Distraction distance predicts noise disturbance in open-plan offices

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ABSTRACT

Measurements according to ISO 3382-3 are generally used to objectively describe the room acoustic quality of open-plan offices. The standard results in four single-number quantities: distraction distance, the spatial decay rate of speech, speech level at 4-meter distance and background noise level. The relationship between these quantities and perceived noise disturbance has not been established in field studies. Our aim was to synthesize evidence from 21 workplaces (883 respondents) covering a wide range of room acoustic conditions. The data included both questionnaire surveys and room acoustic measurement data from each office. The results showed that an increase in distraction distance predicts an increase in disturbance by noise. The results give strong support to the view that the investment on room acoustic quality of open-plan offices is beneficial. Good quality is achieved by the simultaneous application of room absorbers, sound masking and office screens.

INTRODUCTION

Speech is the primary noise source in open-plan offices [1]. The disturbance caused by speech is associated with speech intelligibility [2]. Noise control can be provided e.g. by investing on room acoustic quality, by setting up behavioral guidelines and by installing sound insulating booths [3]. Nowadays, open-plan offices are also often provided with quiet rooms where employees can temporarily move during periods of concentration-demanding tasks or confidential conversations.

The international standard ISO 3382-3 [4] describes a method for measuring the room acoustic conditions in open-plan offices. The standard is based on a study conducted in 16 open-plan offices [5]. The measurement is conducted by placing a loudspeaker in a single workstation. The loudspeaker mimics a single person speaking in the open-plan office. The loudspeaker produces pseudo-random noise with a known sound power level. The noise produced by the loudspeaker is measured at several workstations at different distances from the loudspeaker. Typically, a measurement line is selected where the workstations are located at different distances, r [m], from the loudspeaker. In the analysis phase, the measured octave-band levels of noise are normalized to normal-effort speech so that the A-weighted level of speech can be determined in every workstation. In addition, the Speech Transmission

Index, *STI*, is measured in each workstation. The *STI* is an objective predictor of speech intelligibility. The *STI* values range between 0.00 and 1.00.

ISO 3382-3 describes four result quantities (see Figure 1). The distraction distance, r_D [m], expresses the distance where the *STI* of a single speaker, speaking with normal effort, falls below 0.50. A small value describes high speech privacy. The spatial decay rate of speech, $D_{2,S}$ [dB], describes how many decibels the A-weighted level of speech is reduced when the distance to the speaker is doubled. A large value means that speech levels are rapidly attenuated when the distance to the speaker is reduced. The speech level at 4-meter distance, $L_{A,S,4m}$ [dB], describes the A-weighted level of speech at a nominal distance of 4 meters from the source. A small value means strong local attenuation in the workstation where the speaker is located. Background noise level, $L_{A,B}$ [dB] is the A-weighted level of background noise (ventilation, masking sound) in the office when the employees are absent. The measurements are conducted when the employees are absent.

STI was decided to be used as a primary quantity of ISO 3382-3 based on the hypothesis of Ref. [2] according to which the effects of office noise on cognitive performance would depend on speech intelligibility. After 2005, several laboratory studies have been conducted which provide some support to the hypothesis, see review in Ref. [1].

Subjective disturbance caused by speech can be associated with the reduction of cognitive performance. Actually, subjective disturbance effects have been found more often than performance effects in laboratory experiments. Performance effects are very difficult to measure in work environments. Therefore, disturbance by noise and the lack of acoustic privacy (or alternatively satisfaction with acoustic privacy or acoustic conditions) are usually inquired in field conditions.

Despite of the existence of an international standard [4], the association between the standardized single-number quantities (r_D, $D_{2,S}$, $L_{A,S,4m}$ and $L_{A,B}$) and noise disturbance have been studied only in laboratory conditions [6] or at single workplaces [7-9].

The purpose of this study was to determine whether the single-number quantities are associated with noise disturbance in field conditions.

