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Sound Environment of Waiting Areas in Large General Hospitals in China

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Summary
Based on field measurements and questionnaire surveys, sound environment in 150 waiting areas in 15 large modern general hospitals in China has been analysed. It has been shown that most of the waiting areas are U-shaped, where the dominant frequency range is 250 Hz–4 kHz and the maximum SPL occurs at around 1 kHz. The average LAeq in the morning is greater than that in the afternoon, with a difference of 1–7 dBA. Patients and staff believe that speech sound is the dominant sound in the waiting areas. There are statistically significant associations among the physical environmental factors, and the sound environment and light environment are most closely correlated, evaluated by both patients and staff. The sound environment satisfaction is evaluated at 'neutral' level, lower than that of other physical environmental factors. The effects of social factors of patients and staff on the evaluation of sound environment are generally insignificant.

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1. Introduction

Noise pollution in modern hospitals is becoming an increasingly serious concern and has attracted wide attention in both research and practice. The results of a noise survey at Johns Hopkins Hospital in Baltimore showed that at all locations and all times of day, in terms of the equivalent continuous sound pressure level Leq, no location was in compliance with the current World Health Organization Guidelines [1]. In China, the concern about the sound environment is the rather prominent [2], also for large modern general hospitals. Large modern general hospitals, which are supposed to receive patients with severe or dangerous diseases or those who are suffering from complicated or refractory diseases, also attract many patients with common diseases or frequently-occurring diseases. These hospitals used to have a large inpatient department, but in the past ten years the ratio of the outpatient department (including the clinics and medical and technical departments) to the inpatient department has become 2:1 [3]. Consequently, many problems have occurred. For example, ambient air quality can be relatively poor [4], and it is not easy to find the right clinic as they are scattered. A survey has shown that most people believe that noise is the most uncomfortable factor in the hospital environment [5], which could affect patients and staff both physically and psychologically [6, 7, 8, 9, 10, 11, 12, 13], in terms of stress, tiredness [9], and blood pressure [10], for example. Noise could also reduce the work efficiency of doctors and nurses [11].

Waiting areas make up a large proportion of the hospital outpatient space, and it has been shown that the average A- weighted Leq, LAeq, of waiting areas for the day time could be greater than 66 dBA, which is higher than that of other areas such as the entrance halls, registration halls, and staircases [14]. Figure 1 shows a crowded waiting area in a typical large general hospital. According to the Ministry of Health in China, in 2005 the number of patients of Chinese general hospitals had reached 1.058 billion, and meanwhile, the outpatient departments of the large hospitals are expanding rapidly [15]. Even if the average waiting time for outpatient departments is not long, acoustic comfort is important, in terms of general quality of a hospital.

The aim of this study is therefore to systematically examine the sound environment of waiting areas in large modern general hospitals in China. This paper first presents the methodology used in this study, including the selection of case study sites, the classification of waiting areas, the questionnaire design, and the measurement methods. Then the acoustic measurement and subjective survey results, considering both patients and staff, are discussed. The research contents include the sound source type, the variation of noise with frequency and over time, sound identification, sound preference and physical environmental factors evaluation, and the impact of social/demographical, behavioural, and subjective factors on the evaluation of the sound environment.

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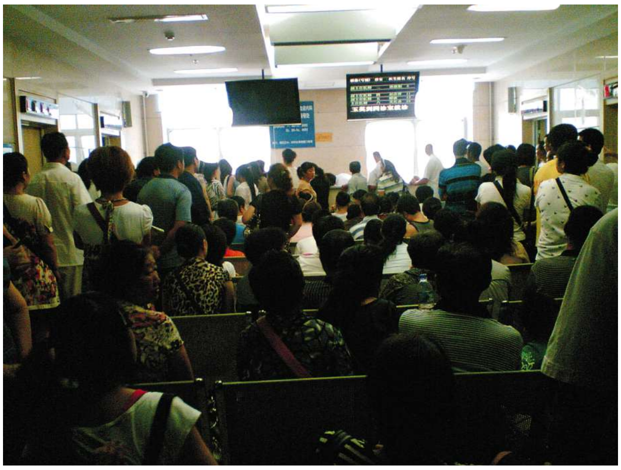

Figure 1. A crowded waiting area in a typical large modern general hospital in China.

