inter.noise 2010
noise and sustainability
13-16 June 2010 . Lisbon . Portugal
www.internoise2010.org

RESPONSE TO OCCUPATIONAL NOISE OF MEDIUM LEVELS AT FOUR TYPES OF WORK PLACES

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Abstract

Occupational noise exposure at levels below those recognized as causing hearing impairment can cause annoyance and tiredness, and impair work performance. Few studies have addressed these and other responses to occupational noise of medium levels. Furthermore, studies typically explore one type of work place due to the hypothesized influence of situational factors. Our interest was to explore if a dose-response relationship between annoyance and measurements of sound levels in different work places could be derived. Four categories of occupational environments were studied; education, health care, offices and control rooms, including in total 26 work places. An average sound pressure level for each work place was derived from measurements at different positions in the rooms (range: 28.7 – 59.5 LpAeq dB). A global dose-response relationship between average A-weighted sound pressure levels and proportion of employees annoyed was found, despite disparity in conditions for the different categories of work places. Alternative descriptors of the sound pressure levels did not significantly improve the relationship. The result will be discussed in the view of impact of sound versus that of moderating factors.

Keywords: Occupational noise, dose-response relationship, sound characteristics, psycho-social factors.

1 Introduction

Occupational noise is known as a risk for several psychological and physiological adverse effects. Most studies have addressed the effects due to sound of levels that could cause hearing impairment. It is however known that also sound at levels that can be characterised as medium, here defined as A-weighted equivalent levels below 75 dB, cause serious disturbance [1]. For example, work performance could be impaired due to tiredness and lack of concentration, and as a consequence of disruption and intelligibility of irrelevant speech [2]. These effects, including a general decrease in well-being, have in work place studies been captured in subjective measurements of noise annoyance. Such measurements are however typically carried out at one type of work place at a time, e.g. [3], [4] and [5], even though some studies include up to three types of work places [6]. It would be of interest to explore if it is possible to assess a dose-response relationship between sound exposure and risk of noise annoyance that could be generalized beyond type of work place. A global dose-response relationship for occupational noise would contribute to the effort to reduce impairing sound levels, in the way dose-response curves for community noises have done.

The objectives of this paper were to (i) find a general dose-response relationship between sound pressure levels and perceived annoyance at work places exposed to medium levels of sound and (ii) to explore possible work place related factors other than sound pressure levels that could explain variation in noise annoyance.

2 Method

The sound pressure levels at 17 work places were measured and compared with the prevalence of noise annoyance measured in questionnaires. The sound load between cellular and landscape settings in offices differed substantially and some offices were therefore explored at two independent work places. Furthermore, work places with less than 5 respondents were excluded, leaving 26 work places that were included in the analyses. The data base comprised four categories of work places: auditorium (n = 9), offices (n = 9), primary health care units (n = 4) and control rooms (n = 4). The study sample comprised employees in the chosen work places. For auditorium, students attending lectures in the studied rooms were included for analyses of noise annoyance and perceived sound characteristics, but not for analyses with work related variables.

Sound measurements were performed in several rooms at each work site using a Bruel & Kjaer 2260 sound level meter with the microphone B&K 4189. For each measured room, 2 minutes measurements at 3 measurements positions were logarithmically averaged. The measurements took place during regular working hours in empty rooms in order to measure the back ground sound pressure levels without activity sound. At some work places, such as large open space offices, this was not always possible. However, sound from direct conversation was avoided during the measurements. Four different sound exposure metrics were assessed: dB(A)Leq, dB(C)Leq, dB(A)L10 and dB(A)L90.

