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INFLUENCE OF THE SPATIAL SOUND DISTRIBUTION ON SOUND QUALITY AT WORKPLACES

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ABSTRACT
This study is focused on some practical experiences with subjective listening at workplaces. Sound quality parameters related to workplaces such as "annoyance", "disturbance of concentration" or "speech intelligibility" are expected to be dependent on the sound distribution in time and space. Accordingly not only the source signal, but also the room shape and the distribution of absorption should be considered. Three example rooms were chosen (cubic, extremely flat, extremely long) for room simulation and auralization. Sound signals were compared regarding basic room shape and placement of absorbers. The results were similar for the flat and the long room. Slightly more unfavorable were the sounds in the cubic room. Although the subjective differences were very small, they could be identified well by objective evaluation of roughness, sharpness and loudness.

1 - INTRODUCTION
The workplace issue is an important topic within the area of acoustic quality. A considerable task in seen in development of subjective attributes to be employed on rating acoustic quality judgements. But in contrast to the effects of high-level noise exposure on human activities and health, other issues beyond the dimension characterized by dB(A), have not yet been resolved. Some psychoacoustics indices obtained from impulse responses are based on subjective studies of the acoustical characteristics of large rooms. The quantities refer to perceived definition, clarity, the balance between clarity and reverberance, speech intelligibility and the perceived width of the sound source. These parameters, however, are not applicable in working environments. In spite of many advances in the area of acoustic quality of concert halls, a lack of knowledge on acoustic quality in workplaces still remains.
This work deals with the problem of sound propagation in large rooms, characteristically workplaces. In workspaces such as open-plan offices, workshops and factories, the lack of diffusion on the sound field affects the validity of classical room acoustics theory [1, 2]. Therefore the aim of this project is to consider particularly non-diffuse sound propagation.
Binaural technology and psychoacoustic measures were applied to understand the factors influencing the perceived sound quality. The work was concentrated on comparison of different spatial sound fields and different strategies for placement of sound absorbing material. Provided the simple monaural acoustical physical measures like reverberation time and sound level remain equal in diverse rooms, the question remains whether subjective attributes of sound and consequently dissimilar effects on humans beings, e.g. feeling of annoyance, are different.

2 - PARAMETER STUDY
The perceived sound quality of workplaces is multifaceted, associated with a chain of subjective and physical dimensions. The correlation between the perceptual aspects and physical properties of 3-D sound fields of non-diffuse spaces are complex and still largely unknown.
In the seek for sound quality evaluation, it is appropriate to associate physical properties of the enclosure to subjective features. Objective measures offers an intermediate description between design and

the subjective effect. The sound field in a factory can be satisfactory characterized by the sound pressure level and reverberation time. Among other objective attributes significant for our sound perception, the quantities "loudness", "roughness" and "sharpness" provide a useful point of reference for discussion. Sharpness describes the spectral balance between the relationship of high and low frequencies [3]. Roughness characterizes fast modulations; fluctuation strength characterizes slow modulations [4]. Loudness and tonality also presents significant relations with the variables influencing the preference analysis. The results of loudness is directly related to the sensation and is a more precise quantity than the sound pressure level [5].

Defining subjective sound parameters requires the survey with test subjects. They have to listen to real or synthesized signals and rate their sensations. Psychoacoustics measuring methods can be classified in several ways, i.e. according to the level of judgement the subject is required to make or how the sound signals are presented to the subjects.

The basic test condition was to compare noise signals presented in different room configurations concerning room shape and absorber placement. Sound level and reverberation time were fixed. Accordingly the comparison involved just the differences in loudness, sharpness and roughness in these configurations. The differences were expected to be caused be the spatial distribution of the sound and the corresponding particular HRTF filtering.

The room shapes used were cubic, flat and long, thus producing sound fields of special dimensionality and directionality of the room reflections.

