Acoustic environment of comprehensive activity spaces in nursing homes: A case study in Harbin, China

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Abstract
Nursing homes are places where the elderly conduct their daily activities, and frequent gatherings of nursing home residents may lead to a complicated acoustic environment in which elderly people may have declining ability to function. This study explores the acoustic environment of an activity hall in a nursing home in Harbin, China and assesses the elderly residents' perception of and preference towards sounds by using site observation, sound measurements, and a questionnaire. The results showed that the elderly evaluated the activity hall's acoustic environment as poor. When the reverberation time in the hall exceeded four seconds or the sound pressure level exceeded 65 dB(A), their subjective evaluation of the comfort of the acoustic environment declined. Overall, the participants evaluated background and foreground music positively, liked to participate in music-related activities, were not bothered by mechanical sounds, and disliked speech sounds. They preferred (near-) silent activities, while the evaluation of activities with low-dB(A) and high-dB(A) depended on the degree of participation and personal preference. During activities in the activity hall, participators' acoustic evaluation was generally more positive than that of the onlookers, and music-related activity sounds (singing and dancing) were perceived as more comfortable than vocal activity sounds (playing chess and cards). The results also show that the acoustic environment evaluation is associated with social background factors. This study may help improve the elderly's quality of life in nursing homes by providing a reference for the construction and design of elderly facilities.
Keywords: acoustic environment; activity space; nursing home; acoustic evaluation

1 *Introduction*

With the aging of the world's population, research related to the living environment of the elderly has attracted much attention. One particular aspect of the living environment, the acoustic environment, is especially relevant, since it influences resident's experience and places such as residential care facilities, nursing homes, or hospitals are often occupied by fragile groups: people with disabilities or the elderly(Aletta et al., 2017). The acoustic environment can seriously affect the health of the elderly (Peris and Fenech, 2020; Devos et al., 2019; Xie et al., 2020). Too much harmful noise may harm their health; in particular, it may prevent elderly people with hearing loss in nursing facilities from functioning properly(Wang and Kang, 2020). Some studies have pointed out that long-term exposure to sounds above 65 dB(A) can cause serious health problems, such as sleep disorders, hearing loss, tinnitus, hypertension, and cardiovascular disease (Kerns et al.,2018; Janus et al., 2020).

According to Du(Du, 2020)the elderly have a higher tolerance for sound compared to younger people, but they are also more sensitive to it, since it can interfere with speech communication. Little research has been conducted on the effects of sound on the elderly in indoor environments, as most studies focus on landscape design, architectural layout, and music-related buildings(Sharaf, 2014).

Schafer has pointed out that traditional acoustic environment research is designed to work toward eliminating noise, and proposed the concept of the 'soundscape', which can instead emphasise the collection and planning of sound (Schafer, 1993; Brown et al., 2011). It has been shown that human behaviour and perception can be influenced by sounds and soundscapes in cities (Meng and Kang, 2016) and acoustic comfort can reflect individual evaluations of sound and soundscape (Vardaxis et al., 2018). Evaluation of acoustic comfort may be affected by income, education, and occupation, but not by gender or age (Meng and Kang, 2013). Acoustic comfort has a great impact on the elderly, and is an important factor that should be considered when designing nursing homes.

Acoustic comfort can be defined as the presence of opportunities for acoustic activities that do not annoy others, while undesired sound is absent (Thomas et al., 2020; Xiao and Aletta, 2016). In the literature, sounds typically have been divided into indoor- and outdoor-generated sounds. Typical indoor sound sources include fan noise, music, tv, and communication between people (Torresin et al., 2020). Sound sources are an important factor in sound comfort (Guski, 1997; Lercher and Schulte-Fortkamp, 2003). Tamura found that the majority of people surveyed liked natural sounds such as running water, rain, and birdsong and almost half disliked mechanical sounds the most (Tamura, 1998). When mechanical sounds are predominant, one's degree of relaxation becomes smaller, resulting in reduced acoustic comfort(Yang and Kang, 2005a). Yang and Kang also stated that in the same environment, women's acoustic comfort and sound sensitivity levels are higher than men's (Yang and Kang, 2005b) . Kang further investigated the evaluation of age on acoustic comfort and found that older people prefer the sound of birdsong (Kang, 2006).

