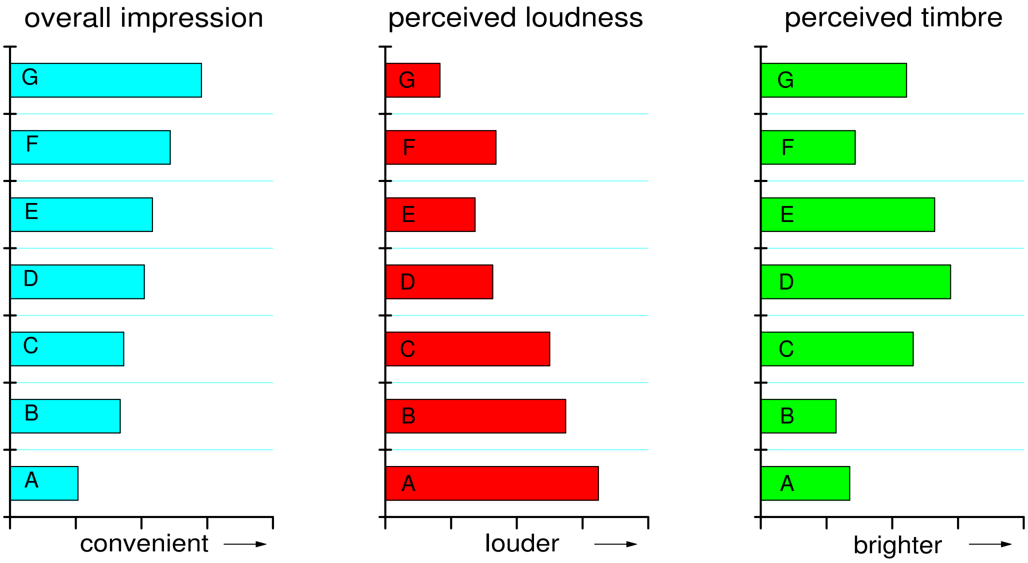

Figure 1: Results of the walking noise listening test

- elastic and damping properties of the foundation,
- damping properties of the flooring panels,
- softness/hardness of flooring surface and the impacting body,
- shape and speed of impacting body,
- unevenness of the base floor,
- mass (per unit area) of the flooring,
- bending stiffness of the flooring.

While most of these factors depend on the flooring itself, some also depend on the impacting body. Thus, it is very different to control test conditions.

Perception: listening tests

As a first step towards a deeper insight on the human perception of walking noise a series of listening tests were implemented. The main goal was to find the parameters or items needed for a proper rating of different floors.

For the tests walking noise from seven different floorings were recorded for a male and a female walker. An artificial head was used for recording. For each sample four steps were recorded.

Within each of two groups (male/female) seven sound samples were compared to each other in a listening test with the following items:

- perceived loudness,
- perceived timbre,
- overall impression.

28 persons of all ages and both genders took part in the test.

A common hypothesis on which all walking noise rating methods are based is that a louder floor is less convenient. The results of the listening tests (Fig. 1) showed that this hypothesis holds not in all cases. Despite its higher perceived loudness sample F was rated to sound more convenient than D and E. However, the correlation between perceived loudness and the overall impression is quite good. No correlation exists between the perceived timbre and the overall impression.

The recorded samples were also subject to a technical analysis. The estimated L_{eq} has a very good correlation (0.95) with the perceived loudness and the estimated frequency of the dominant 1/6-octave band correlates good with the perceived timbre. Thus, it may be concluded that both the perceived loudness and the timbre may be estimated from measurements. It is not clear at the moment if this is possible for the overall impression too.

Conclusion

Both sound generation mechanisms and the perception of walking noise are not well understood. A more in-depth analysis of the sound generation should precede the possible development of a standard test procedure.

Acknowledgments

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