3 - BINAURAL ROOM SIMULATION OF WORKROOMS

The fundamental method employed for the realization of this work is the binaural auralization technique. The principle consisted on creation and the presentation of the sound pressure at the two eardrums. Hence listening tests could be performed to answer the question whether certain criteria in workrooms must be taken into account in architectural planning, particularly considering the room shape and the placement of absorbers or diffusers.

For the investigation purpose, the three different rooms were fed into a binaural room simulation [6]: cubic, flat, and long. The reverberation time (Early Decay Time, EDT) and the sound strength (G) at the receiver points within the rooms were adjusted to the same value. Furthermore, their volumes were kept similar (approximately 2190 m^3). The absorption coefficients were varied just in the ceiling of each room, preserving the value of 0,15 for all other surfaces. The different room configurations are shown in figure 1.

Room type	Dimensions (m^3)	ceiling absorption	EDT (s)	G (dB)	RT_{Sabine}(s)
Cubic	13 x 13 x 13	0,64	1,3	12,5	1,37
Long	60 x 6 x 6	0,23	1,3	12,5	1,38
Flat	40 x 13,7 x 4	0,50	1,3	12,7	0,85

Table 1: Physical properties used on the room acoustics simulation.

The simulation was performed using a hybrid sound particle-image source algorithm [7]. For the evaluation, simulation and auralization of room acoustics the software CAESAR [6] was used.

4 - LISTENING TESTS

The listening test was applied on fifteen males and one female subjects. The average age was around 35 years. The main idea was to make comparisons between room shapes and distinct absorption configurations.

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

The 'sound events' corresponded to the noise of a machine tool for shaping and to a computer keyboard. The noise signals were recorded in the near field. These signals were almost anechoic and could be convolved with the binaural room impulse responses and replayed through headphones. The equipment specification was: PC Pentium 166 MHz with Sound Board: ITA AES/EBU, DSP Software: Monkey Forest (ITA), Headphone: Stax SR-l – open head-PL, DA-Converter: (ITA) High Resolution DA (20 bit).

The subject was asked to scale a quantitative relation between the three signals and the attribute studied (in figure 2: cubic: F1, F2, F3 / flat: F4, F5, F6 / long: F7, F8, F9). For this purpose, the semantic