While various sound sources impact acoustic comfort, the sounds of interpersonal communication and human activities are considered the main factors that affect an indoor acoustic environment(Wu et al., 2020; Peng et al., 2018). Some scholars have investigated the impact of the acoustic environment on people's perceptions and behaviours, and discovered various negative impact of sounds in indoor spaces, for example, difficulties in speech communication, psychological problems such as lowered self-esteem and loneliness, and health problems (Janus et al., 2020). In many studies, acoustic comfort is measured by objective room acoustic parameters, such as sound pressure level (SPL) (Iachini et al., 2012). In addition, a series of studies measured the direct improvement of acoustic comfort and the reduction of noise annoyance (related to corresponding reduction in SPL) (Yang and Kang, 2005b). Although it has been found that acoustic comfort is related to SPL, reducing SPL alone may not be enough to improve acoustic comfort in urban areas. Acoustic comfort seems to be determined by more factors than just the sound level; for example, the type of sound also has an impact (Cheng and Kang, 2017; Wu et al., 2020). A number of acoustic comfort levels in nursing homes have also been analysed and measured using SPL, and it was found that reducing noise levels can make residents more relaxed and less agitated (Thomas et al., 2018; Aletta et al., 2018).

China's nursing homes typically contain a comprehensive activity hall to provide a space for residents'leisure activities (Chu and Chi, 2008; Wu et al., 2012). With elderly people's increase in activities and the purchase of new activity equipment in nursing homes (Chu and Chi, 2008) sound types have also increased, resulting in more complex acoustic environments. This can cause residents to feel discomfort in a noisy environment or an environment in which there is poor communication (Büchler et al., 2005). Joosse found that staff voices are also an important factor that affects the acoustic environment of nursing homes (Joosse, 2011). SPLs generated by conversations between staff are even higher than those of conversations between residents themselves or with staff. Although noise generated by mechanical equipment, such as central air conditioning and large fans, is considered to be familiar indoor sound, previous studies have shown that it can also result in less comfort, increased annoyance, and reduced satisfaction with the indoor acoustic environment (Torresin et al., 2020; Wang et al., 2018). Currently, the research on mechanical noise mainly concentrates on large public places, while that on nursing homes is relatively limited. Another familiar sound in nursing homes is the background music in the activity halls and some studies have pointed out that both background, and foreground music can enhance the attractiveness of the environment to individuals and heighten people's sense of happiness (Yi and Kang, 2019). Therefore, as places with complicated acoustic environments, nursing homes must systematically study their sound sources and the effects to improve the acoustic environment of their residential indoor spaces.

This study aims to investigate the evaluation of the acoustic environment of the elderly in activity spaces and the impact of different sound sources on behaviours. In this study, the activity hall in a nursing home in Harbin, China, was used as the research site; objective acoustic parameters, subjective behavioural observations, and questionnaires were used as data-gathering instruments. The major research objectives were as follows:

To conduct an overall assessment of the acoustic environment in the activity hall based on the measurement of SPL and reverberation time (RT).

To investigate the impact of sound types and sound sources on acoustic environment evaluations.

To explore the impact of residents' activity types and behaviours on acoustic environment evaluations in different areas of the activity hall.

To analyse the personal and social factors that affect the acoustic environment evaluations of elderly people.

This study focuses on how both the behaviour and the acoustic environment evaluations of elderly people are affected by the acoustic environment in a nursing home's large-scale integrated activity space, and can provide a reference for the construction and design of facilities for the elderly.

