Subjective evaluation of sound in workplaces

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1. Introduction

The acoustic quality of workspaces is a field of increasing importance. Principles of noise control are well established in many applications. This study intends to expand this issue, examining the influence of the sound field on subjective attributes of sound. The matter involves the search for acoustic measures to be employed beyond upper limits of noise in the workplace, usually characterised by dB(A).

This work focuses on some practical experience obtained from the connection between experimentally measured values and subjective sensations related to sound quality in workplaces.

2. Investigation

For the investigation purpose, three different rooms: cubic, flat, and long geometry (see Tab. 1), representing typical work spaces, were designed in a binaural room acoustic simulation program, CAESAR (Schmitz, 1997). The absorption of certain surfaces was adjusted in order to maintain similar early decay times (EDT) and sound levels at one point within each kind of room geometry. Binaural impulse responses calculated for those three rooms were then convolved with typical workplaces noise. Those auralised signals were used in listening tests for subjective evaluation and the respective psychoacoustics parameters were as well objectively calculated.

Tab. 1. Room descriptors

	Dimensions	**EDT**
Cubic room	16mx14mx10m (2197 m^3)	2.5 s in 125 Hz; 1.3 in in 250, 500, 1k, 2k, 4k Hz; 0.8 in 8 kHz.
Long room	60mx6 mx6 m (2160 m^3)	1.3 s in 125 Hz; 0.8 s in 250, 500, 1k, 2k, 4k Hz; 0.6 s in 8 kHz.
Flat room	40x13,7mx4 m (2192 m^3)	1.0 s in 125 Hz; 0.6 s in 250, 500, 1k, 2k, 4k Hz; 0.3 s in 8 kHz

2.1 Construction of the Binaural Room Impulse Responses

From the variety of conceivable situations possible for comparison, 3 situations that better characterise a working environment were chosen to study the perceived sound quality in workrooms: the effect of the introduction of absorption (a) in the ceiling; (b) in the ceiling and the floor simultaneously; (c) and in ceiling and in the back wall (surface opposing the source) concurrently. See absorption configurations in Fig. 1.

The process consisted on the construction of broadband binaural impulse responses equalised for free field, resulting from the summation of bandpass impulse responses undertaken for seven octave bands (from 125 Hz to 8 kHz).

For the three different room geometries presenting the same kind of absorption configuration, the absorption coefficients for the 'treated' surfaces varied and the ones for further surfaces remained the same.

Thus, nine binaural impulse responses were generated, presenting always the same distance source-listener (approximately 8m) and the same direction (listener looking to the direction of the source), for each one of the room configurations.

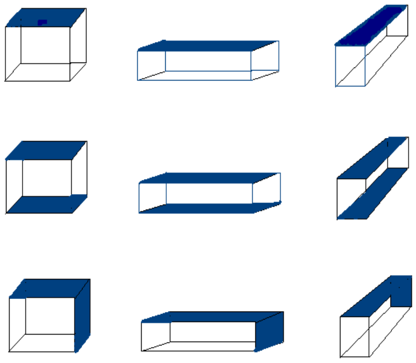


Fig. 1. Configuration of the distinct spatial sound fields (cubic; flat; and long room with absorption treatment on the ceiling; ceiling and floor; ceiling and back wall) and labels used on the test

2.2 Listening tests

Fifteen males and one female constituted the subjects group of the listening tests (two professionals of acoustics; seven university students; six workshop employees; one secretary). The average age was around 35 years old.

The subject was asked to scale a quantitative relation between the three signals and the attribute studied (in Fig. 2: F1,F2,F3; F4,F5,F6; F7,F8,F9). For this purpose, the semantic differential incorporating a 7 point rating scale was used. The intention was to judge the placement of absorption within each kind of room geometry, for two 'sound events' (a machine tool for shaping and a keyboard).

In order to execute the hearing survey and for posterior comparison with psychoacoustics parameters, it was selected to represent the roughness sensation: *rauh-glatt* (rough-smooth); to represent the sharpness sensation*: scharf-stumpf* (sharp-dull); and to represent loudness: *stark-schwach* (powerful-weak).

It was important to maintain equal the overall level of all test signals belonging to the same 'sound event', in order to grant a comparative study. The test signals were set to present a similar level to the 'real' listening situation in workplaces: the machine tool for shaping was equalised for presenting a level of 72 dB(A); the keyboard was equalised for a level of 60 dB(A).

2.3 Psychoacoustic calculations

In order to cross information with the listening tests, loudness, sharpness and roughness were objectively calculated using the software ARTEMIS (Head Acoustics GmbH). In all calculations, free field equalisation was used. The following parameters were set: for calculating loudness, FFT/ISO 532 was applied; for specific roughness, the "hearing model of Sottek" (Sottek, 1993); for sharpness, the calculation method "von Bismarck" (von Bismarck, 1974).

