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ACOUSTIC COMFORT, QUALITY AND ATMOSPHERE IN 'NON-ACOUSTIC' SPACES – CASE STUDIES IN RAILWAY STATIONS AND OPEN PLAN OFFICES

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Abstract
As part of a series of studies on acoustic comfort, quality and atmosphere in various building types, this paper presents case studies in railway stations and open plan offices, focusing on the relationship between the characteristics of sound fields and perceptions of acoustic comfort. Not only the importance of acoustic comfort, but also users' adaptation, has been revealed through the cases studies. Some conventional treatments, although effective in terms of acoustic indices, might not be preferred by the users. It seems that in such spaces the effect of demographic factors is insignificant in terms of acoustic evaluation.

INTRODUCTION

Whist the acoustic quality in 'acoustic spaces' such as concert halls and recording studios has been intensively examined, research on 'non-acoustic' buildings/spaces has been rather limited. Moreover, existing works concentrate on some basic technical indices; whereas little attention has been paid to the acoustic comfort, quality and atmosphere. Recently a series of studies have been carried out on this topic [1], considering various spaces including shopping mall atrium spaces [2], library reading rooms [3], football stadiums [4], swimming spaces [5], churches [6], dining spaces [7], railway stations [8], hospital dialysis centres [9], open plan offices [10], and halls of residence [11]. The studies consider characteristics of sound fields as well as perceptions of acoustic comfort. It has been demonstrated that the acoustic atmosphere is an important consideration in such spaces and the acoustic comfort may vary considerably with the same objective acoustic indices. The relationships between subjective and objective indices would be useful for developing guidelines for acoustic design of such 'non-acoustic' spaces. This paper presents case studies in railway stations and open plan offices.

RAILWAY STATIONS

Sound environment in railway stations is related to general comfort as well as the intelligibility of public address (PA) systems for daily travel information and emergency announcement. In this study, objective measurements and subjective surveys were carried out in two typical medium-sized UK railway stations, Sheffield and Derby, with 8 and 6 platforms respectively [8]. At platform level, the stations were semi-open rectangular spaces, with concrete/stone walls, steel supporting structures, and granite-paved floor. In total 179 questionnaires were handed out to travellers, 101 in Sheffield and 78 in Derby, and 28 to the station staff members, who had all worked in the stations for over 3 years. In the questionnaire three to five linear scales were generally used. In the following analysis the results are based on the average of the two stations considering both platforms and waiting rooms for the traveller group, except where indicated.

The temporal sound pressure level (SPL) distribution is shown in Figure 1a, based on LAeq of 15s with an interval of 3 minutes. It can be seen that the SPL fluctuated significantly, mainly due to trains and PA announcements, by about 20dBA, and the fluctuations usually happened in a very short period, say one minute. The patterns of SPL fluctuation were generally similar in waiting rooms and platforms, whereas in the first class lounge the SPL was the lowest and fluctuated the least. Due to the high background noise level, the announcements sometimes reached up to 80-85dBA. The measured reverberation times (RT) are shown in Figure 1b.

It is interesting to note that despite the high background noise, the clarity of announcement was generally acceptable, with a mean score of 3.49 on the platforms and 3.88 in the waiting rooms, where 1, cannot hear; 2, not clear; 3, average; 4, clear; 5, very clear. In the waiting rooms the scores were significantly ($p<0.01$) higher than those on the platforms. This was probably because in the former the SPL was about 3dBA lower, and the noise sources were people chatting rather than trains.

Although the reverberation time was not long, as shown in Figure 1b, the level of echoes seemed to be serious, as almost 80% of interviewees heard ‘some’ or ‘a lot of’ echoes. Although echoes might not have a serious impact on the subjective evaluation of announcement clarity in this case, it would probably contribute to acoustic discomfort, particularly for conversation.

