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Objective method for predicting office noise annoyance

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ABSTRACT

Based on several independent surveys, noise is the most distracting environmental factor in offices. However, there is no established objective method to assess the distraction of specific office work environment when occupants are present. There is evidence that sound level is not sufficient predictor of distraction. Our purpose was to test whether the distraction could be objectively predicted from standard acoustic variables, such as L_{Aeq}. We conducted a psychoacoustic study, where 39 participants rated the distraction of several sounds that represent typical office noise scenarios within 40–60 dB. We measured several acoustic variables for each sound. Mathematical optimization revealed a model, where the observed annoyance could be predicted using three acoustic variables with very good agreement. The method can be easily applied in the objective assessment of noise distraction in working and learning environments, since the three variables are available in standard sound level meters.

Keywords: speech, office noise, annoyance, distraction, measurement

1. INTRODUCTION

Sound in an office is usually perceived as noise if the sound is irrelevant, or it is annoying. Colleagues' irrelevant speech is most usual source of office noise.

The Speech Transmission Index (STI) is an objective quantity (value range 0.00–1.00) of assessing subjective speech intelligibility. STI is measured in an open-plan office according to the ISO 3382-3 standard. It is determined by placing sound source (producing specific test signal) to speaker's position and microphone to the listener's position. Unnecessary speech is known to significantly impair work performance if STI > 0.50 [1]. Therefore, according to Finnish building regulations [2], the room acoustics of open-plan offices must be implemented in such a way that speech intelligibility is minimized (STI < 0.50).

Because of the original reason of developing STI, it is limited to single speaker situation. In rooms, STI only describes the characteristics of the room w.r.t. the transmission of speech from source to listener.

During working hours in the office, occupants do not think about room acoustics *per se*, but they pay attention to sound environment if it is annoying or distracting.

The sound environment in the office changes all the time, because the occupancy and number of simultaneous speakers (and their distances to listener and speech efforts) vary. When a professional needs to assess the sound environment in the office, e.g., from the point of view of noise complaints, occupational health issue, facility development, it should be possible to objectively and quantitatively assess the distractive nature of the sound environment. It should also be possible to compare the result with some reference values. Such method or reference values have not yet been developed.

The distraction caused by a specific sound certainly increases as the equivalent A-weighted sound pressure level (SPL), L_{Aeq}, increases. If the sound contains speech, distraction does not depend on L_{Aeq} only. Even a quiet speech (L_{Aeq}<35 dB) impairs work performance and elevates distraction if the speech is intelligible [3].

According to the theory behind STI, perfect speech intelligibility (STI=1.00) is only possible (in anechoic environment) if the signal-to-noise ratio, SNR (difference of the SPLs of speech and background), is +15 dB or higher.

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In this case, also the sound level variability (SLV) exceeds 15 dB, because of speech peaks and pauses.
The variability of L_{Aeq} in different speech environments is illustrated in **Fig. 1**. Our hypothesis is, that SLV itself could be a predictor of distraction for sounds environments involving speech.
Previous literature supports our hypothesis partially. However, these studies are limited to single speaker condition [4–6] and the versatility of office noise scenarios were not studied.
Office noise environments can involve random number of simultaneous speakers, varying SNRs, and large range of L_{Aeq} levels (40–60 dB usually). There is no previous experimental research, which has investigated the distraction of such scenarios.
Our aim was to develop an objective prediction model that can be used to objectively assess the distraction caused by office noise. The model is based on a special psychoacoustic experiment, where participants rated a large range of office noise scenarios [7].

2. MATERIALS AND METHODS

2.1 Psychoacoustic experiment - design

Thirty-nine Finnish speaking participants attended in the experiment, which was conducted in the psychophysics laboratory of Turku University of Applied Sciences.
During the experiment, no real work or task was at hand, but the participants were advised to imagine such situation, by these words: "*When the sound is playing, imagine that you are doing independent work that requires concentration and thinking, for example in an open office or a library. The sounds are not related to the work you are doing*." Distraction was measured by: "*How much sound would distract your working*?" Eleven-point numeric rating scale was applied where the extreme options were verbally labeled (0 Not at all, 10 Extremely much). Each sound was played for about 10 seconds before the rating was made.

2.2 Psychoacoustic experiment - sounds

The total number of sound stimuli was 111. Three of them contained only masking at three overall levels 40, 50, and 60 dB L_{Aeq}. The rest (108) contained both speech and masking. The spectral shape of speech and masking conformed with the standard effort speech of ISO 3382-3. These sounds were formed of 36 core sounds explained in **Table 1**. They were presented and three overall levels making 108 sounds. Speech consisted of sentences taken from a Finnish Moomin book and randomized so that there was no plot to follow. In multi-speaker conditions, the starting moments of sentences were stirred so that the sound scenario was natural babble. When number of simultaneous speakers was increased, the level of masking sound was reduced to keep the fixed overall level.