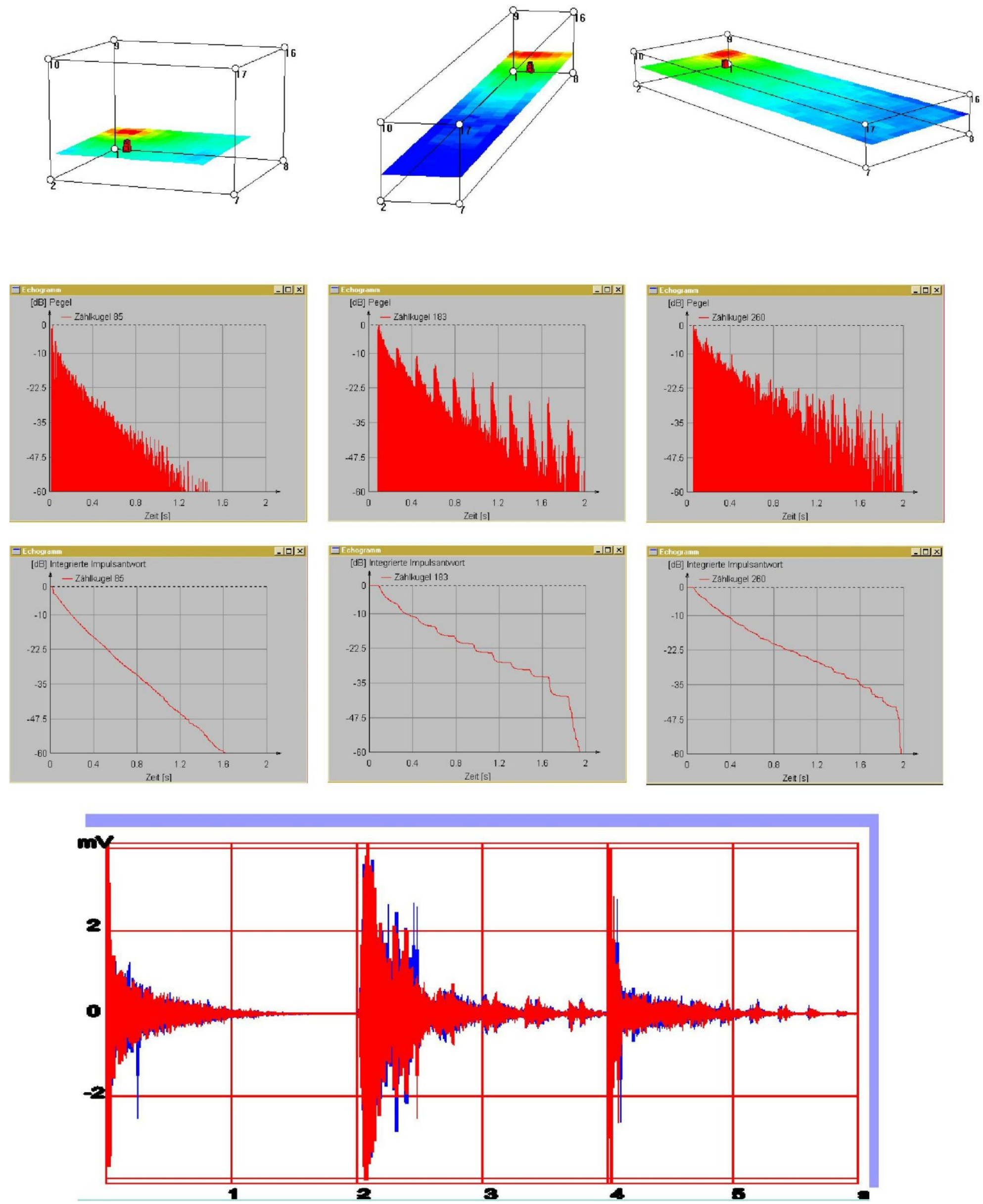

Figure 1: Typical results of the room acoustic binaural simulation.

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 perform the hearing survey and for posterior comparison with psychoacoustics parameters, it was selected to represent the roughness sensation: rough-smooth; to represent the sharpness sensation: sharp-dull; and to represent loudness: 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 adjusted for presenting a level of 72 dB(A); the keyboard was adjusted for a level of 60 dB(A).

Furthermore, in order to correlate information with the listening tests, loudness, sharpness and roughness were objectively calculated using the software ARTEMIS. The following parameters were set: for calculating loudness, FFT/ISO 532 was applied; for specific roughness, the hearing model by Sottek [3] and for sharpness the calculation method by von Bismarck [4].

5 - RESULTS

At first, it can be seen that the judged differences between room shapes and absorber placement are

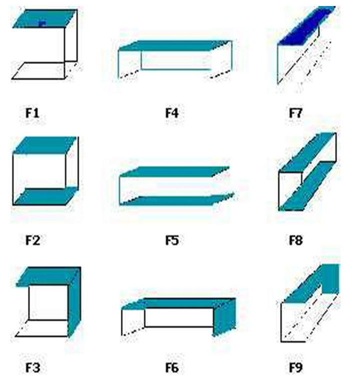

Figure 2: Configuration of the distinct spatial sound fields (cubic; flat; and long room with absorption treatment on the ceiling; ceiling and floor; ceiling and back wall) and labels used in the test.

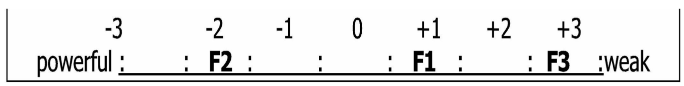

Figure 3: Example for an assignment of three signals in the same scale.

not as big as expected. A slight preference can be observed for the flat and long room compared with the cubic room (figure 4), which is unfavorable. The big variances in the responses suggests that the placement of absorption within distinct rooms is not so meaningful. However, there is a slight preference for the placement of absorption on the ceiling and a slight preference for flat an long enclosure compared with the cubic room. In figures 5 and 6 the mean judged values for roughness and loudness over all room configurations are presented.
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 figures 7 and 8). 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.