The mean acoustic comfort score of the staff members was 3.46, significantly ($p<0.01$) higher than that of travellers, 3.07, where the five scales were: 1, very uncomfortable; 2, a little uncomfortable; 3, average; 4, comfortable; 5, very comfortable. 50% of the staff members regarded the acoustic environment as comfortable or very comfortable, whereas this figure was only 26% with travellers. On the other hand, it is noted that 54% of the staff members found the station noise contributed to their stress level comparing to the level of 40% for travellers. This was probably due to the staff members’ long-term exposure to noise. In a study by Barnes various noise stressors were applied to disturb the railway personnel [12].

In average female travellers were slightly more satisfied about the acoustic comfort than males, with the mean scores of 3.19 and 3.03 respectively, although the difference was not statistically significant due to the fact that females tended to choose extreme scales. With the increase of age, there was a slight increase in evaluation score, namely 2.95 for <20 group, 3.10 for 20-40 group, and 3.30 for >40 group, but this increase was again not statistically significant.

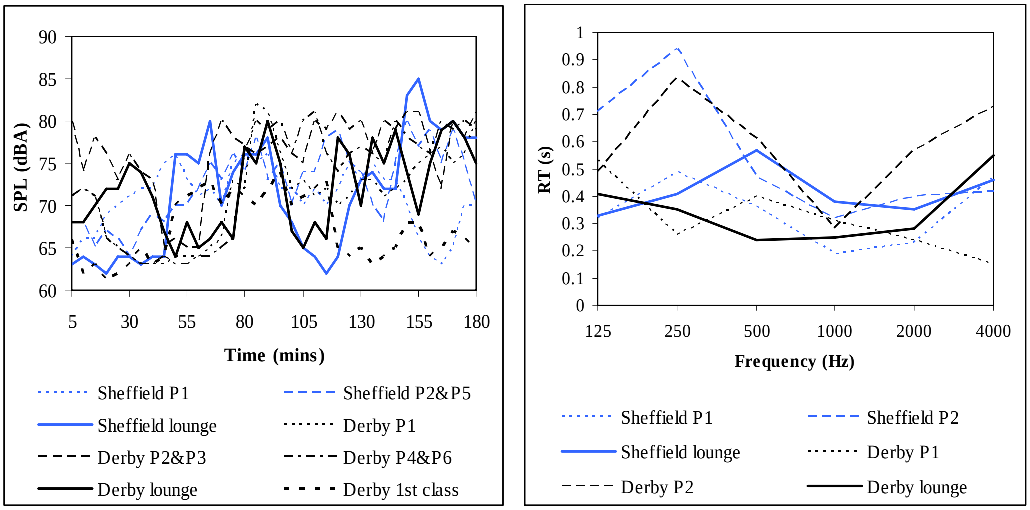
There was a significant correlation, with R^2=0.82, between acoustic comfort scores and the duration of stay, from less than 5 minutes to over 30 minutes, as shown in Figure 2a, suggesting that people felt acoustically uncomfortable as they stayed longer in the stations. There was also a significant correlation, with R^2=0.67, between acoustic comfort and the frequency of travel, ranging from everyday to less than 5 times a year, as shown in Figure 2b, suggesting that people who travelled less frequently tended to feel acoustically more uncomfortable. It is noted, however, although the above correlations were significant, the variation range in evaluation score was only within 0.4.

Figure 3a shows the relationship between the acoustic comfort evaluation and the measured SPL, based on the average in each waiting room and platform. The correlation was rather strong, with R^2=0.82, indicating that the acoustic comfort level became lower as SPL increased. Travelers in the first class lounge were the most satisfied, with a mean evaluation of 3.67, corresponding to its low SPL, 67dBA.

The disturbance of five typical sounds found in the stations was evaluated by travellers, with four scales: 1, very disturbing; 2, disturbing; 3, a little disturbing; 4, not disturbing. The SPL of those sounds ranged from 65 to 85dBA. The mean scores were: train, 2.55; announcement, 2.87; baby screaming, 3.02; mobile ringing, 3.18; people chatting, 3.54. It is noted that although train was on the top of the list, only 46% of the travellers found it disturbing or very disturbing. This could be explained by their high level of expectation for train noise, indicated in their comments in the questionnaires. For the similar reason, although the peak SPL of announcements was often 80-86dBA, higher than train noise, travellers regarded it as less disturbing. It is interesting to note that the evaluation of staff tended to be more extreme, especially for train noise, with a high percentage of ‘very disturbing’ or ‘not disturbing’.