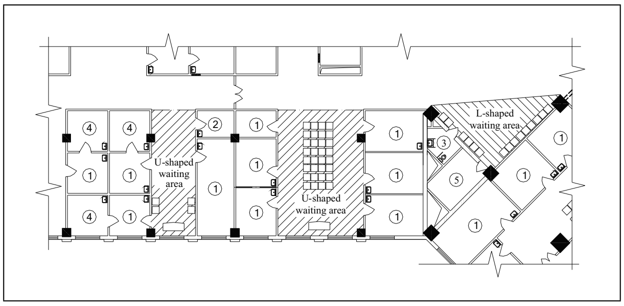

Figure 2. Plan view for U-shaped and L-shaped waiting areas of the main study hospital, where '1' represents clinic, '2' represents staff room, '3' represents public restroom, '4' represents examination room, and '5' represents smoking room.

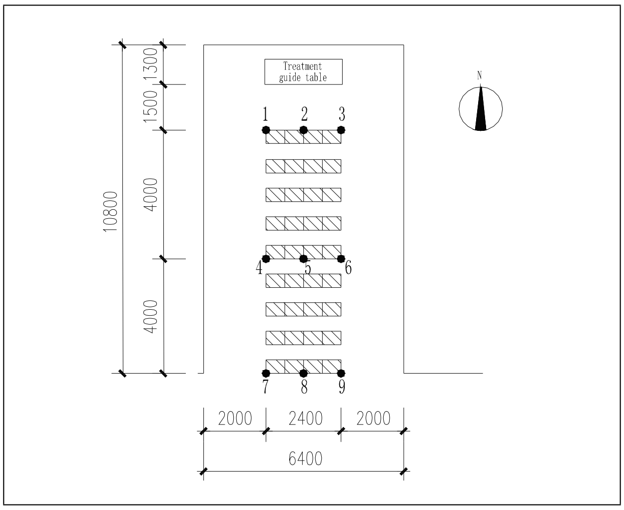

Figure 3. Measurement points (shown in dark dots) in a U-shaped waiting area.

2. Methodology

2.1. Main case study site

Considering various factors including the typicality and feasibility of measurement, a number of waiting areas in an outpatient building of a hospital in Harbin, China (the hospital will be called the main study hospital below) were chosen for case study. The building, which was opened in July 2007, had the largest floor areas, the widest range of functions and the most advanced facilities in Northeast China [16].

It has been found that there are three types of waiting area according to their plan shape. As can be seen in Figure 2, the first type is U-shaped, where three sides are enclosed and one side is open. It is usually located among the clinics, adjoining to some public areas such as halls or corridors [17, 18]. The second type is L-shaped (see Figure 2), where two sides are enclosed and the other two sides are open. This type of waiting areas is usually located in a large corner, adjoining to a hall or corridor. The advantage of this type is that the hospital space can be used effectively, but they are often far away from the clinics and there are many passers-by. The third type is the corridor type, where the waiting patients occupy part of the traffic corridor and the privacy is poor due to the special features of the sound field [19, 20, 21, 22, 23]. Therefore, usually this type is not adopted in large modern general hospitals, and if it is adopted, it is only used as a secondary waiting area. Considering the typicality of the study, this study focuses on the U-shaped waiting areas. In the studied outpatient building this type takes about 80% of the total waiting areas and is distributed on floors 1–5.

2.2. Acoustic measurements

The acoustic measurements were carried out in the main study hospital from February 2009 to May 2011, where no measurement was made on holidays or festive days in order to maintain the typicality. The primary measurement times were 9:00–11:00 and 13:00–15:00 because the patients mostly saw doctors in these two time periods. BSWA801 sound level meters were used in the measurements. The equivalent continuous A-weighted sound pressure level LAeq was used to assess the noise [24, 25]. Since the sound environment in waiting areas remained relatively stable at 10 s intervals based on pilot investigations, the data were read at an interval of 10s during the tests, and at every point measurement was made for at least 3 minutes continuously. The presented noise level is the average of LAeq of all measurement points in a waiting area. The measurement points were uniformly distributed in the seating part of the waiting areas. It was ensured that all measurement points were at least one meter away from any wall or other reflective surfaces. The receiver height was 1.2–1.5 m above the floor. Figure 3 shows a typical layout plan with 9 measurement points in a U-shaped waiting area. Measurement results of four typical waiting areas are presented in this paper, given that the characteristics of a given type of waiting area are rather similar.

