Health effect of variation in noise absorption in open-plan office: a cross-over design field study

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ABSTRACT

The present study focuses on the evaluation of the effect of noise on occupants of an open-plan office environment. If office noise is frequently studied in controlled environments, this study investigates real conditions in two comparable floors of a building in use. A cross-over methodology was designed to test out hypotheses regarding the existence of a correlation between the quality of room acoustic absorption and occupant-rated noise disturbance, cognitive stress and performance. On one floor, the building sound absorption properties were changed from better to worse to better and from worse to better to worse for the other. The furniture was unaltered. The acoustical effects of these manipulations were assessed according to the ISO standard 3382-3:2012 for open-plan room acoustics. Employees answered questionnaires after each change to rate the effect of their environment on them. The results analysis shows that, for both floors and setups, an enhanced room acoustical environment correlates with lower perceived disturbance and cognitive stress. Even a small deterioration in acoustical properties has a negative impact on these parameters. The impact on self-assessed performance was not significant.

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, 3, 4, 5]. Noise has been suggested to cause interruption, irritation and lowered performance among employees [6], and is one of the most common reasons for complains in open-plan office environments [7]. 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 [8].

Hence, the purpose of the present study is to test the effect of different acoustical environments on employee self-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 [9]. We also collected behavioural measures, in order to understand how the acoustical environment impacts on the employees.

1.1 Aims and hypotheses

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. The second and third measure of disturbances focused on disturbances from sounds from nearby and distant sources, respectively. Apart from the self-rated measures, we also used objective acoustical measures. The respondents' perception of the environment is followed over three time-points (T1, T2 and T3).

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. METHOD

2.1. Participating organization and employees

Two out of the six floors of an office building 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 furbished 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. Six individuals have been excluded from the sample for specific reasons not detailed here, which led to a final analytic sample size of 145 persons. 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). In total, around 40 individuals had a full set of data for T1, T2 and T3.

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. The employees were informed of the purpose of the study, but not of the details of modifications done to the environment.

The baseline survey was collected just before any manipulations were made to the office environment. Each manipulation resulted in one of two conditions: in the better condition, wall panels were set up and the pre-existing, highly sound absorbing ceiling tiles were maintained. In the worse condition, highly sound reflective ceiling tiles were installed, replacing 55% of the original absorbing tiles. Both types of tiles had similar colour and form and could not easily be distinguished from each other.

During the weekend after the baseline survey (T0) had been collected, changes were made on floor 4 to create the better condition and on floor 5 to create the worse condition. Two weeks after the first manipulations had been made, the first survey was sent out. The surveys were always sent out on Mondays. During the weekend after, floor 4 was changed to create the worse condition and vice versa. After two weeks of exposure to the new conditions, the second survey was sent out. The three weeks following after the second survey contained many national holidays. In order to ensure that most employees had been exposed to the sound environment for two full weeks, the third survey was sent out six weeks after the second survey had been completed (see Figure 1).

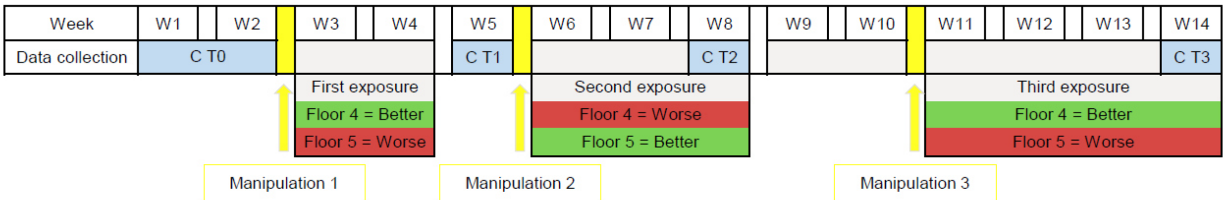

Figure 1: Illustrating the process of data collection. W1-W14 = Week 1 to week 14. CT0 to CT3 = Collection period for data at T0 to T3. Week 9-11 contained many national holidays which was handled by postponing the last manipulation and the last data collection (T3) so that everybody would be exposed to the last condition for at least two weeks before answering the survey. Each manipulation was made at the weekends following week 2, 5 and 10.