Subjective measurements were obtained by a questionnaire. Response to noise was measured as annoyance on a 5-point scale rating from “not” to “extremely annoyed”. For some analyses, the scale was dichotomized into “not annoyed” (point 1 or 2) and “annoyed” (point 3, 4 and 5). Noise sensitivity was measured in 2 items, one referring to noise in general and one to low frequency noise, both with 4-point scales from “not at all sensitive to noise” to “very sensitive to noise”. The respondents’ characterization of the sound at their work place was measured with 13 items on 100 mm visual analogue scales. Weather or not sounds from 6 suggested sources at the work place were heard was measured binary (no/yes); annoyance due to these sources was measured with the same scale as described for noise annoyance. The above described questions were given to all employees and students present at the study days (n = 935), of which 750 responded.

Participating employees (n = 342), i.e. not students, were approached with additional questions about their work situation. Perceived control of the work situation was measured with one item on a 4-point scale from “never/seldom” to “always/almost always”. Stress at work was measured with 3 items on the same scale. The 3 items showed high internal consistency (alpha = 0.823) and the scores were therefore added to form one stress-scale, ranging from 3 to 12.

Relationships between sound exposure and proportion of employees annoyed by noise were tested statistically with linear regression. Associations between annoyance (not annoyed/annoyed) and possible explanatory variables were tested with binary logistic regression. All tests were two-sided and a p-value below 0.05 was considered as an indication of a statistically significant relationship.

3 Results

3.1 Dose-response relationship

The prevalence of annoyance was statistically significantly associated with all four metrics of sound exposure (Table 1). The linear regression models showed for example that an increase of one dB(A)Leq increased the prevalence of annoyance 2.1 percent units. The distribution of sound pressure levels differed substantially between the four types of work places. The regression models were therefore adjusted for work place. The impact of sound on annoyance decreased somewhat when the linear regression model was adjusted for type of work place. The association was however still highly statistically significant. Also, the adjusted R-square showed that a higher proportion of the variability in prevalence of annoyance was explained by the sound exposure.

Table 1. Relationship between sound levels and proportion of annoyed modelled with linear regression (26 work places).

	Crude				**Adjusted** [a)]			
	B [b)]	Beta [c)]	p	AdjR-sq	B	Beta	p	AdjR-sq
dB(A)Leq	2.15	0.86	<0.001	0.73	1.87	0.75	<0.001	0.76
dB(C)Leq	2.95	0.79	<0.001	0.60	2.12	0.57	<0.01	0.69
dB(A)L10	2.09	0.81	<0.001	0.85	1.73	0.70	<0.001	0.74
dB(A)L90	2.25	0.86	<0.001	0.72	2.16	0.82	<0.001	0.75

[a)]Adjusted for type of work place (auditorium, office, health care, control room).
[b)]Unstandardized regression coefficient.
[c)]Standardized regression coefficient.

The relationship between dB(A)Leq and prevalence of annoyance for all four types of work places is shown in Figure 1. Offices and health care units show agreement with the linear regression model, while auditorium and control rooms form a diverse pattern. No statistically significant relationships between annoyance and any of the exposure variables were found for auditorium and control room respectively; neither when parametric nor nonparametric tests were used (data not shown).