2.3. Questionnaire survey

In order to examine the subjective perception of patients and staff of the sound environment of waiting areas, two types of questionnaire, one for staff and the other for

Table I. Standard deviations of SPL (dB) at different frequencies in waiting areas.

Frequency [Hz]	63	125	250	500	1k	2k	4k	8k	Avg.
Cardiology	1.51	1.32	2.38	2.58	1.67	1.09	1.12	1.52	1.65
Ultrasonic diagnosis	1.08	0.85	0.76	0.63	1.12	0.60	1.22	1.37	0.95

patients, were designed. Before the formal investigation, tests of reliability and validity of the questionnaire were carried out based on detailed statistical analysis to ensure that the final questionnaire was appropriate.

The survey was carried out from February 2009 to February 2011. In total, 580 questionnaires were distributed in 150 waiting areas of 15 large modern general hospitals in Heilongjiang Province, one of the three provinces in Northeast China. Among the 580 questionnaires, 511 were received and valid. The questionnaire consists of the following parts:

1. The basic information and social/demographical factors of patients and staff, including gender, education, age and occupation [26].
2. The evaluation of the sound environment.
3. The evaluation of other physical environmental factors such as light environment, temperature, humidity, and smell, so as to examine the relationships among various environmental factors comprehensively, which has been proved to be important based on previous studies of different space types [27, 28, 29, 30, 31, 32, 33].

3. Results

3.1. Frequency spectra and SPL variation with time

Taking the waiting areas of cardiology and ultrasonic diagnosis departments as examples, the frequency spectra are shown in Figure 4a and b, respectively. The average number of people in each of the two waiting areas was about 10 when the measurements were carried out in the afternoon. It can be seen that the dominant frequencies are at 250 Hz–4 kHz, which is the main frequency range of the human voice. The maximum SPL of each curve in Figure 4 is above 55 dB, at about 1 kHz. The average difference between the C-weighted and A-weighted SPL is 3.3 dB in the waiting area of cardiology and 3.5 dB in the waiting area of ultrasonic diagnosis. This suggests that the low frequency sound takes a certain proportion of the total sound energy.

The SPL variation at each frequency is shown in Table I. It can be seen that they are generally rather small, within about 1–2 dB. The average value of standard deviation of SPL at different frequencies is 1.65 dB in the waiting area of cardiology and 0.95 dB in the waiting area of ultrasonic diagnosis.

Figure 5 compares the measured frequency spectra with NR40, as mentioned in British Health Technical Memorandum 2045 [34, 35], although it is noted that NR is mainly for general background noise. In Figure 5 four waiting areas are considered, including (1) otolaryngology, (2) gynecology, (3) general surgery, cardiovascular surgery and chest surgery, and (4) orthopedic surgery and pediatric surgery. The average number of people in each of the four waiting areas was about 40, the central seats were all occupied and a few people were standing beside the seats when the measurement was carried out. It is in-

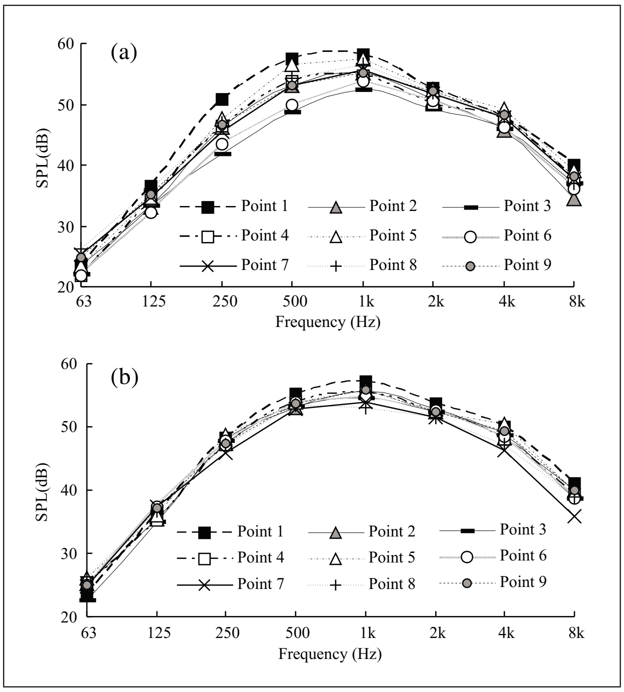

Figure 4. The frequency spectra measured at different measurement points in the waiting areas in the afternoon. (a) Cardiology; (b) Ultrasonic diagnosis.