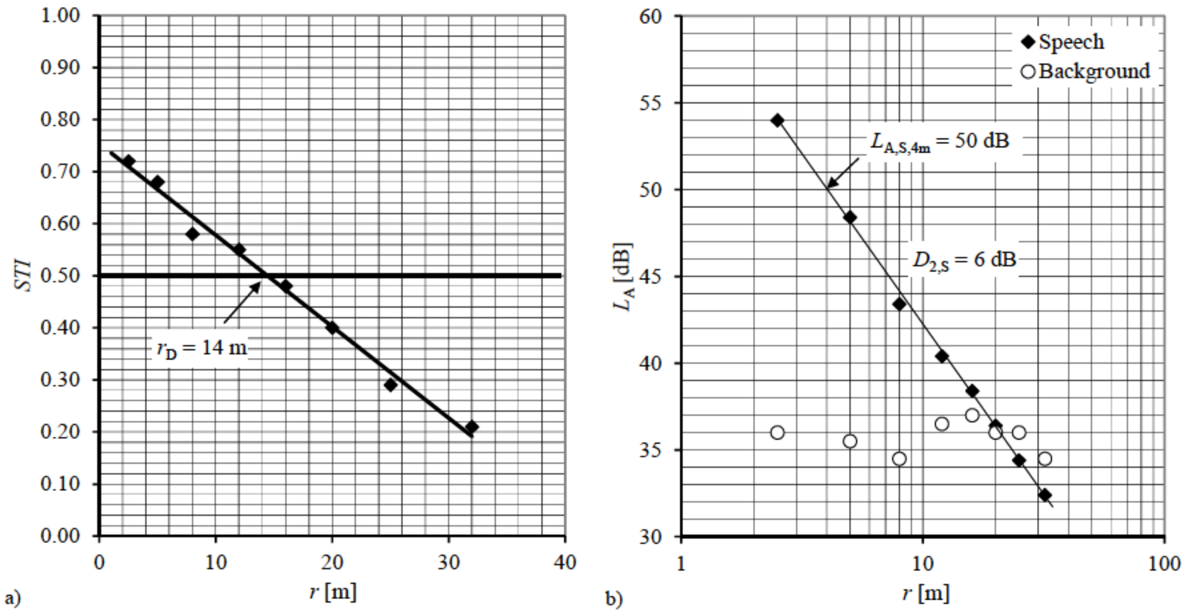

Figure 1. The definitions of the four acoustic variables of ISO 3382-3. a) A-weighted sound pressure level of speech and background noise. b) *STI* as a function of the distance *r* from the speaker.

MATERIALS AND METHODS

The room acoustic measurement data and questionnaire data (N=883) were collected from 21 open-plan offices during years 2002-2014. An open-plan office means a workspace of at least six employees. The data does not contain call-centers because they can be expected to involve much more speech sounds than typical open-plan offices. Four out of twenty-one offices were open-plan offices involving a large number of quiet rooms in addition to the workstation in the open-plan office. All respondents had assigned workstations in all studied offices.

Two variables were analyzed from the original questionnaires: *disturbance by noise* (referring to all noise sources) and *disturbance by speech*. The amount of disturbance was assessed using a 5-point verbal scale (1 Not at all, …, 5 Very much). Both variables concerned the perception at the workstation. The original 5-point variables were dichotomized so that the highest two categories (4 Quite a lot, 5 Very much) were re-coded as ”highly disturbing” (%HD) and the lowest three categories 1-3 as ”not disturbing”. Age and gender were included in the models.

The room acoustic properties of the open-plan offices were measured according to the ISO 3382-3 [4]. The principle was explained in Introduction.

Pearson’s correlation coefficients were determined between the values of room acoustic quantities and the values %HD over the 21 open-plan offices.

Because the data was collected from separate research projects over several years, the data was combined applying a meta-analytic approach [9]. One-stage meta-analysis of individual participant data [10] was conducted using two-level logistic regression with respondents (level 1) nested in workplaces (level 2). The method takes into account the hierarchic structure of the data where individual respondents belong to specific organizations (level 2) which can have their own influence on the results. Room acoustic measurement data were organization-level variables because their values were identical for all employees of an organization. The Odds Ratio, OR, and the 95% confidence interval is reported. Odds ratio is statistically significant when the 95% confidence interval does not involve the value 1.00. The analysis was conducted with R software (version 3.2.2) [11] using the lme4 package [12].