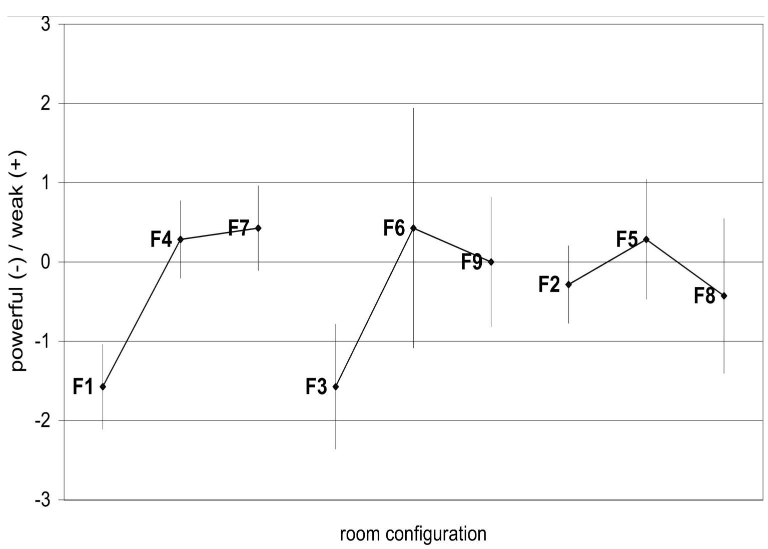

Figure 4: Mean judged room shape averaged across all subjects (loudness).

6 - Conclusion

Among the objectives of this research project, it becomes important to understand the mechanisms underlying the influence of spatial sound field on subjective attributes of sound and moreover on task performance. The comprehension of all aspects of this wide-ranging topic is essential to develop criteria that can be used to define the quality of working environments. It is expected that this work contributes to