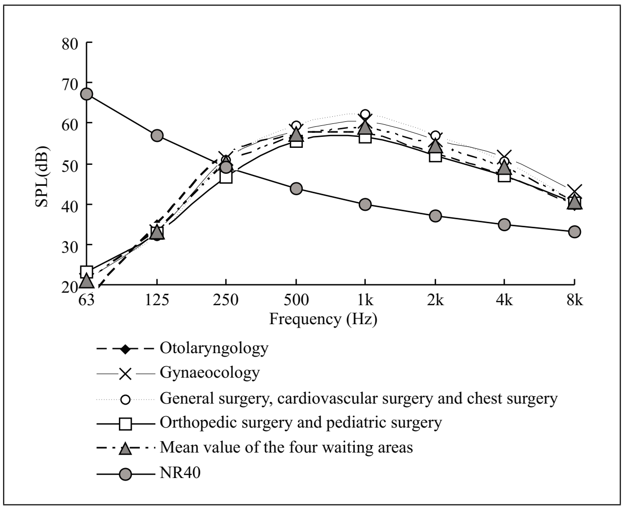

Figure 5. The frequency spectra in the four waiting areas, compared with NR40.

Table II. Main sources of sound heard by patients and staff.

Sound type	Sounds
Sounds from people	Talking voices, hubbub, cries, crying and screaming, broadcast sound, footsteps, running steps, slap, horns outside hospitals, vendors' cries.
Sounds from instruments, equipment, vehicles	Electronic number calling system, mobile phone ringtones, elevator noise, air conditioning noise, printing noise, trolley noise, vehicle horns produced outside hospitals, ambulance siren sound.
Other sounds	Gurgling sounds in public toilets, sound of wind, sound of rain, twitter.

teresting to note in Figure 5 that SPL is greater than NR40 from about 250 Hz, which is the frequency range relating to speech intelligibility and privacy [36, 37, 38, 39]. It is also noted that while the talking voices among the waiting patients were the main noise components of the waiting areas, the spectrum may not be the same as that of the normal speech. A number of sounds, including computer simulated young female voice from electronic number calling system, nurses shouting voices to keep order and to inform a patient to see a doctor (all the nurses in the waiting areas were female), crying and screaming of children and some adults, all have considerable high frequency components. The SPL above 4 kHz in the waiting area of gynecology is generally higher than those in the other three waiting areas, possibly because most of the people in the waiting area of gynecology were women, with higher SPL at high frequency ranges [40].

Figure 6 shows LAeq variation over time, considering two time periods, in the morning and afternoon of the same day, respectively. The average number of the waiting people in the waiting area of otolaryngology was about 60 in the morning and 20 in the afternoon, and those numbers were 26 and 18 respectively in the waiting area for general surgery, cardiovascular surgery and chest surgery. It can be seen that the LAeq in the morning was higher than that in the afternoon, by 6.8 dBA in the waiting area of otolaryngology, and by 1.9 dBA in the waiting area of general surgery, cardiovascular surgery and chest surgery. The fluctuations in the curves in Figure 6 were mainly caused by the electronic number calling system. Generally speaking, the noise level for a U-shaped waiting area of any clinic with about 40 waiting people was in the range of 64–73 dBA.

3.2. Sound sources and sound preference

The main sources of sound heard by patients and staff are shown in Table II. It can be seen that the sound environment was dominated by sound sources inside the waiting areas, whereas external noise sources or the sounds from other nearby areas were not dominant.

Questions about sounds heard and sound preference were asked. The results showed that the main sounds that the patients and staff heard were talking voices, footsteps, electronic number calling system, mobile phone ringtones, and hubbub. The proportion of patients and staff who heard these sounds is shown in Figure 7. The top sounds heard by

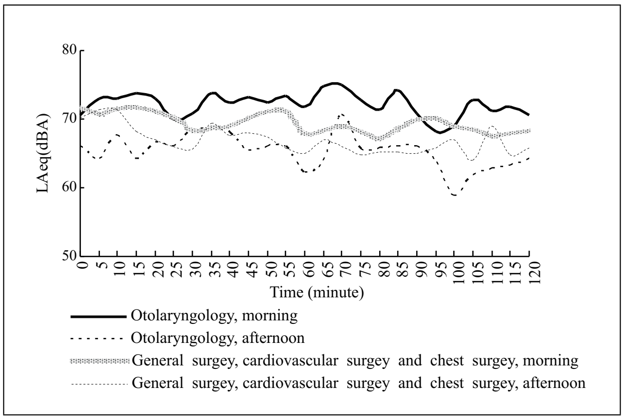

Figure 6. LAeq variation over time.