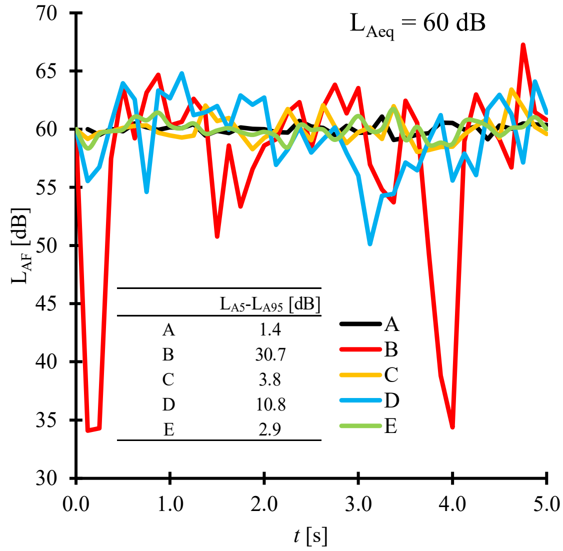

Figure 1. Sound level profile for five sounds out of 111. A) Zero speakers, just masking. Small SLV. B) One speaker with high SNR (+25 dB). Speech stands out perfectly. SLV is the greatest. C) One speaker with low SNR (-5 dB). Speech intelligibility is poor because of masking. D) Six speakers with high SNR (+25 dB). Very few words stand out from the babble. E) Six speakers with low SNR (-5 dB). The babble is hardly audible because of masking.

No. of simulta-neous speakers	Speakers	SNR				
		−∞	-5	+5	+10	+25
1	a		x	x	x	x
1	b		x	x	x	x
1	c		x	x	x	x
2	ab		x	x	x	x
2	ac		x	x	x	x
2	bc		x	x	x	x
3	abc		x	x	x	x
6	abcabc		x	x	x	x
12	abcabcabcabc		x	x	x	x
0	-	x				

Table 1. Properties of the 36 core sounds (grey). Speakers a and b were male, and speaker c was female. Each core sound was played at 40, 50, and 60 dB L_{Aeq} making 111 sounds.

The sounds were played via headphones. Desired levels and spectra were measured using the in-ear microphones head-and-torso simulator and by placing the headphones on the torso. For each sound, the L_{Aeq} and $L_{A5} - L_{A95}$ were measured to be used in the development of the prediction model.

3. RESULTS

The means of the subjective distraction of the 39 participants are shown by the 111 symbols in **Fig. 2**. Distraction was clearly higher when the sound level L_{Aeq} was higher (different colors). However, distraction varied significantly within each L_{Aeq}. For example, at 50 dB, the distraction varied between 1.5 and 7.0. The dependence of distraction on SLV at each three L_{Aeq} levels followed quite similar shape.
At a fixed SNR and L_{Aeq}, distraction increased with reducing (positive) number of simultaneous speakers. Single-speaker or dual-speaker condition was usually the most distracting and twelve-speaker condition the least distracting. However, we did not base our model on number of simultaneous speakers, because sound level meter cannot count that.
Instead, we used mathematical reasoning to identify a function that fits the functional dependence of distraction on L_{Aeq} and SLV. Microsoft Excel Solver was used to find the constants of this function. The predicted distraction, D_p, is calculated by:

$$(1)\quad D_p = 0.205 \cdot L_{Aeq} + 8.63 \cdot SLV_{15}/(SLV_{15}+4.65) - 10$$

where SLV_{15} [dB] is the minimum of measured SLV (L_{A5} - L_{A95}) and +15 dB. The Pearson's correlation coefficient was extremely high, 0.96.
The predicted values are shown in **Fig. 2** with lines. The predicted distraction agreed well with subjective distraction. The linear association between predicted and observed distraction is also shown in **Fig. 3**.

4. DISCUSSION

The model of Eq. (1) confirmed our hypothesis that distraction depends both on sound level and sound level variability. Our model was partially supported by previous studies [4–6]. However, they were limited to single-speaker condition. Our model goes much farther because it is based on 0–12 simultaneous speakers and very wide range of signal-to-noise ratios (-5 … +25 dB) and overall sound levels (40–60 dB). Therefore, our work provides very strong evidence about the mechanisms under perceived distraction.

