SPEECH PROPAGATION IN OPEN-PLAN OFFICE: A CROSS OVER DESIGNED FIELD STUDY

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The ISO standard 3382-3 for Open Plans was released 2012, looking into more depth on the speech propagation. With this study we wanted to investigate real office conditions, not controlled conditions, by isolating the sound environment in the manipulation that occurred we could then test our five hypotheses. The aim with this study was to find the building performance, with a fixed interior, in open-plan offices is reflected in the employees' ratings of disturbances, health, and performance. The study was performed with a cross over design in order to have double control groups. The acoustical effects of these manipulations were assessed according to the new ISO standard 3382-3: 2012 for open-plan room acoustics. In addition, the employees responded to questionnaires after each change. The results suggest that even a small deterioration in acoustical room properties measured; have a great impact on the employees' perception of disturbances, wellbeing and cognitive stress.

Keywords: Open office acoustics, stress, cognition, speech propagation

1. 1 INTRODUCTION

In relation to other ambient factors, the impact of unwanted sound or noise is probably the most studied when it comes to office environments [1, 2, 7, 12, 13]. Noise has been suggested to cause interruption, irritation and lowered performance among employees [10], and is one of the most common reasons for complains in open-plan office environments [5]. However, this study addresses something that is less known about noise, namely, how better or worse acoustical conditions in open-plan offices affect employees' perception of disturbances, health, and performance. It has also been found that different noise types, for example speech, music, and office noise in general, in comparison with quiet conditions, negatively impact different cognitive outcomes, such as memory performance, reading comprehension, and proofreading [3]. Hence, the purpose of the present study is to test the effect of different acoustical environments on employee ratings on indicators of disturbances, health, and performance. This is done by a crossover design that compares two different types of sound absorbents installed in contrasting sequences on two similar floors within the same office building. In order to obtain a comprehensive understanding of the room acoustics, we collected objective acoustical data in accordance with the international standard regarding room acoustics parameters [4]. We also collected behavioural measures, in order to understand how the acoustical environment impacts on the employees.

2. 2 Theory

In this study the aim was to investigate if enhanced and worsened room acoustic characteristics in open-plan office environments are reflected in changes in the employees' own perception of disturbances, health and/or performance. The manipulation consisted of different acoustic elements in the office building, where one condition enhanced the acoustic environment (better condition) and one worsened the acoustic environment (worse condition) as compared to a baseline condition. Our overall hypothesis was that the acoustical conditions would have an impact on the respondents' experiences regarding the outcome variables that is within each floor:

Hypothesis 1: the better condition is associated with lower disturbances in general
Hypothesis 2: the better condition is associated with lower nearby disturbances,
Hypothesis 3: the better condition is associated with lower distant disturbances,
Hypothesis 4: the better condition is associated with lower cognitive stress,
Hypothesis 5: the better condition is associated with higher personal efficiency.

2.1. Participating organization and employees

Two out of the six floors were used for the study (floors 4 and 5) as they had identical layouts, were similarly furnished, and the employees on these floors had similar work assignments. Each floor was highly open, with limited or no partitions, carpeted and with ceilings with highly sound absorbent tiles. Each employee had his/her own designated desk. The sample consisted of 151 employees in a municipality office outside of Stockholm, Sweden. 77% (n = 117) of the total sample completed the baseline survey in its entirety (T0), 70% (n = 106) the first survey (T1), 62% (n = 94) the second (T2), and 64% (n = 97) the third (T3). The analytic sample size was thus 145 persons.

2.2. Study design and procedure

This study employed a crossover design in an office environment to investigate if enhanced and worsened acoustical environment impact employees' perception of disturbances, self-rated health and performance.

Table 1. Illustrating the process of data collection.

1	2	3	4	5	6	7	8	9	10	11	12	13	14
Collection of T0				Collection T1			Collection T2						Collection T3
Collection of T0				Collection T1			Collection T2						Collection T3

The grey columns illustrates the period before the manipulation began; white text on black background = the better condition; black text on white background = the worse condition. Collection TX= illustrates when data were collected. Week 9-11 contained many national holidays which was handled by postponing the last manipulation and the last data collection (T3) so that everybody would be exposed to the new condition for two weeks before answering the survey. The manipulations in the physical environment were made the end of the following weeks: 2, 5, and 10. The data collections ended the following weeks: 2, 5, 8, and 14.