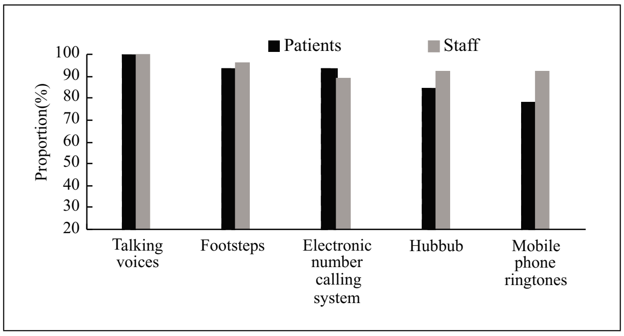

Figure 7. The proportion of patients and staff hearing the main sources of sound in waiting areas.

patients were talking voices, footsteps, electronic number calling system, hubbub and mobile phone ringtones. As for staff, the top sounds heard were talking voices, footsteps, hubbub, mobile phone ringtones and the electronic number calling system. It can be seen that the main sounds heard by people were the sounds related to speech, suggesting that the objective measurement results were consistent with what people subjectively felt.

The average values and standard deviations of sound preference of patients and staff are shown in Table III, where five categories were used, namely: 0, not heard; 1, dislike very much; 2, dislike; 3, neutral; 4, like; 5, like very much. The principal component analysis results are shown in Figure 8, as well as in Table IV and Table V, aiming at finding what sound sources were more important and how they related to one another.

Table III. Average values and standard deviations of sound preference of patients and staff. Calling system: Electronic number calling system; Mobile phone: Mobile phone ringtones.

	Talking voices		Footsteps		Calling system		Hubbub		Mobile phone		
	Avg.	std	Avg.	std	Avg.	std	Avg.	std	Avg.	std	Avg.
Patients	2.56	0.76	2.87	0.57	3.40	0.97	2.26	0.81	2.68	0.85	2.75
Staff	1.89	1.09	2.42	1.06	3.00	1.29	1.40	0.76	1.84	0.88	2.11

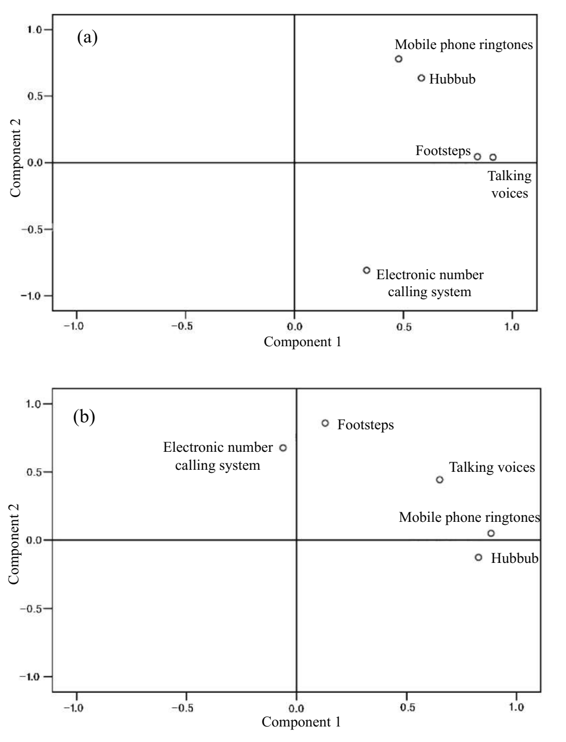

Figure 8. Principal component analysis of the main sounds, by staff and patients. (a) Staff; (b) Patients.

From Table III it can be seen that the average evaluation value of staff on the five types of sound is 2.11, a number between 'dislike' and 'neutral'. The preference rating of staff for each type of sound is not more than 3 (i.e. 'neutral'). They disliked the hubbub and mobile phone ringtones more than the other three types of sound. Also, as can be seen in Figure 8a and Table IV, the five types of sound can be approximately classified into two groups, one including footsteps, talking voices and electronic number calling system, and the other including mobile phone ringtones and hubbub. A possible reason for disliking ringtones of mobile phones was that they did not appear regularly, so that the sudden appearance would surprise staff. The hubbub made the normal conversations more difficult so that staff would need to speak more loudly [41].