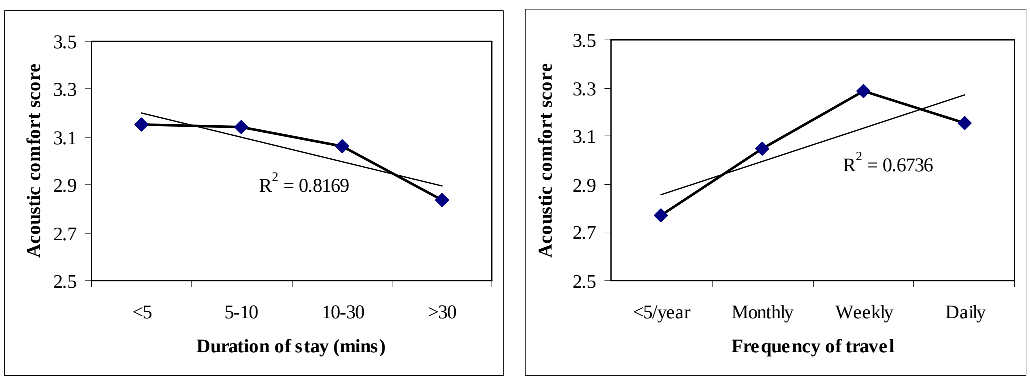
The disturbance level for various activities was evaluated, with three scales: 1, very disturbing; 2, disturbing; 3, not disturbing. The mean scores were: talking on mobile phone, 1.80; reading business documents, 2.22; listening to music, 2.30; reading magazine, 2.40. Clearly, as people raise their voice for better mobile phone communication, privacy level decreases and annoyance level increases. Whist 48% of the travellers found listening music was not disturbed, their comments actually suggested that they did not attempt to listen to music as the station was too noisy.

The importance of four environmental factors was compared, as shown in Figure 3b, where four scales were considered: 1, not important; 2, little important; 3, important; 4, very important. The four factors were all regarded as important, with air quality and thermal comfort as slightly more important than acoustics and lighting. In Figure 3b the results of travellers and staff members are also compared, suggesting that the two groups generally had similar evaluation, except that the staff group tended to think lighting was important. Many travellers indicated the importance of the aesthetics in the stations, suggesting the significance of considering aural/visual interactions. The correlation between the evaluation of acoustic comfort and general comfort in the stations was rather strong, with R^2=0.87.



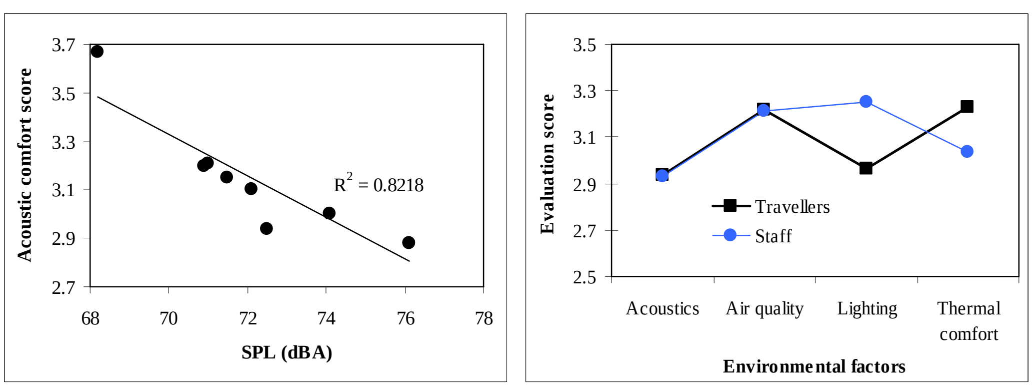
(a) (b)

Figure 1 – Measured SPL distribution (a), and reverberation time (b) in the two stations.