RESULTS

The correlation coefficients between the variables are shown in Figure 2 and Table 1. The results of the multi-level modelling are shown in Table 2.

Table 1. Pearson’s correlation coefficients between the main variables shown in Figure 1.

	r_D	$D_{2,S}$	$L_{p,A,S,4m}$	$L_{p,A,B}$	%HD by noise
$D_{2,S}$	0.05				
$L_{A,S,4m}$	0.42	-0.41			
$L_{A,B}$	-0.83***	-0.02	-0.38		
%HD by noise	0.54*	-0.04	0.47*	-0.56**	
%HD by speech	0.54*	0.08	0.57**	-0.52*	0.88***

* p < 0.05, ** p <0 .01, *** p < 0.001
%HD = percentage of highly disturbed

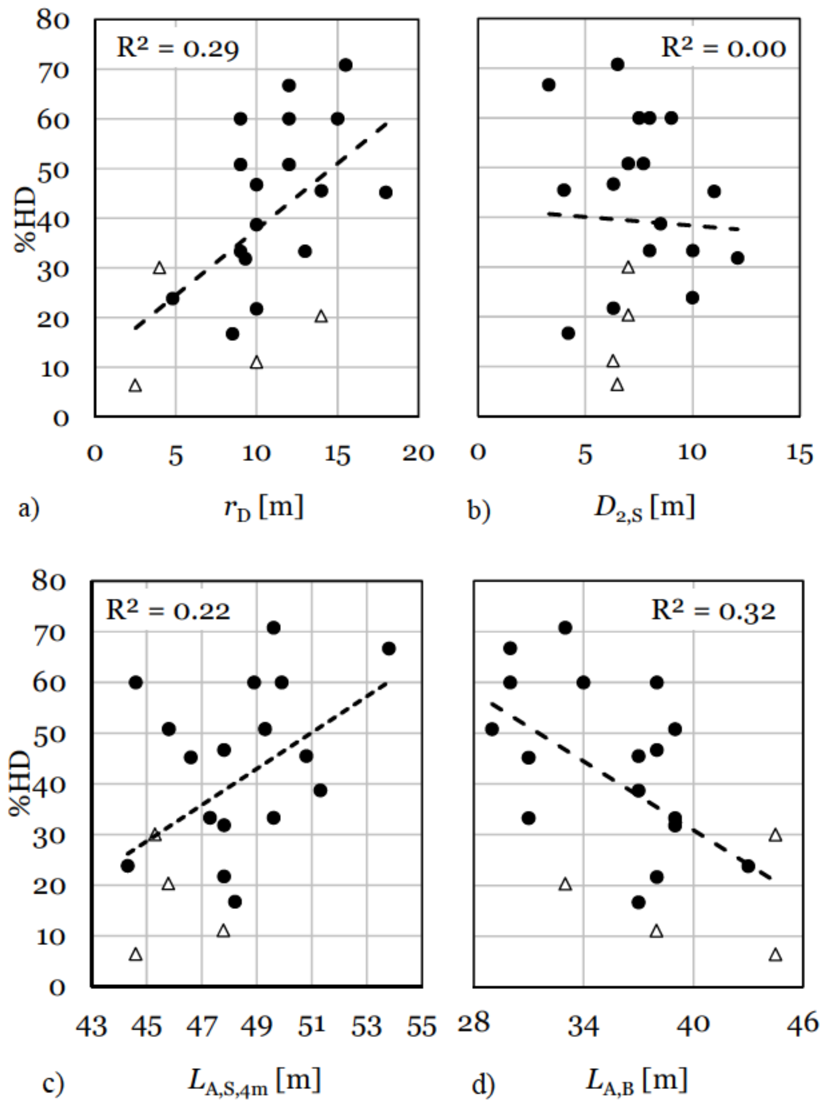

Figure 2. The percentage of highly disturbed by noise (%HD) at 21 workplaces in relation to the room acoustic variables. a) Distraction distance; b) Spatial decay rate of speech; c) Speech level at 4-meter distance; d) background noise level. R^2 is the square of Pearson's correlation coefficient. Statistical significance are clarified in Table 1. Open-plan offices involving a large number of quiet rooms are indicated with hollow triangles and conventional open-plan offices with black squares.