As shown in Table III, the average evaluation value of the patients on the five types of sound is 2.75, also a number between 'dislike' and 'neutral', but the number is higher than that of staff. This is perhaps because patients stay in the waiting area for a relatively shorter time compared with staff and most patients concentrate on seeing the doctor. Also, as can be seen in Figure 8b and Table V, the five types of sound can be classified into two groups, one including footsteps and electronic number calling system, and the other including mobile phone ringtones, hubbub and talking voices. Similar to the results of staff, patients also disliked the hubbub most.

It is interesting to note that both patients and staff regarded the electronic number calling system as the most acceptable sound. The ratings for patients and staff are

Table IV. The rotated component matrix of the factor analysis of sound preferences by staff. Rotation method: Varimax with Kaiser normalization.

Sound type	Component 1	Component 2
Footsteps	0.822	0.227
Talking voices	0.821	0.251
Electronic number calling	0.650	-0.474
Mobile phone ringtones	0.079	0.796
Hubbub	0.171	0.724

Table V. The rotated component matrix of the factor analysis of sound preferences by patients. Rotation method: Varimax with Kaiser normalization.

Sound type	Component 1	Component 2
Mobile phone ringtones	0.884	0.051
Hubbub	0.827	-0.126
Talking voices	0.651	0.443
Footsteps	0.130	0.859
Electronic number calling	-0.062	0.677

Table VI. The rotated component matrix of the factor analysis of environmental factors' satisfaction evaluation by patients. Rotation method: Varimax with Kaiser normalization.

Sound type	Component 1	Component 2
Smell	0.831	0.127
Humidity	0.696	0.351
Temperature	0.681	0.013
Light environment	0.027	0.863
Sound environment	0.251	0.772

Table VII. Correlation coefficients between sound environment and other environmental factors, where the significance levels (2-tailed) are also shown (** indicates p<0.01 and * indicate p<0.05).

Environmental factors	Light environment	Temperature	Humidity	Smell	Overall environment
Patients' satisfaction evaluation	0.473 (**)	0.410 (**)	0.246 (*)	0.463 (**)	0.636 (**)
Staff's satisfaction evaluation	0.581 (**)	0.513 (**)	0.470 (**)	0.509 (**)	0.667 (**)

Table VIII. Average values of sound environment evaluation by patients and staff.

Environmental factors	Sound environment	Light environment	Temperature	Humidity	Smell	Overall environment
Patients' evaluation	3.16	3.41	3.38	3.31	3.28	3.50
Staff's evaluation	2.74	3.26	3.41	3.37	2.96	3.22

'neutral' and close to 'like', respectively, and this is the only sound that is slightly liked by the patients.

3.3. Evaluation of sound environment and other environmental factors

Various physical environmental factors of the waiting areas were evaluated, including sound environment, light environment, temperature, humidity, smell and the overall environment. Table VI and Figure 9 show the principal component analysis of the evaluation by patients, and the correlation coefficients between various environmental factors are shown in Table VII, where the scales used are: 1, very uncomfortable; 2, uncomfortable; 3, neutral, 4, comfortable; 5, very comfortable. In this paper, the '*' and '**' indicate that certain factors are statistically significant at either the 5% or 1% level, respectively. In Table XIII are shown the average values of sound environment evaluation by patients and staff.

It can be seen in Table VIII that the average evaluation value of the patients on the overall environment is 3.5, which is between 'neutral' and 'comfortable'. These two categories were selected by 43.8% and 53.1% of the patients, respectively. The average evaluation value by patients on each of environmental factors is greater than 3, between 'neutral' and 'comfortable', with a total percentage of over 80%, whereas the average evaluation value of the patients for the sound environment is 3.16, lower than all other factors.

The results in Table VII indicate that all environmental factors are significantly correlated. Two principal components can be abstracted from the corresponding principal component analysis, as shown in Table VI and Figure 9. The light environment and the sound environment belong to the same principal component and they are related to each other most closely. This corresponds to previous results in urban open public spaces [28, 29].