(a) (b)

Figure 2 – Correlation between acoustic comfort and duration (a) and travel frequency (b).



(a) (b)

Figure 3 – Correlation between comfort and SPL (a) and importance of various factors (b).

OPEN PLAN OFFICES

Attention has been paid to acoustics in open plan offices for a number of years, where there is a variety of noise sources: steady noise such as a continuous hum from ventilation systems or computers, intermittent noise such as conversations between staff, and impulsive noise such as telephones ringing. Whist individual office equipment is becoming quieter, for example, typewriters are disappearing, the number of noise sources is increasing. Research has been carried out for open plan offices in terms of sound field as well as perception [13-17]. Akiyama and Mouri [13] carried out a laboratory study to investigate the relationship between phones ringing and neurotic behaviour of human beings. It was suggested that noise had an effect on the build up of annoyance.

In our research, three open plan offices were studied, including the Mercury Taxi call centre in Sheffield, with 50 telephone operators working on a daily shift basis, where most of the operators were working around a U-shaped table; the NHS Primary Care Trust in Rotherham, mainly the financial and IT departments; and the architectural practice AEDAS in Manchester, with about 60-70 staff members who occupied three separate floors of a converted chamber building in the centre of the city of Manchester [10]. In Figure 4 the three offices are illustrated. They all rarely had full staff attendance in the office at any one time, due to sickness and meetings, for example. In the three offices the external noise level was all rather low.

The SPL was measured in the offices at several receiver points in a number of time periods, each typically 20 minutes, with a reading of A-weighted level every 5s. In Figure 5 the temporal SPL distribution is shown. In the Mercury Taxi call centre three different points were considered: Point 1, where the majority of office equipment was located; Point 2, where the call operators were working; and Point 3, 1m away from where the communicator was working. From Figure 5a it can be seen that the SPL in Mercury is rather high, often over 70dBA. Between day and night periods there was typically a 5dBA difference. In the NHS Primary Care Trust, a clear difference could be noticed between two measurement points: sitting closer to the main circulation space, namely at Point 1, had greater exposure to various kinds of office noise, whereas at Point 2, which was in a more enclosed area, the SPL was systematically lower, typically by about 10dBA. In AEDAS, at the two measurement points the SPL was not significantly different, and the SPL was relatively constant, but occasional peaks were recorded at about 70dBA which was caused by the door being opened and closed. In Mercury and NHS the door slamming noise was also causing high peaks. Overall, although the average SPL in the three offices differed, the ranges of variation were similar, with L90, L50 and L10 of 55.1, 61.5, 67.2dBA in Mercury, 47.3, 50.8, 56.7dBA in NHS, and 46.6, 50.5, 58.2dBA in AEDAS.

A questionnaire survey was conducted, and in total 105 people participated, 30 in Mercury, 38 in NHS, and 37 in AEDAS, of which 52 were males and 53 females. Over 90% of the participants stated that they worked for 6 hours or more per day in the office.

In terms of the subjective evaluation of sound level, the percentages of choosing various categories were: 1-very quiet, 1%; 2-quiet, 13.3%; 3-acceptable, 56.2%; 4-

noisy, 25.7%; 5-very noisy, 3.8%. The mean score was 3.47 in Mercury, 3.18 in NHS, and 2.95 in AEDAS, generally corresponding to the average SPL in the three offices: 60.9, 51.7, and 51.2dBA, respectively. This suggested that a noise level of around 51dBA might be generally at an 'acceptable' level for open plan offices. It is noted, however, that the standard deviation in the evaluation scores was 0.51 in Mercury, 0.83 in NHS and 0.74 in AEDAS, indicating that there was a considerable variation of people's opinion. A question was asked about preferred sound level at work. The percentages of choosing various scales were: deadly, 0%; quiet, 25%; acceptable, 70%; loud, 5%; very loud, 0% – it is very interesting to note that the percentage of people of preferring just 'acceptable' noise level, rather than 'quiet', was actually very high in such a working environment.