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 points 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) [10]. 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). Cronbach’s α for internal reliability from the first survey was 0.88, indicating satisfactory consistency.

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 to 7=daily). Cronbach's α for internal reliability from the first survey was 0.85, indicating satisfactory consistency. See Table 1 for a correlation matrix between the dependent variables at T0.

The covariates included in the model were age (continuous: ranging from 21 to 69), gender (0 = male, 1 = female), and educational level (dichotomized: 0 = low for those without an academic degree, 1 = high for those with an academic degree).

Table 1: Correlation between outcome variables at T0.

	Disruption in general	Cognitive stress	Nearby disturbances	Distant disturbances	Professional efficiency
Disruption in general	1	0.43[b]	0.76[b]	0.64[b]	-0.17
Cognitive stress		1	0.37[b]	0.35[b]	-0.35[b]
Nearby disturbances			1	0.58[b]	-0.22[a]
Distant disturbances				1	-0.16
Professional efficiency					1

[a] Correlation is significant at the 0.05 level (2-tailed)

[b] Correlation is significant at the 0.01 level (2-tailed)

2.4. Acoustic measurements

We included several acoustical measures in accordance with ISO 3382-3:2012 guidelines [9]. These are $D_{2,s}$, L_p,A,S,4 m, and radius of comfort (r_c). $D_{2,s}$ is a rate of spatial decay of A-weighted sound pressure level of speech per distance doubling. $D_{2,s}$ is therefore a measure of how fast the decibel level has been attenuated at a certain point from the sound source. L_p,A,S,4 m is a nominal A-weighted sound pressure level of normal speech at a distance of four meters from the sound source. In other words L_p,A,S,4 m shows how much normal speech sound has been attenuated at a distance of four meters from the sound source. Radius of comfort (r_c) is the distance from the sound source where the sound pressure level of speech meets 48 dBA, which is the targeted value of L_p,A,S,4 m according to ISO-3382-3:2012. These measurements were carried out for each condition in furnished rooms without staff along four measurement paths, two paths on each floor. In addition, dBA levels were recorded from four points by two microphones on each floor. See [12] for the full acoustical report. All objective acoustical data were gathered in order to confirm that the manipulations made to the physical environment had led to two distinguishable acoustical conditions on each floor.

2.5. Data analyses

Separate repeated analyses of covariance (ANCOVA) 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 test if the repeated manipulations to the different floors affected the outcome measures in the supposed direction. That is, the exposure for each floor either went from better to worse to better (floor 4), or from worse to better to worse (floor 5) which was hypothesised to yield approximately symmetrically different U-shape curves of the outcome variables for the two floors that significantly differed in their 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 2, 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. The figure also shows a trend that the dBA levels seem to increase from morning to late afternoon.

For the other objective measurements, please refer to Table 2. According to expectations, and as shown in Table 2, 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 [13]. Speech level is thereby spread longer.