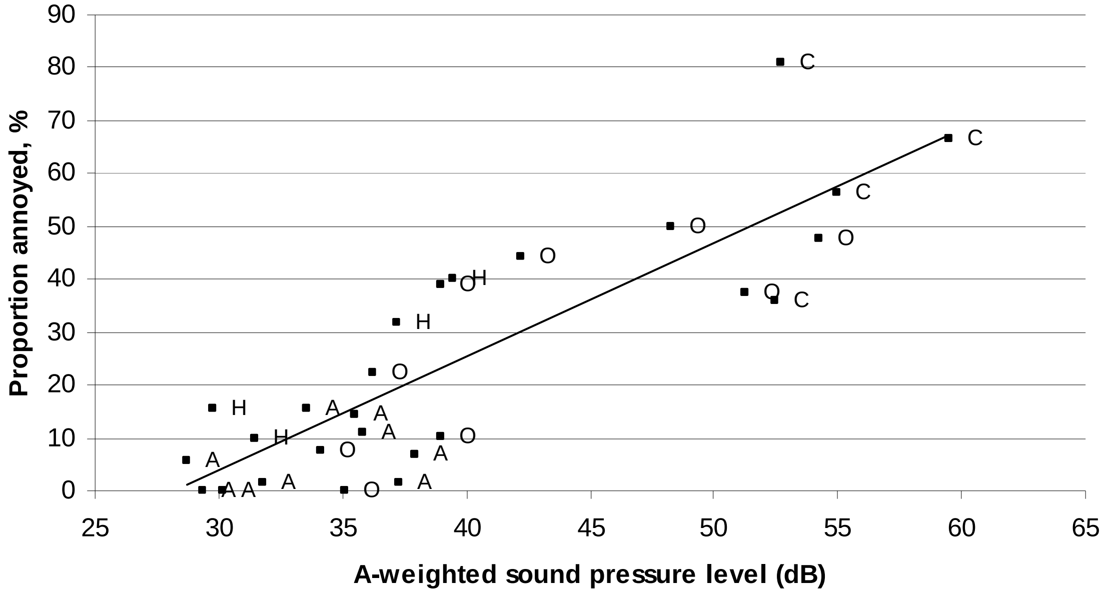

Figure 1. Relationship between A-weighted sound pressure level and prevalence of noise annoyance in four types of work places: auditorium (A), office (O), health care (H) and control rooms (C).

3.2 Sound characteristics

The respondents described the sound environment at their work place as whispering, as well as rumbling, ringing, high frequency, low frequency, scraping and beeping. There was a high agreement, despite type of work place, of which sound characters that were present, even though respondents working in control rooms (with higher equivalent sound pressure levels than other work places) reported an overall higher content of the characters in the sound environment (Table 3).

Table 3. Perception of sound characteristics at each type of work place, mean values.

Auditorium	Office	Health care	Control room
1. Whispering 3.1	1. Whispering 4.0	1. Whispering 3.6	1. Whispering 6.9
2. High frequency 2.4	2. Ringing 2.9	2. Rumbling 2.3	2. Rumbling 5.2
3. Low frequency 2.4	3. Low frequency 2.5	3. Low frequency 2.2	3. Low frequency 5.0
4. Rumbling 2.0	4. High frequency 2.3	4. Ringing 2.2	4. Hissing 4.4
5. Scraping 1.7	5. Rumbling 2.1	5. Hissing 1.7	5. Beeping 3.8

Whispering was also the sound characteristics that had the highest association with annoyance at auditoriums, while rumbling was more annoying in health care and control rooms (Table 4). Stuttering, which was not among the five characteristics most easily perceived (Table 3), were related to noise annoyance in offices, and to some extend, in auditorium.

Table 4. Associations between sound characteristics and noise annoyance (not annoyed/annoyed) tested with binary logistic regression. Adjusted for A-weighted sound pressure levels. Statistically significant associations in bold.

Auditorium		**Office**		**Health care**		**Control room**	
	OR		**OR**		**OR**		**OR**
1. Whispering	**1,587**	1. Stuttering	**1,371**	1. Rumbling	**1,741**	1. Rumbling	**1,390**
2. Pulsating	**1,567**	2. Thumping	**1,356**	2.Tonal	1,445	2. Whispering	**1,331**
3. Stuttering	**1,494**	3. Tonal	**1,323**	3. Hissing	**1,334**	3. Low frequency	**1,260**
4. Ringing	**1,450**	4. Scraping	1,278	4. Beeping	1,320	4. Pulsating	1,244
5. Tonal	**1,443**	5. Rumbling	**1,259**	5. Pulsating	1,231	5. High frequency	**1,226**

Sounds from conversation, from activity in the corridor and from ventilation were the most common reported among respondents in auditoriums (Table 5). Of these sounds, ventilation was the most annoying. The same sound sources were heard in offices and health care units, together with computers. Conversation and activity in the corridor were at these work places the most annoying. Also, at health care units, traffic was heard and reported as annoying. Ventilation and conversation was the most heard sound sources in the control rooms and also the most annoying.