Table 1a compares the evaluation of various environmental factors, including temperature, lighting, humidity, comfort of own work space, degree of privacy, and overall working environment, where five scales were used: 1, unacceptable; 2, poor; 3, satisfactory; 4, good; 5, very good. It can be seen that the mean evaluation score was mainly around 3, namely at a satisfactory level, for various factors as well as for the overall environment, except for privacy, which had a mean score of 2.58, significantly ($p<0.001$) lower than that for other factors.

The annoyance level of six typical sounds in open plan offices was evaluated using five scales: 1, very disturbing; 2, disturbing; 3, acceptable; 4, noticeable; 5, hardly noticeable. The mean scores were: telephones ringing, 2.52; colleagues chatting, 2.80; office equipment, 3.89; keyboard typing, 4.08; noise from outside, 4.16; and ventilation, 4.21. It is interesting to note that telephones ringing and colleagues chatting were the two most annoying sounds, significantly different from the other sounds ($p<0.001$). It was also indicated by many interviewees that door slamming was a major noise source, although this was not included in the questionnaire.

In a related question regarding whether people were distracted by other people's conversation, the percentages of each category were: never, 2.7%; rarely, 25.3%; sometimes, 57.3%; often, 10.7%; frequently, 4.0%.

Further analysis showed that gender, age and the acoustic environment at home did not have significant effects on the acoustic evaluation in the office environment.

A number of possible treatments were evaluated in terms of their usefulness in reducing background noise in the offices, where five scales were used, with 1 being not useful and 5 very useful. The mean scores were: installing higher panels to separate work space, 1.99; work in a close cell workstation, 1.45; fitting in some natural features (e.g. fish tanks), 2.09; introducing natural background sounds (e.g. birds singing), 0.89; and better headsets (Mercury only), 2.76. It is important to note that these conventional treatments were generally not preferred by the users.

Table 1b shows the percentage of people who experienced work-related symptoms, including tinnitus (Mercury only), hypersensitivity to loud sounds, easily getting tired, and depression. It can be seen that a high percentage people, around 20-30%, had various symptoms. The percentage of tiredness was particularly high, with 67% people choosing sometimes/often/frequently. Acoustic environment might be a contributing factor on this, although further research is needed.

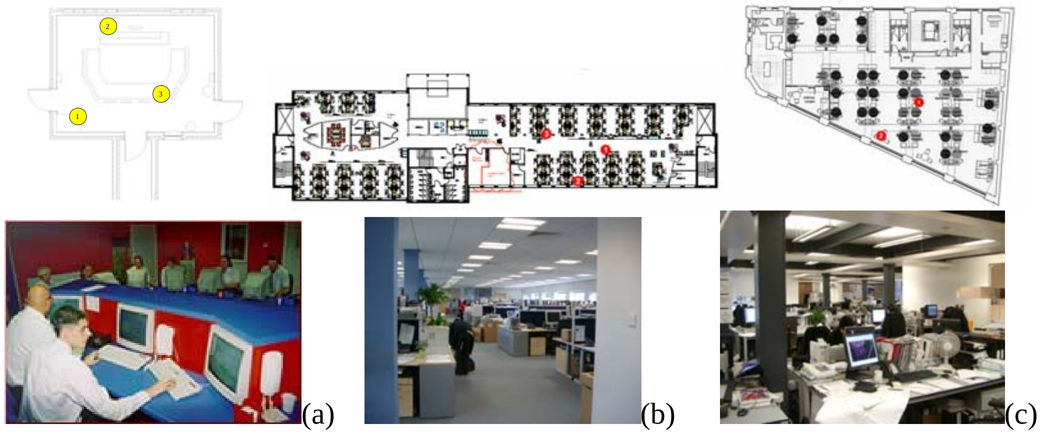


Figure 4 – Plan/photos of Mercury (a), NHS (b), & AEDAS (c), showing measurement points.