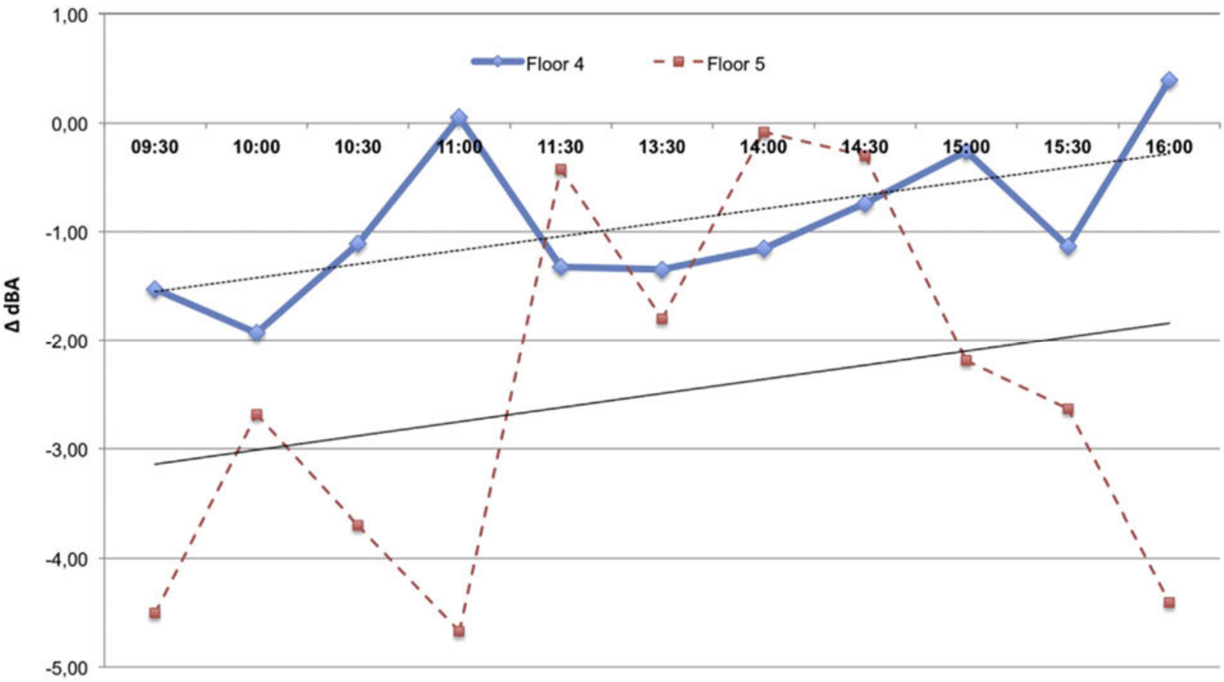

Figure 2: The sound pressure level (dBA) difference between the better and worse acoustical condition for the active parts of the working days and for each floor. The differential is an aggregated mean for the specified time intervals across the total duration of the study. Each line represents in general how much lower dBA levels were in the better condition as compared with the worse at different time-points throughout the working days. The negative scale suggests that the quiet acoustical condition was associated with lower dBA levels. The lower straight line shows the trend for floor 5 while the upper straight line shows the trend for floor 4.

The total mean for the active parts for floor 4 during the better condition was 46 dBA and 47 dBA for the worse condition. The total mean for the active parts for floor 5 during the better condition was 45 dBA and 47 dBA for the worse condition.

Table 2: Objective acoustic measurements on floor 4 and 5 for the different conditions.

Floor	Path	Time period	Description of the condition	D2,s [dB]	Lp,A,S,4 m [dB]	rc [m]
4	1	T0	Original condition (absorbing tiles)	4.9	48.2	4.5
		T1 & T3	Better condition (absorbing tiles and wall absorbers)	4.9	47.8	4.2
		T2	Worse condition (reflective tiles)	4	49	5.3
	2	T0	Original condition (absorbing tiles)	4.5	50.1	6.1
		T1 & T3	Better condition (absorbing tiles and wall absorbers)	4.9	49.3	5.2
		T2	Worse condition (reflective tiles)	3.6	50.2	6.8
5	1	T0	Original condition (absorbing tiles)	5	47	3.8
		T1 & T3	Worse condition (reflective tiles)	4.5	49.5	5.5
		T2	Better condition (absorbing tiles and wall absorbers)	5.3	46.7	3.7
	2	T0	Original condition (absorbing tiles)	6.6	48.1	4.3
		T1 & T3	Worse condition (reflective tiles)	6.8	50.2	5.3
		T2	Better condition (absorbing tiles and wall absorbers)	6.8	47.1	3.9

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.