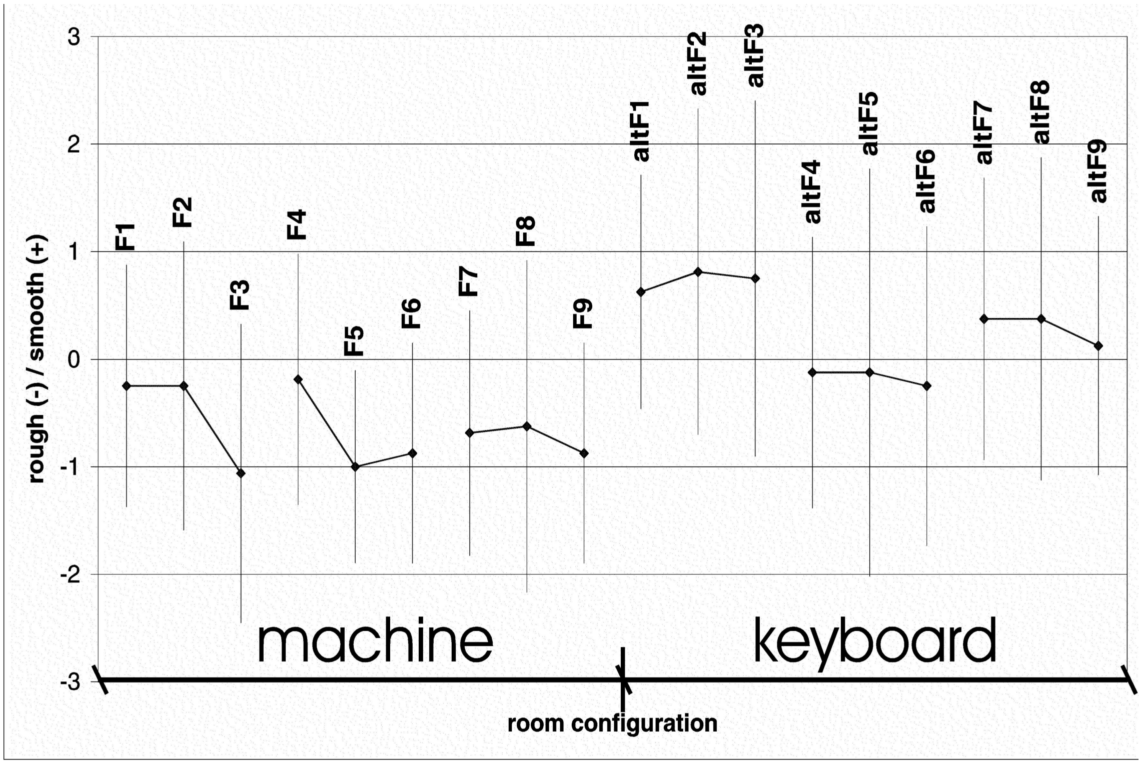

Figure 5: Mean judged roughness over two sound events, for all room configurations.

a future guidelines for designing workplaces and for acoustic treatments with attention to intrinsic effects on human beings, based on knowledge of parameters other than sound pressure level and reverberation time.

However, consideration of spatial attributes (binaural attributes) is not as important as expected. The cubic room was judged slightly worse than the long and flat room. "Diffuse" noise seems to be more disturbing than localized noise. However, this may not be generalized for receiver position near the absorbers or other surfaces. Nevertheless psychoacoustic objective parameters should be used as additional indicators of sound quality at workplaces.

Results indicate that the evaluation process of sound quality here utilized is rather effective, despite of the small differences between the preference results in the examples used so far. However, much work remains to be done integrating methods for assessment of sound quality in workplaces generally. It could be shown that integration of sound quality evaluation into binaural room simulation and auralization is possible, and the results of listening tests match fairly well the results of the objective parameters.

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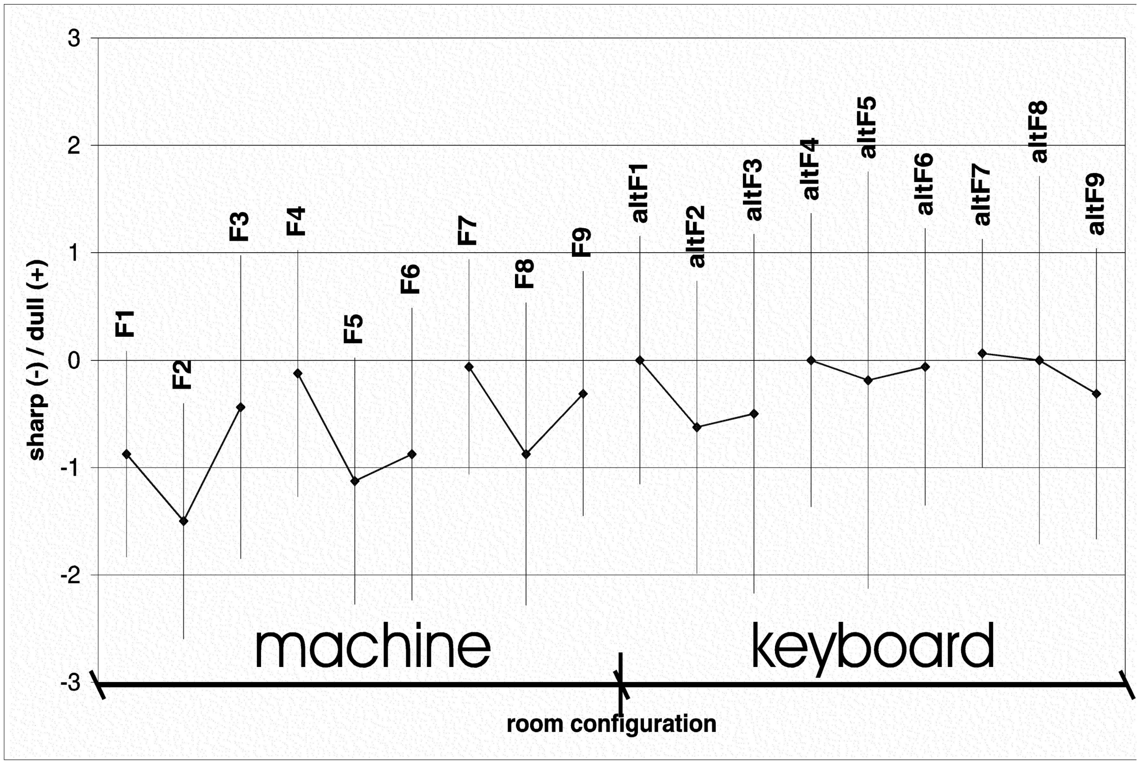