3. Results

The big variances in the responses suggests that the placement of absorption within distinct rooms is not so meaningful. However it would appear that there is a slight preference for the placement of absorption on the ceiling. In Fig.2 – Fig. 4, it is presented the mean judged values for all room configurations.

When comparing qualitatively the results for the listening tests and the objective calculation of the respective psychoacoustic parameter, it can be noticed that the tendency of the plots is fairly similar (see Fig. 5 and Fig. 6). It denotes that despite of the similarities in the results, the listening tests were reasonable sensitive, considering that small effects of psychoacoustics variations were identified.

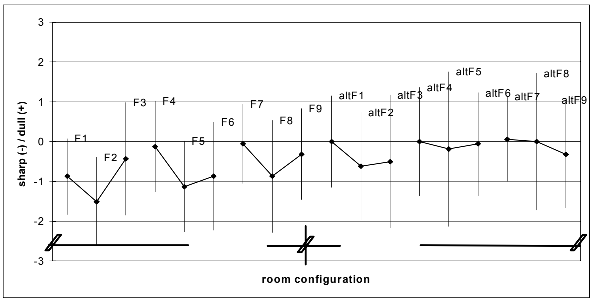
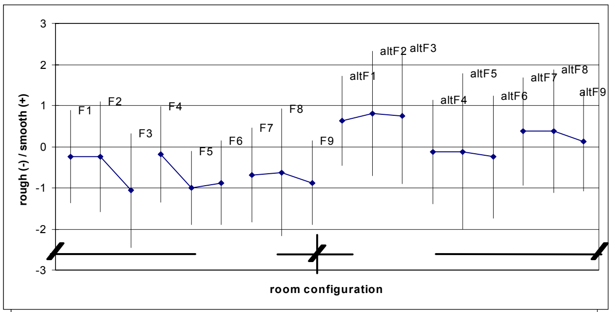
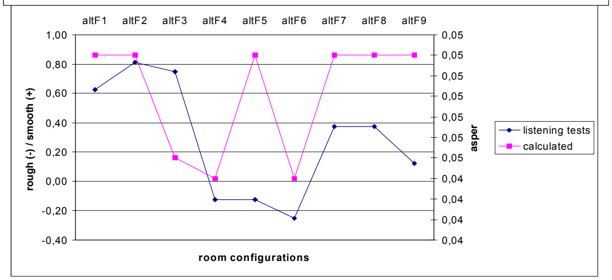


Fig. 2. Mean judged sharpness over two sound events, for all room configurations, all subjects. Errorbars are +- 1 standard deviation





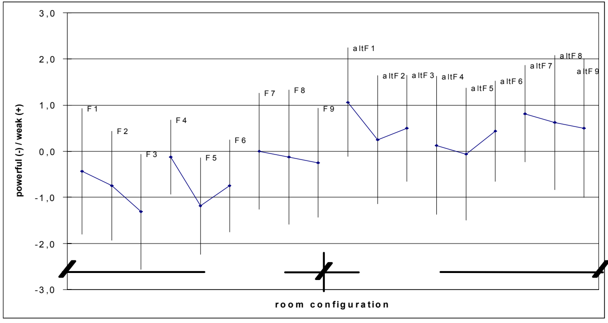
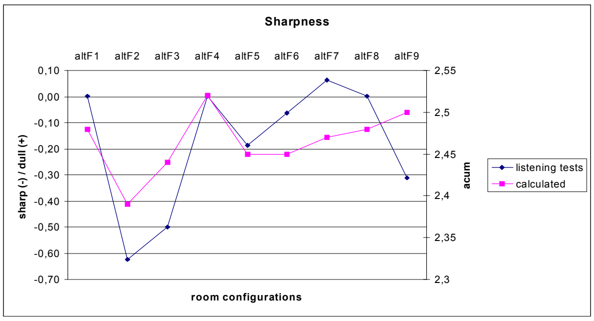


Fig. 3. Mean judged roughness over two sound events, for all room configurations, all subjects. Errorbars are +- 1 standard deviation
Fig. 4. Mean judged loudness over two sound events, for all room configurations, all subjects. Errorbars are +- 1 standard deviation
Fig.5. Mean judged roughness over one 'sound event' (keyboard) for all room configurations, all subjects, represented by lozenges. Overall roughness objectively calculated represented by squares
Fig.6. Mean judged sharpness over one 'sound event' (keyboard) for all room configurations, all subjects, represented by lozenges. Sharpness objectively calculated represented by squares



4. Outlook

Consideration of spatial attributes is not as important as expected. However, this may not be generalised for receiver position near the absorbers or other surfaces.

Results indicate that the evaluation process of sound quality here utilised is rather effective, despite of the small differences between the preference results. However, much work remains to be done integrating methods for assessment of sound quality in workplaces.

5. References

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2. Sottek, R. (1993), *Modelle zur Signalverarbeitung im menschlichen gehör.* Ph.D. dissertation, Aachen Techn. Hochsch., Aachen, Germany.
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