2.3. Survey measures

All respondent data was collected by means of an electronic survey. Disruption in general was measured by four items. The questions were "To what extent have you in the past seven days been disturbed by ventilation sounds"; "… by sounds from computers"; "… by ringing phones"; and "… by colleagues' phone calls". All questions concerning disruptions were measured by using a five-point rating scale (1="to a small extent", 5="to great extent"). Cronbach's α for internal reliability from the first survey was 0.71, indicating satisfactory consistency. Nearby disturbances were measured by the question "To what extent have you in the past seven days been disturbed by speech and laughter from colleagues sitting near you (within a radius of 10 metres)". Distant disturbances were measured by the question “To what extent have you in the past seven days been disturbed by speech and laughter from colleagues who sit further away (beyond a radius of 10 metres)”. Cognitive stress was measured by the cognitive stress scale from the Swedish version of the Copenhagen Psychosocial Questionnaire (COPSOQ) [6].

Sample question: How much of the time during the past week have you found it difficult to think clearly? All items were scored on a 5-point rating scale (1=never, 5=always). The personal efficacy subscale (6 items) of the Swedish version of the Maslach Burnout Inventory – General Survey (MBI-GS) was used to assess self-rated performance [11]. All items were scored on a 7-point rating scale (ranging from 1=never, 7=daily). See Table 2 for a correlation matrix between the dependent variables at T

Table 2. Correlation between outcome variables at T0.

	Disruption in general	Cognitive stress	Disturbances near	Distant disturbances	Personal efficiency
Disruption in general	1	0.40**	0.75**	0.66**	-0.12
Cognitive stress		1	0.30**	0.28**	-0.33**
Disturbances near			1	0.58**	-0.17
Distant disturbances				1	-0.14
Personal efficiency					1

** Correlation is significant at the 0.01 level (2-tailed).

2.4. Acoustic measurements

We included several acoustical measures in accordance with ISO 3382-3 guidelines, N.B not all paths were 16 meters long (ISO-3382-3, 2012). As an outcome we calculated the radius of comfort that was suggested at EuroNoise 2012 [8]. In addition, dBA levels were recorded from four points by two microphones on each floor. See [14], 2014 for the full acoustical report. All objective acoustical data were gathered in order to confirm that the manipulations we had made to the physical environment had led to two distinguishable acoustical conditions on each floor.

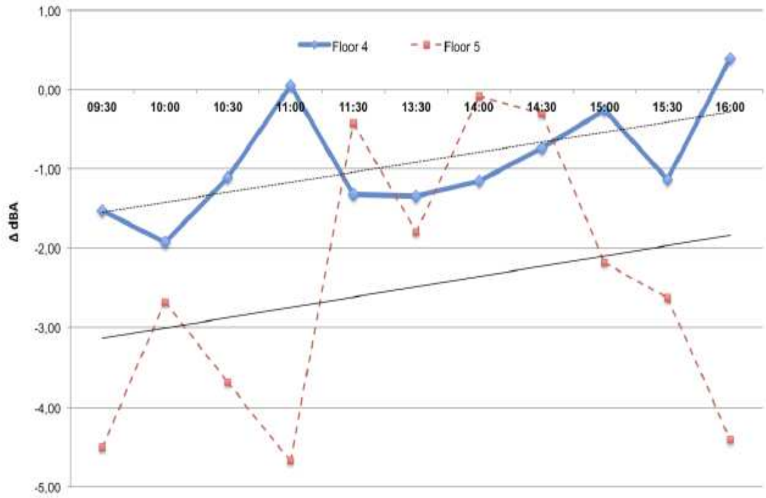
2.5 Data analysis

Separate repeated ANCOVAs were carried out for each of the five outcome variables for T1, T2, and T3 in order to test if the different order of the better versus worse conditions generated a different development of the outcome measures over time. By investigating if the quadratic function of time and floor was significant, the repeated ANCOVAs tests if the repeated manipulations to the different floors affected the outcome measures in the supposed direction. A significant quadratic function of time and floor would mean that the better and worse conditions affected the employees according to intentions, which will allows us to conduct further analyses to test if the manipulations between the better and the worse conditions differed meaningfully within each floor. The analyses were conducted in SPSS version 21 by means of the General Linear Model. Sex, age, and educational level were included as covariates.

3. Results

The difference between the better and the worse acoustical condition for the active parts of the working days and for each floor are shown in figure 1, which illustrates that in general throughout the days during data collection, both floors had a lower dB (A) level during the better condition in comparison to the worse. Floor 5 had a larger variation than floor 4..

Figure 1: SPL over day



According to expectations, and as shown in Table 4, the condition with both absorbing tiles and wall absorbents, absorbed noise better than the condition with reflective tiles and no wall absorbents according to the latest ISO standard and the Radius of comfort R_c [8].Speech level is thereby spread longer.