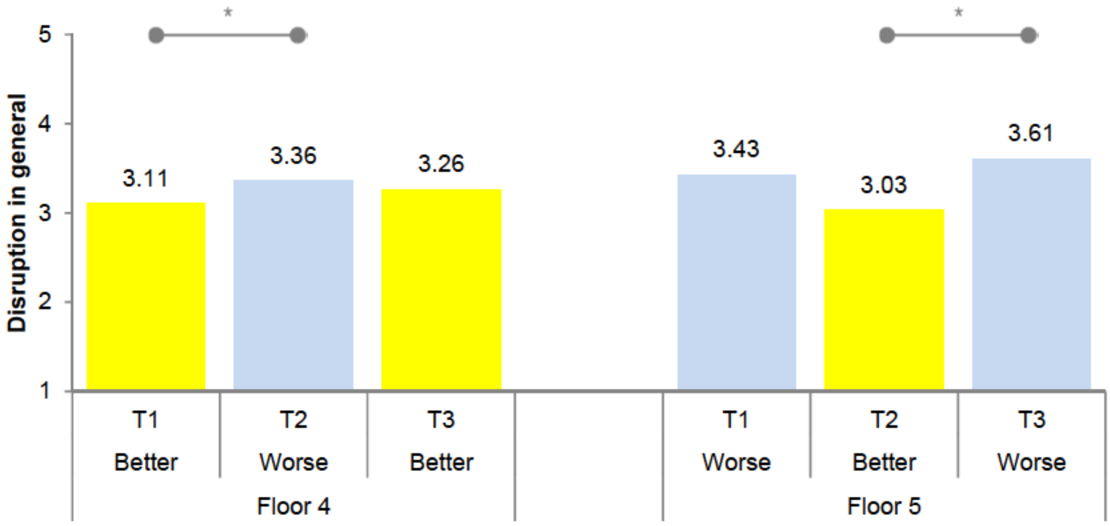

Figure 2a: Mean for Disruption in general at T1-T3 for floor 4 and floor 5.
The scale ranges from 1: "To a small extent" to 5: "To a great extent". "*" = $p < 0.05$.

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.

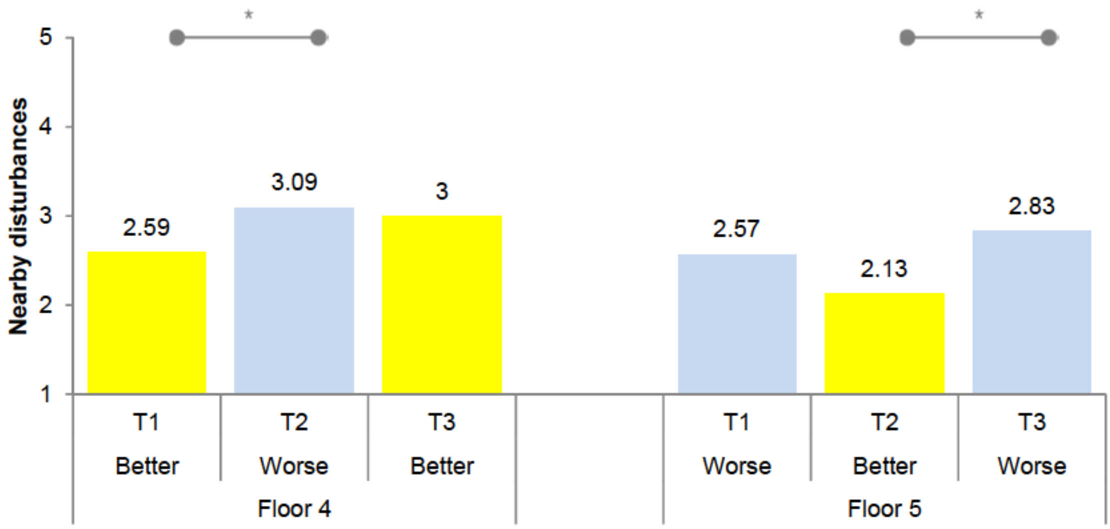

Figure 2b: Mean for Nearby disturbances at T1-T3 for floor 4 and floor 5.
The scale ranges from 1: "To a small extent" to 5: "To a great extent". "*" = $p < 0.05$.

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 $\eta^2 = 0.12$). As shown in Figure 2c, the manipulations on each floor yielded symmetrically different U-shaped curves for distant disruption - suggesting 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 $p < 0.05$; 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 ranges from 1: "To a small extent" to 5: "To a great extent". "*" = $p < 0.05$.

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 $\eta^2 = 0.16$). 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 $\eta^2 = 0.17$). 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 ranges from 1: “Never” to 5: “Always”. “*” = $p < 0.05$.