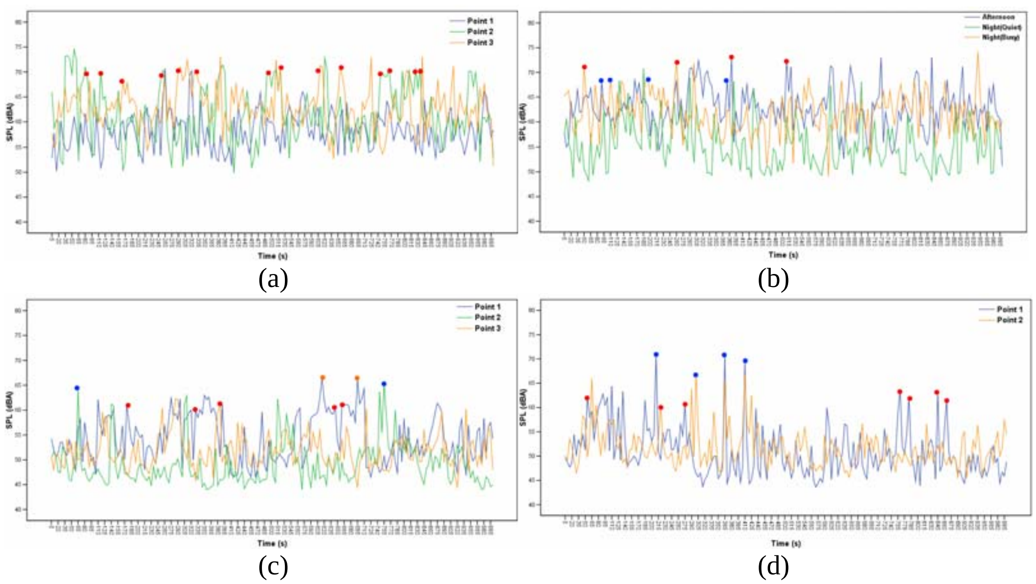


Figure 5 – Temporal SPL distribution. (a) Mercury – at three points in an afternoon period. Red dots: raised voice conversation. (b) Mercury – three time periods at point 3. Red dots: door slamming; blue dots: raised voice conversation. (c) NHS. Red dots: laser printer; blue dots: conversation. (d) AEDAS. Red dots: conversation; blue dots: door slamming.

	All		Mercury		NHS		AEDAS	
	Mean	STD	Mean	STD	Mean	STD	Mean	STD
Temperature	2.93	0.77	2.87	0.82	3.00	0.85	2.92	0.64
Lighting	3.29	0.85	2.83	0.75	3.58	0.72	3.35	0.79
Humidity	3.00	0.79	3.00	0.83	3.05	0.71	2.95	0.85
Work comfort	3.30	0.77	3.13	0.86	3.37	0.71	3.35	0.75
Privacy	2.58	0.70	2.87	0.63	2.45	0.60	2.49	0.80
Overall	3.36	0.72	3.50	0.73	3.34	0.75	3.27	0.69

(a)

	Symptoms			
	1	**2**	**3**	**4**
Never	59	53	12	41
Rarely	7	26	21	28
Sometimes	14	12	38	19
Often	10	4	15	5
Frequently	10	5	13	8

(b)

Table 1 – (a) Evaluation of environmental factors, and (b) possible work-related symptoms (%): 1, tinnitus (Mercury only); 2, hypersensitivity; 3, tiredness; 4, depression.

CONCLUSIONS

Not only the importance of acoustic comfort, but also users' adaptation, has been revealed through the cases studies. Some conventional treatments, although effective in terms of acoustic indices, might not be preferred by the users. It seems that in such spaces the effect of demographic factors is insignificant in terms of acoustic evaluation. It would be interesting to further examine possible effects of acoustic environment on work-related symptoms such as stress and tiredness.

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