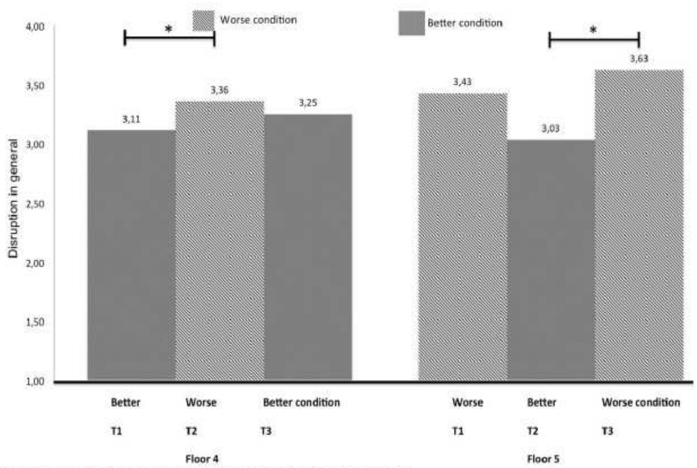
Table 4. Objective acoustic measures on floor 4 and 5 for the different conditions.

Floor	Path	Time period	Description of the condition	$D_{2,S}$ [dB]	$L_{p,A,S,4\,m}$ [dB]	r_C [m]
4	1	T0	Original condition (Absorbing tiles)	4,9	48,2	4,5
4	1	T1 & T3	Better condition (Absorbing tiles with wall absorbents)	4,9	47,8	4,2
4	1	T2	Worse condition (Reflective tiles)	4,0	49,0	5,3
4	2	T0	Original condition (Absorbing tiles)	4,5	50,1	6,1
4	2	T1 & T3	Better condition (Absorbing tiles with wall absorbents)	4,9	49,3	5,2
4	2	T2	Worse condition (Reflective tiles)	3,6	50,2	6,8
5	1	T0	Original condition (Absorbing tiles)	5,0	47,0	3,8
5	1	T1 & T3	Worse condition (Reflective tiles)	4,5	49,5	5,5
5	1	T2	Better condition (Absorbing tiles with wall absorbents)	5,3	46,7	3,7
5	2	T0	Original condition (Absorbing tiles)	6,6	48,1	4,3
5	2	T1 & T3	Worse condition (Reflective tiles)	6,8	50,2	5,3
5	2	T2	Better condition (Absorbing tiles with wall absorbents)	6,8	50,2	5,3

3.1 Disruption in general

According to Wilks' criterion there were no significant main effects of time or floor. The interaction effects between time and the covariates were not significant. The time and floor interaction was significant for the hypothesized quadratic function ($F[1, 38]=7.29$, $p = 0.01$, partial $\eta^2 = 0.16$). As shown in Figure 2a, the manipulations on each floor yielded symmetrically different U-shaped curves for disruption in general which suggested lower disturbances in the better conditions in comparison to the worse. Contrast analyses comparing the conditions within each floor where carried out to test the first hypothesis. On floor 4 the change from the better (T1) to the worse (T2) condition was significant while the change from the worse (T2) to the better (T3) condition was not. On floor 5 the change between the worse (T1) to the better (T2) condition was not significant but the change between the better condition (T2) to the worse was significant (all $p < 0.05$; please see figure 2a). To conclude, the first hypothesis was supported in that the better acoustical condition is related to less reported disturbances in general.

Figure 2a. Mean for Disruption general at T1-T3 for floor 4 and floor 5.



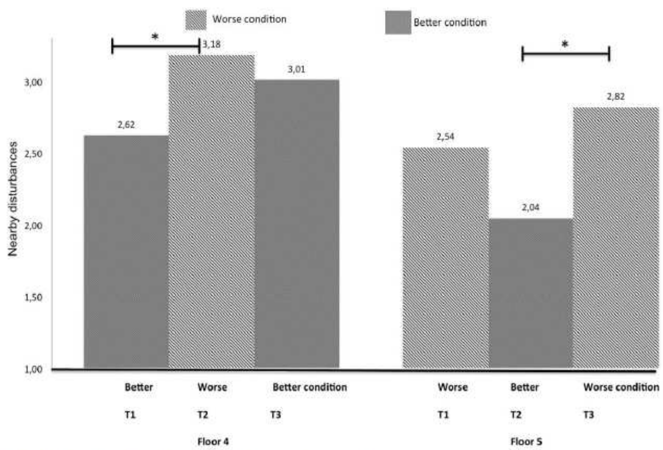
The scale ranging from 1 = "to a small extent" to 5 = "to great extent".
* = p< 0.05.