3.5. Professional 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.

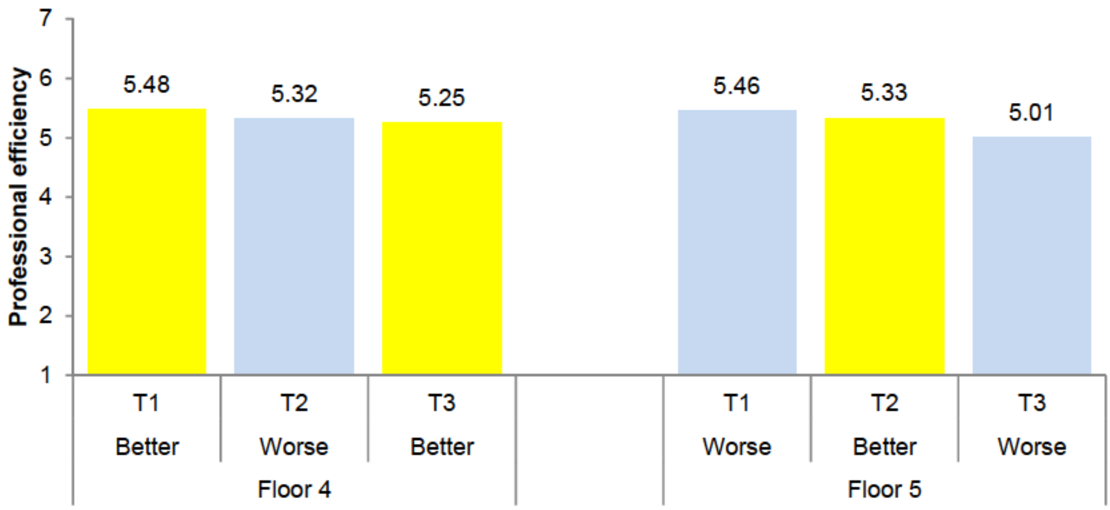

Figure 2e: Mean for Professional efficiency at T1-T3 for floor 4 and floor 5.
The scale ranges from 1: “Never” to 7: “Daily”.

4. DISCUSSION

This study investigated if better and worse acoustic environments, created by more or less absorption, affect employees' perception of disturbances, cognitive stress and professional efficacy.

In line with our expectations, the acoustical measures showed a lower overall noise level during the working day as well as lower $D_{2,S}$, $L_{p,A,S,4\,m}$, and r_c in conditions where sound absorbing tiles and wall panels had been installed. In addition, also supporting our expectations, the acoustical measures showed a higher overall noise level during the working day and higher values of above-mentioned parameters in the case where the more reflective tiles where installed and wall panels removed.

Our results are in line with previous studies [7] 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 [14], 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. Hence, the acoustical condition of the open-plan office seems to have a direct relationship to indicators of both health and performance of employees. This would suggest that even a minor improvement made to room acoustics could impact employees perceived health and disturbances.

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. However, the short exposure time might also explain why not all contrast analyses were significant, even if the effects went in the expected direction (i.e. better acoustics leading to less problems, for our measures of disturbances and health).

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 is its 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. In addition, we also gathered objective data. The objective measurements ensured that the manipulations we carried out had an impact on the acoustical environment and further strengthened our findings by corresponding to the survey responds. By so doing we were able to show that improvements in acoustics have a direct impact on measures of both health and disturbances.

A concern that could be raised as a limitation is the short exposure period for each condition before we collected the survey data. If people after some passage of time learn to adapt to an increased noise level then our findings might not be as relevant as they might suggest. However, a study by Banbury and Berry [15] could not find any lasting habituation to office noise, which speaks against any major adaptation to increased noise levels taking place among employees.

5. CONCLUSION

By means of a crossover design, we investigated the effect of two different room acoustics on employees' perception of disturbances, cognitive stress, and professional efficacy.

Although the acoustical measurements showed that the manipulations between our two conditions in general were quite small, the better acoustical condition nevertheless had a more positive effect on employees' perception of disturbances and cognitive stress. It was also shown that manipulations in the acoustical environment measured by measurements suggested in ISO 3382-3:2012 correspond well with employees' self-reported measures of health and disturbances. The study shows the importance of focusing on the acoustical conditions in open-plan offices in order to improve employees' health and well-being and through means of that also organizational efficiency.

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