Table 5. Proportion of respondents that heard and/or were annoyed by, respectively, sound from six different sources

	Auditorium n=416	**Office n=139**	**Health care n=61**	**Control room n=106 [a)]**
Hear, %				
Ventilation	36.1	47.9	54.0	72.5
Projector	28.8	22.9	11.7	8.4
Computers	3.6	49.3	59.0	58.9
Conversation	64.2	87.1	54.0	64.1
Corridors	43.0	77.1	65.1	29.8
Traffic	11.3	38.6	41.3	3.8
Annoyed, %				
Ventilation	14.9	5.0	11.1	39.7
Projector	4.1	6.4	1.6	4.6
Computers	0.7	7.9	4.8	18.3
Conversation	12.7	27.9	14.3	25.2
Corridors	9.6	20.7	17.5	6.9
Traffic	2.2	7.1	17.5	0.0

[a)]Missing data = 25 because this question was not asked in one of the control rooms.

3.3 Influences of individual factors on response to noise

Individual factors differed between the four different types of work places (Table 6). A larger proportion of the employees at health care units reported that they were sensitive to noise than that of offices and control rooms. They also reported more stress. Employees in control rooms and health care had less possibility to control their work situation than those working in offices.

Table 6. Individual factors related to sub samples (type of work place) and in total.

	Auditorium A	**Office O**	**Health care H**	**Control room C**	**Total**
n	8	140	63	131	342
Age, mean (SD)	50.9 (12.5)	45.8 (11.4)	48.8 [C)] (10.2)	43.2 [H)] (10.5)	45.5 (11.0)
Gender, %male	75.0 [O) H)]	33.6 [A) H) C)]	12.7 [A) O) C)]	79.8 [O) H)]	48.2
Noise annoyance, %	0.0	24.3 [C)]	22.2 [C)]	62.6 [O) H)]	38.0
Noise sensitivity					
Generally, %sensitive	37.5	27.9 [H)]	43.5 [O) C)]	22.3 [H)]	28.8
Low frequency noise, % sensitive	50.0	26.6	37.1	25.2	28.2
Work control, %low control	0.0 [H) C)]	20.7 [H) C)]	40.0 [A) O)]	44.6 [A) O)]	32.9
Stress, mean (SD)	6.9 (2.7)	6.5 [H) C)] (2.1)	7.7 [O) C)] (1.9)	5.8 [O) H)] (1.6)	6.5 (2.0)

[A)] Statistically significantly different from Auditorium. [O)] Statistically significantly different from Office. [H)] Statistically significantly different from Health care. [C)] Statistically significantly different from Control room. Continuous variables were tested with ANOVA. Binary variables were tested with Mann-Whitney U-test.

Several individual factors were found to be associated with noise annoyance (Table 7). Self-rated noise sensitivity, both to noise in general and to low frequency noise, as well as perceived stress at the work place were positively associated to noise annoyance. No association between the possibility to control the work on one hand, and reduced risk for noise annoyance on the other, was observed.

Table 7. Associations between noise annoyance at the work place (not annoyed/annoyed) and individual factors tested one by one with binary logistic regression. Statistically significant estimates in bold.

	OR[a)]	**95% CI**
Noise sensitivity, general, 4-point scale	**2.50**	**1.65 to 3.77**
Noise sensitivity, low frequency noise, 4-point scale	**2.32**	**1.59 to 3.38**
Work control, 4-point scale	0.94	0.69 to 1.28
Stress, 9-point scale	**1.45**	**1.24 to 1.68**

[a)] Adjusted for A-weighted equivalent sound pressure level, age, gender and type of work place.