Figure 6: Mean judged loudness over two sound events, for all room configurations.

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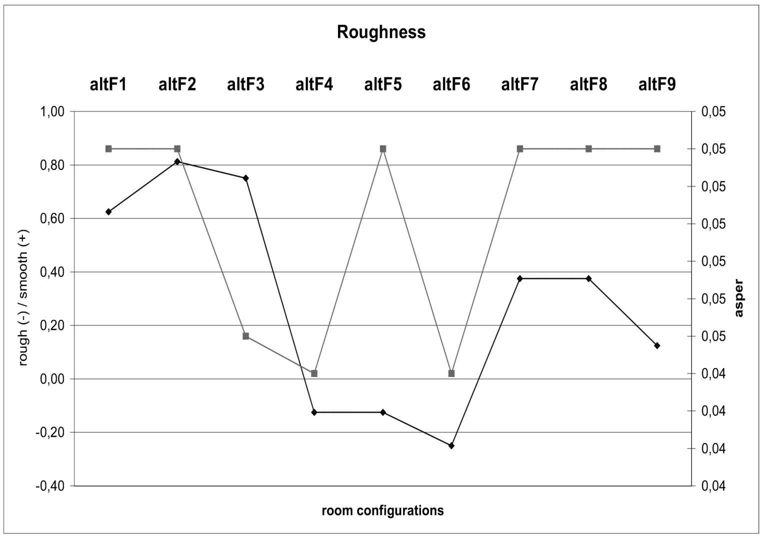

Figure 7: Mean judged roughness of the keyboard signal.

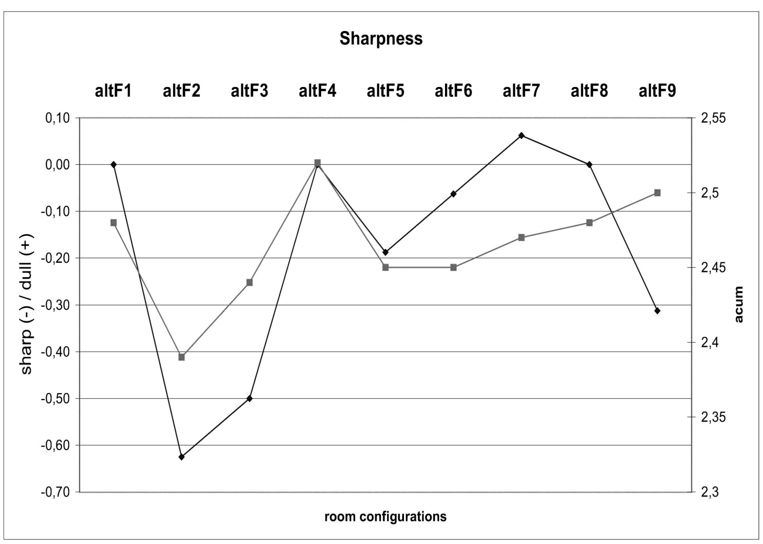

Figure 8: Mean judged sharpness over one 'sound event' (keyboard) for all room configurations.