It can be seen in Table VIII that the average evaluation value of staff on the overall environment is 3.22, where 55.6% of them selected 'neutral' and 18.5% selected 'comfortable'. The average evaluation value for each environmental factor, except the sound environment, is greater than, or approximately equal to 3. The average evaluation value for the sound environment is 2.74, where 37% of them selected 'neutral' and 22.2% selected 'uncomfortable'.

As shown in Table VII, in terms of the evaluation of staff, all environmental factors are significantly correlated. Table IX shows the principal component analysis of the evaluation by staff. It can be seen that there is only one principal component, and all environmental factors are distributed in the component.

Table IX. The rotated component matrix of the factor analysis of environmental factors' satisfaction evaluation by staff.

	Component 1
Humidity	0.924
Temperature	0.914
Light environment	0.876
Smell	0.799
Sound environment	0.622

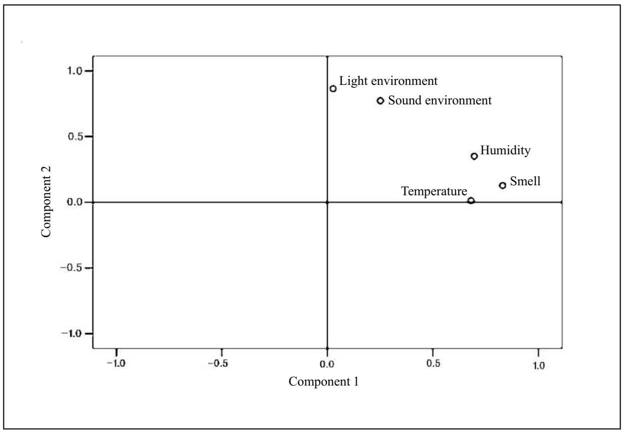

Figure 9. Principal component analysis of the evaluation of environmental factors, by patients.

3.4. Effects of social/demographical, behavioural and subjective factors on the sound environment

The results of patients show that their social/demographical characteristics including gender, age, occupation, and education are not significantly related to their evaluation of sound environment. The following three factors are significantly related to the satisfaction regarding the sound environment: 'How long have you stayed in the hospital all together', 'How long have you stayed in the waiting area' and 'How much does the noise in the hospital affect you', and correlation coefficients are −0.476(**), −0.361(*) and 0.431(*), respectively. Based on the questionnaire survey results, it can be derived that the average hospital stay time of the patients is about 2.7 hours, and the average waiting area stay time is about 1 hour. The average evaluation value for 'How much does the noise in the hospital affect you' is 3.66, where the scales are: 1, extremely; 2, greatly; 3, fairly; 4, somewhat; 5, not at all.

As for staff, their social/demographical factors are also not significantly related to their evaluation of sound environment. Two items of the subjective evaluation – 'How much does the noise in the hospital affect you' and 'Can you hear echoes when you work at your own position' – are significantly related to the subjective evaluation of sound environment, with correlation coefficients of 0.406(*) and 0.382(*), respectively. The average evaluation value for 'How much does the noise in the hospital affect you' is 2.85, which is similar to that of the patients; and the average evaluation value on 'Can you hear echoes when you work at your own position' is 2.96, where the scales are: 1, very unclear; 2, unclear; 3, neutral; 4, clear; 5, very clear.

4. Conclusions

Through a series of survey of sound environment in the waiting areas of large modern general hospitals in China, it has been shown that: The noise sources of waiting areas, dominantly U-shaped, is mainly distributed in the range of 250 Hz–4 kHz, and the maximum SPL occurs at around 1 kHz; The average noise level in the morning is greater than that in the afternoon, and the difference is in the range of 1–7 dBA; The main sounds heard in the waiting area include talking voices, footsteps, hubbub, electronic number calling system and mobile phone ringtones; The speech-related sound sources are the main noise sources, for both patients and staff, and for both groups, the number calling voice is most acceptable, and mobile phone ringtones and hubbub are most unwanted. The evaluation of patients and staff on the overall environment is generally at the level of 'neutral', although the evaluation of the patients is slightly better than that of staff. All environmental factors are significantly correlated in terms of subjective evaluation. The sound environment is most closely related to the light environment. According to both patients and staff, the sound environment is the worst of all environmental factors. The social/demographical factors including gender, age, occupation, and education of patients and staff, do not have significant effects on the evaluation of the sound environment. For patients, the length of stay in hospital or waiting areas significantly affects their satisfaction towards the sound environment. For staff, the perception of echoes in waiting areas significantly affects their evaluation of the sound environment.

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