Two models that predicted noise annoyance (not annoyed/annoyed) were derived using binary logistic regression (Table 8). In the base model, the influence of sound pressure levels on annoyance was explored, only adjusted for age, gender and type of work place. An increase of 1 dB in exposure increased the odds for respondents to be annoyed (vs. not annoyed) with 8 % in the base model. In Model 1, possible individual predictors were added. The influence of sound pressure levels were approximately the same as in the base model. However, three of the four individual variables were also associated with annoyance, (self-rated sensitivity to noise and reported stress) and the variance explained increased. The assumed direction, i.e. that the individual variables lead to noise annoyance, can not be tested in cross sectional studies like those here described. The observed association could hence be due to noise annoyance leading to noise sensitivity or stress. Working in a control room increased the risk for noise annoyance in Model 1. Respondents in control rooms reported less noise sensitivity and less stress than the other respondents at the same time as they reported high annoyance (Table 6) while the model failed in explaining the variance of annoyance for this sub sample. Hence working in a control room becomes a risk.

Table 8. Models of the influence of sound pressure levels on noise annoyance with individual factors derived with binary logistic regression. Dependent variable was noise annoyance (not annoyed/annoyed). Statistically significant estimates in bold.

	OR	95% CI
Base model. Estimated R-square: 0.17 – 0.24		
Equivalent A-weighted sound pressure level	**1.08**	**1.03 to 1.14**
Age, continuous scale	1.01	0.98 to 1.03
Gender, female/male	1.31	0.74 to 2.34
Type of work place		
Office, reference	1.0	
Auditorium	-	
Health care	1.71	0.74 to 4.00
Control room	1.99	0.91 to 4.32
Model 1. Estimated R-square: 0.31 – 0.41		
Equivalent A-weighted sound pressure level	**1.07**	**1.01 to 1.13**
Age, continuous scale	0.98	0.95 to 1.01
Gender, female/male	1.29	0.58 to 2.86
Type of work place		
Office, reference	1.0	
Auditorium	-	-
Health care	0.84	0.31 to 2.27
Control room	**4.17**	**1.53 to 11.37**
Noise sensitivity, general, 4-point scale	**1.93**	**1.17 to 3.17**
Noise sensitivity, low frequency noise, 4-point scale	**1.62**	**1.03 to 2.54**
Work control, 4-point scale	1.08	0.76 to 1.54
Stress, 9-point scale	**1.39**	**1.19 to 1.63**

4 Discussion

It was possible to derive a universal relationship between sound exposure and prevalence of noise annoyance for four types of work places, despite demographical differences between them. The employees' characterizations of the present sound were also surprisingly similar across types of work places, considering that the work places were as disparate when it comes to sound environments as health care units and control rooms. The sound sources that were annoying differed somewhat, but human produced sound such as speech and activity in the corridor were rated as annoying across type of work place. Ventilation noise was heard in most work places but was found to be particularly annoying in control rooms. Traffic sound was heard, and also annoying, mainly at health care units; a type of work place that were among those with the lowest sound exposure levels.

All four derived exposure measurements were related to prevalence of noise annoyance to approximately the same degree. The relationship with A-weighted equivalent sound pressure level was used as a base for the analyses in this paper, but further tests not presented here showed that the results would have been similar if any of the other metrics had been used. It is of course necessary for studies of specified sounds to choose the right metrics; however, this does not appear to be crucial for an overall dose-response between sound pressure levels and annoyance.

The dose-relationship was moderated by noise sensitivity, also known to moderate response to community noise [7]. However perceived control over the work did not predict noise annoyance in the models, a factor previously described to be of relevance for noise annoyance [1]. If this is due to inter-correlation with organization at difference type of work places is yet to explore. Perceived stress was though significantly related to noise annoyance, a relationship also previously shown in occupational settings [8]. It could be hypothesized that variables mainly related to individual variation, such as noise sensitivity, contribute to explaining the variance in noise annoyance despite type of work place, while variables related to the work places, such as the possibility to control the work, only is of interest within samples from the same type of work place.

5 Concluding remarks

A model predicting the risk for noise annoyance at work as a function of sound pressure level is possible to develop. More data is however needed, covering more than the four types of work places studied here, and also increasing the number of observations, i.e. number of included work places.

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