Table 2. The association between room acoustic variables and disturbance in the full sample (n=875, 21 offices). Results indicated by an asterisk (*) remained statistically significant when the four open-plan offices involving a large number of quiet rooms were excluded from the analysis.

Room acoustic variable	***Disturbance by noise***			***Disturbance by speech***		
	OR	95% CI	*p*	OR	95% CI	*p*
r_D	1.13	1.04 - 1.23	0.003*	1.14	1.04 - 1.25	0.006*
$D_{2,s}$	1.00	0.84 - 1.19	0.99	1.07	0.88 - 1.29	0.51
$L_{A,S,4m}$	1.20	1.04 - 1.38	0.01	1.27	1.09 - 1.47	0.002
$L_{A,B}$	0.91	0.84 - 0.98	0.01	0.91	0.84 - 0.98	0.02

DISCUSSION

The correlation between disturbance by noise and disturbance by speech was very high. This supports earlier findings and demonstrates that disturbance by speech largely explains the general perception of disturbing noise in open-plan offices.

The results of the full sample (21 offices) indicated that disturbance increases when

- distraction distance increases,
- speech level at 4-meter distance increases, and
- background noise level reduces.

The raw data of Figure 2 shows that the four open-plan offices involving a large number of quiet rooms had lower disturbance by noise. When the open-plan offices involving a large number of quiet rooms were excluded from the analysis, the results indicated that disturbance increases with increasing distraction distance.

The results support the application of ISO 3382-3 standard. The quantity r_D seems to be of primary importance because it was associated with both disturbance variables in both samples. However, because r_D depends on all three quantities, $L_{A,B}$, $L_{A,S,4m}$ and $D_{2,S}$, as explained in Refs. [5], our result should not be interpreted to indicate that these three quantities are not needed. If a similar study was conducted in open-plan offices where the background noise levels, $L_{A,B}$, are equal and sufficiently large (preferably within 40-45 dB L_{Aeq}), the disturbance would probably be reduced with increasing D_{2S} and r_D, and with reducing $L_{A,S,4m}$. This hypothesis is supported by a recent field experiment which showed that adding room absorption decreased acoustic disturbance [13]. Therefore, further research in this field is still needed.

The disturbance by noise varied strongly between the offices (Figure 2). The %HD values ranged between 6 and 71% in the full sample. The range was between 17 and 71% for seventeen conventional open-plan offices and between 6 and 30% for four open-plan offices involving a large number of quiet rooms. The number of latter offices was only four and the difference between office types was not investigated so the conclusions should be cautious.

This is the first field study which has investigated the relationship between noise disturbance and room acoustic quality as described by ISO 3382-3. Our results partially disagree a previous study which did not find evidence of the relation between acoustic satisfaction and room acoustic quality as described by Speech Intelligibility Index, *SII* [14]. The reason may be that we focused on the acoustic quality of the whole office, which is the approach of ISO 3382-3, while Ref. [14] focused on the *SII* between neighboring workstations. The latter approach does not sufficiently describe the room acoustic quality of an open-plan office [5].

The results suggest that it is beneficial to invest on room acoustic design which reduces the distraction distance. This is achieved by the simultaneous application of sound masking, room absorbers, and screens [5]. The results also suggest that the increment of background noise (sound masking) alone is beneficial. However, it should be noted that an increment of masking level above 45 dB L_{Aeq} is not recommended because it can lead to increased speech effort during conversations and the desired reduction of noise disturbance may no longer be achieved.

Virjonen et al. [5] presented the first target values for the room acoustic quantities of ISO 3382-3. They were based on the observed distribution of room acoustic data among 16 acoustically different open-plan offices. However, their suggestion was not confirmed by employee perceptions. Our results support the suggested target values of Virjonen et al. regarding the quantities r_D, $L_{A,S,4m}$ and $L_{A,B}$.

The results can be used to develop scientifically justified target values for room acoustic design. For example, the linear fit over our data (Figure 2) suggests that the percentage of highly disturbed by noise can be below 30% when the distraction distance is less than 7 meters, speech level at 4 meters is less than 46 dB L_{Aeq} and background noise level is above 40 dB L_{Aeq}.

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