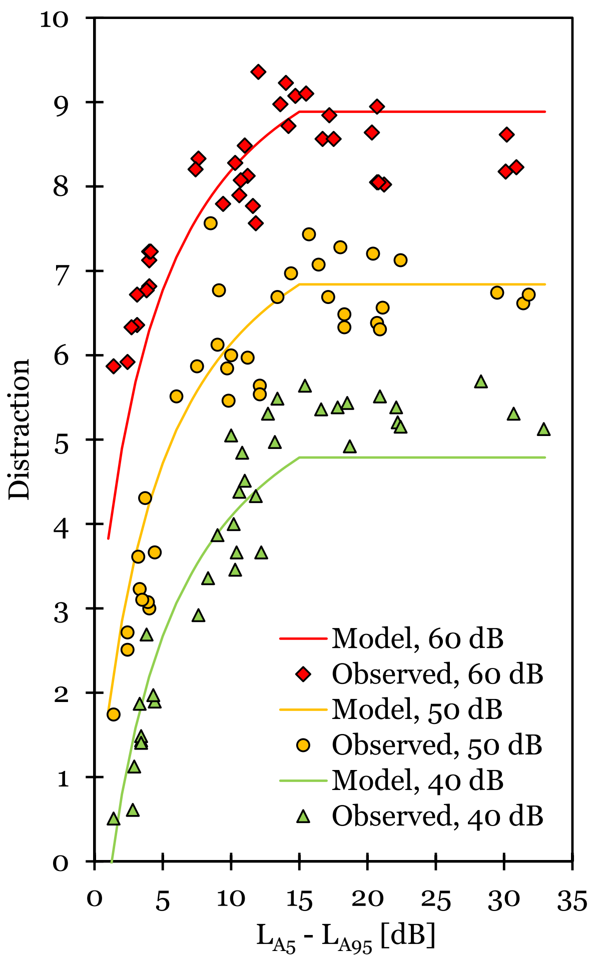

Figure 2. Dependence of distraction on sound level variability ($L_{A5} - L_{A95}$) and overall sound level, L_{Aeq}. The symbols represent the mean of 39 participants lines represent the prediction of Eq. (1).

Our experiment is first of a kind. Further research would be useful to validate or further develop our prediction model. The validity question was partially answered in Ref. [7], which involved three independent Experiments 1–3. Current paper only reports Experiment 2. All three experiments involved different sets of sounds and participants, but the results of each experiment pointed in similar direction. Experiment 1 compared annoyance and distraction ratings. These attributes were rated very similarly. Experiment 3 involved both native Finnish speakers and participants who did not understand Finnish.

The results were very similar in both groups. This suggests that the distraction due to speech might not strongly depend on the understanding of the speech.
The prediction model of Eq. (1) provides a possibility to objectively predict the distraction in workplaces where irrelevant speech is the most usual source of distraction.
The model can be easily integrated to standard sound level meters, because the input variables are already available in most of them.
The ability to objectively assess distraction is useful for several kinds of professionals:

- occupational health physicians and nurses,
- rehabilitation instructors for the hearing impaired,
- occupational health and safety officers,
- occupational hygienists,
- workplace ergonomists,
- workplace designers,
- acoustic designers, and
- noise measurement professionals.

The model may also be interesting among developers of office space management interfaces. The model allows to indicate areas or seats in the office layout where noise distraction potential is low or high.

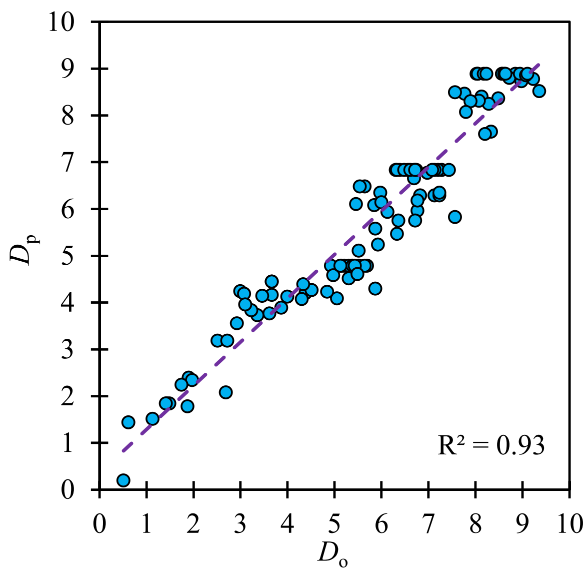

Figure 3. Association between the subjective, D_o, and predicted, D_p, distraction among the 111 test sounds. Prediction was based on Eq. (1).

5. ACKNOWLEDGMENTS

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