2 *Methodology*

This study used a questionnaire and field measurements to collect relevant data. Pre-surveys and trap questions were used to increase the credibility of the questionnaire's answers. From the different areas in the activity hall of the nursing home, the most appropriate locations for measurement of observation, sound source, SPL, and RT were selected. Since high-altitude observation is the most appropriate approach in our context due the lack of obstruction, the main location for video recording was the ring corridor on the second floor, where the activities of the elderly could be clearly seen. Even though the observation points on the first floor did not meet the condition of high-altitude observation, both sides of the corridor area of the activity hall were still selected as measurement points, since this area is not a place where many elderly residents gather and conditions would not be expected to interfere with their movements in the area; in fact, clear observations were recorded. The measured data were sorted and analysed statistically. This research was approved by the ethics review board of the School of Architecture, the University of Sheffield.

2.1 Survey site

Due to the rapidly aging society, the Chinese government has paid increased attention to the construction of facilities for the elderly since the new millennium (Bartlett and Phillips, 1997). Northern China primarily relies on coal for heating in winter (Mestl et al., 2007) which directly correlates with poor winter air quality and indirectly affects people's outside activities during cold weather. People, especially the elderly, need sufficient indoor activity space to meet their daily activity needs (Molzahn et al., 2010). Furthermore, besides air pollution, urban pollution includes noise pollution, which is an invisible and often overlooked pollutant (Jamir et al., 2014). Some studies have found that occupying an environment above 65 dB(A) for a long time can cause serious health problems such as heart, hearing, and cognitive issues (Kerns et al., 2018; Berglund et al., 1999; Ariza-Villaverde et al., 2014; Stansfeld and Matheson, 2003; World Health Organization, 2018).

According to the 2015 Chinese census, the elderly population (over 65 years old) in the case study city, Harbin, totals 1.0420 million—11% of the city's population. Owing to increase in the elderly population, there is an increasing demand for facilities for the elderly from the government and society (Xie et al., 2020; Wang and Kang, 2020). A large-scale nursing home in Harbin was selected as the survey site for this study. The floor plan of the comprehensive activity hall of this nursing home is shown in Figure 1.