3.2 Nearby disturbances

With the use of Wilks' criterion there was no significant main effect of time or floor. The interaction effects between time and the covariates were not significant. The time and floor interaction was significant between time and floor for the hypothesized quadratic function ($F[1, 40]=6.36$, $p< 0.001$, partial $\eta^2 = 0.14$), that is, the manipulations on each floor yielded symmetrically different U-shaped curves for nearby disturbances, which suggested lower disturbances in the better conditions in comparison to the worse. Contrast analyses comparing the conditions within each floor showed that on floor 4 the change from the better (T1) to the worse (T2) condition was significant while the change from the worse (T2) to the better (T3) condition was not. On floor 5 the change between the worse (T1) to the better (T2) condition was not significant but the change between the better condition (T2) to the worse was significant (all $p < 0.05$; please see figure 2b).

To conclude the second hypothesis was supported in that the better acoustical condition is related to lower reported nearby disturbances.

Figure 2b. Mean for Nearby disturbances at T1-T3 for floor 4 and floor 5.

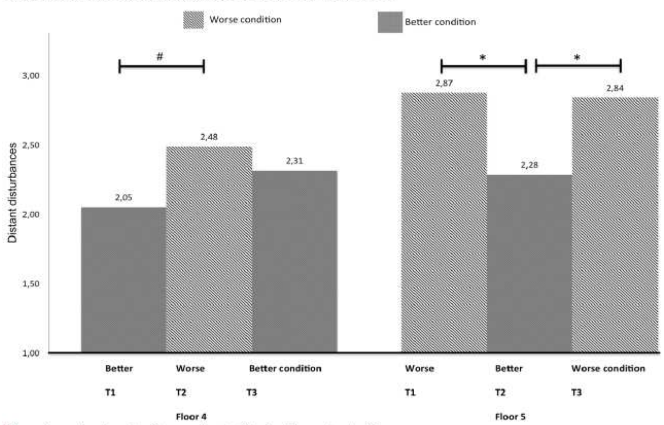


The scale ranging from 1 = "to a small extent" to 5 = "to great extent".
* = p< 0.05.

3.3 Distant disturbances

With the use of Wilks' criterion there was no significant main effect of time or floor. The interaction effects between time and the covariates were not significant. The time and floor interaction was significant between time and floor for the hypothesized quadratic function ($F[1, 40]=5.42$, $p = 0.025$, partial η 2= 0.12). As shown in figure 2c, the manipulations on each floor yielded symmetrically different U-shaped curves for distant disruption suggested lower disturbances in the better conditions in comparison to the worse. Contrast analyses comparing the conditions within each floor where carried out to test the first hypothesis. On floor 4 the change from the better (T1) to the worse (T2) condition was marginally significant ($p = 0.05$) while the change from the worse (T2) to the better (T3) condition was not. On floor 5 the change between the worse (T1) to the better (T2) condition was significant which was also the case for the change between the better condition (T2) to the worse (all $p < 0.05$; please see figure 2c). To conclude, the third hypothesis was supported in that the better acoustical condition is related to less reported disturbances from distant sources.

Figure 2c. Mean for Distant disturbances at T1-T3 for floor 4 and floor 5.

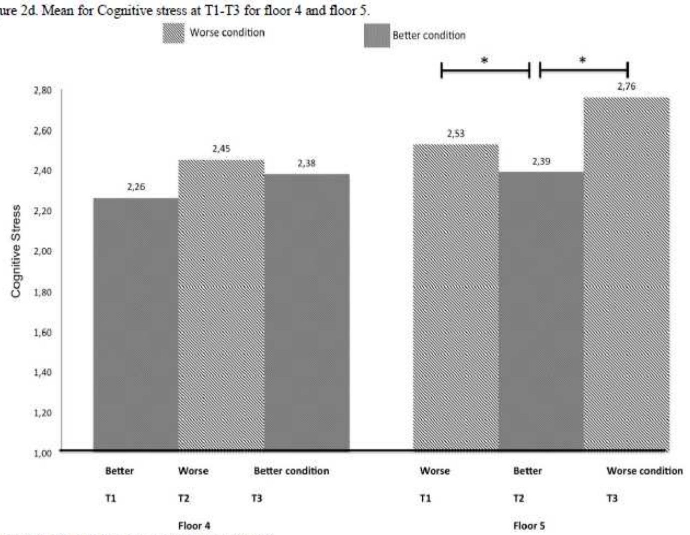


The scale ranging from 1 = "to a small extent" to 5 = "to great extent".
* = p< 0.05. # = p = 0.05.

3.4 Cognitive stress

With the use of Wilks' criterion there was no significant main effect of floor. However, the main effect of time was significant ($F[2, 36]=3.48$, $p= 0.042$, partial η 2= 0.16). The interaction effect between time and covariates were not significant. The time and floor interaction was significant between time and floor for the hypothesized quadratic function (F[1, 37]=7.59 p = 0.009, partial η 2= 0.17). As shown in Figure 2d, the manipulations on each floor yielded symmetrically different U-shaped curves for cognitive stress, which suggested lower stress in the better conditions in comparison to the worse. Contrast analyses comparing the conditions within each floor where carried out to test the fourth hypothesis. On floor 4 neither the change from the better (T1) to the worse (T2) condition nor change from the worse (T2) to the better (T3) condition were significant. On the other hand on floor 5 both the change between the worse (T1) to the better (T2) condition and the change between the better condition (T2) to the worse were significant (all $p < 0.05$; please see figure 2d). To conclude, the fourth hypothesis was supported in that the better acoustical condition is related to less cognitive stress.

Figure 2d. Mean for Cognitive stress at T1-T3 for floor 4 and floor 5.

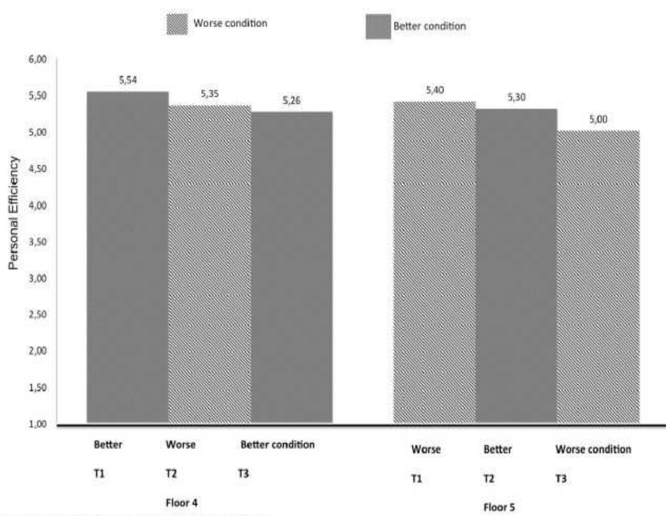


The scale ranging from 1 = "never" to 5 = "always".
* = p< 0.05.

3.5 Personal efficiency

With the use of Wilks' criterion there was no significant main effect of floor or time. The interaction effects between time and the covariates were not significant. Further, the hypothesized quadratic function between time and floor was not significant (see figure 2e), meaning that the employees on each floor did not report significantly higher or lower efficiency depending on the different conditions. Given that the overall quadratic function of time and floor was not significant, no further analyses within each floor were carried out. Therefore the fifth hypothesis could not be supported (see figure 2e).

Figure 2e. Mean for Personal efficiency at T1-T3 for floor 4 and floor 5.



The scale ranging from 1 = "never" to 7 = "daily".

4. Discussion and conclusions

One of the main strengths of this present study is that it was carried out in the field addressing regular office employees. Given that the social and other organizational structure within the organization were not manipulated, we believe that our findings is highly relevant for the effect that noise has on employees' health and perception of disturbances. Another strength of this study, it's the crossover design. By having two groups that constantly were exposed to the opposite condition than the other and by changing back and forth between the conditions, we created a highly controlled field experiment increasing the reliability of our findings. This study investigated; affect employees' perception of disturbances, self-rated health, and performance. Our results are in line with previous studies [5] and suggest that employees' perception of disturbances and health are affected negatively when exposed to increased noise levels. However, in contrast to previous research findings [9], the results from the present study showed that improved room acoustics was associated not only to lower objective noise levels, but also to lower perceived disturbances and lower cognitive stress. Consequently, the results imply that employees perceived better possibilities to make decisions, concentrate, and reported having lower amount of memory loss. Interestingly, these effects were evident despite the short exposure time to the new condition, suggesting that the effect of a change in room acoustics is quite immediate. This would suggest that even a minor improvement made to room acoustics could impact employees perceived health and disturbances. The study shows the importance of focusing on the acoustical conditions in open-plan offices in order to improve employees' well-being and through means of that also organizational efficiency. Our results suggest that even small deterioration in room acoustical properties measured by the new ISO-standard for open-plan room acoustics; have a negative effect on self-rated indicators of both health and performance. This study support previous studies demonstrating the importance of acoustics in work environment and suggest that the measures suggested in the new ISO-standard can be used to adequately differentiate between good and less good room acoustics.

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