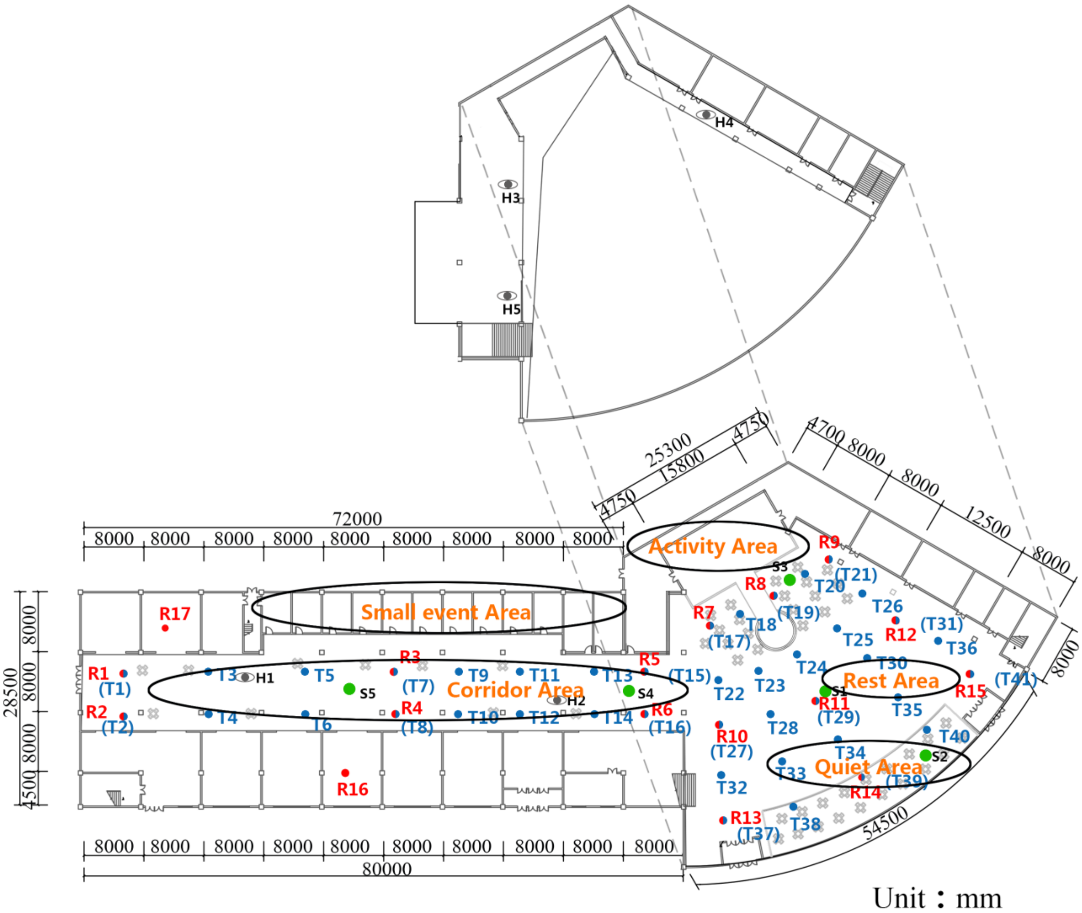


Figure 1. Floor plan of the comprehensive activity hall, with sound source points (S1–S5), SPL monitoring points (R1–R17), and RT test points (T1–41).

The activity hall has two sections: the fan-shaped sunshine hall (1700 m2, 14 m high) and the rectangular living area (850 m2). Both sides of the living area are set up as various small activity areas, such as a calligraphy and painting room, chess room, and lecture room, totalling 1200 m2. The fan-shaped sunshine hall is divided into three main parts: a quiet area, rest area, and activity area. There is no clear boundary between the rest and activity areas, and the total area can be shared according to the needs of an activity. The quiet area is adjacent to the 14 m high glass curtain wall of the fan-shaped hall, which has good lighting and outdoor vision. There is no clear partition between the corridor area and the fan-shaped hall, but owing to the difference in the building structure and building materials of the two areas, the feeling and function of the spaces are quite different.

2.2 SPL and RT measurements

Previous studies have suggested that different sound sources and behavioural patterns influence the sound environment and the acoustic perceptions of people in open and indoor spaces and that the sound environment can, in turn, influence people's acoustic perceptions. The most important indexes that affect the sound environment are SPL and RT (Tavossi, 2003) which in this study were measured by the following methods. The measurement points are shown in Figure 1 and cover the sound source points (S1–S5), SPL measurement points (R1–R17), and RT measurement points (T1–41) all of which may influence evaluation of sound in indoor spaces (Zannin and Marcon, 2007; Meissner, 2008). During the experiment, the number of people in the small activity rooms was generally between 5 and 30. From the calculation using the Eyring formula, the difference in RT was only 0.12 s; therefore, the effect of RT was not considered in the small activity rooms (Meng and Kang, 2017).

The SPL measurements were conducted when the activity hall was in use, and lasted from 8:00 a.m. to 6p.m. During every measurement, the 801 sound level meters were set to slow mode, and A-weighting Leq was measured and recorded every 10 s. To avoid variability in sound sources, at each measurement point SPL was measured 10 times each hour, and the results were represented by the average value of the 10 sets of data. The measurements in each space were taken from a minimum of five different points at least 3 m apart from each other, to avoid measurement errors such as incomplete measures due to measuring point too close or too far away from the sound source, eruption of high-dB(A) noise, which could be part of the acoustic environment or incidental, and measurement of reduced SPL caused by an unclear view of the sound source, which blocks the propagation of sound (Zahorik, 2002) In addition, to study the impact of different types of activities of the residents on evaluation of the acoustic environment, the sound lever meter was setup the same as before and took instant readings every 10 s after each questionnaire was completed. At each measurement point, measurements were made 10 times to avoid sound source variability. A total of one minute of data was obtained in each survey position (Yang and Kang, 2005a, 2005b; Wu et al., 2020). The mean value was calculated to obtain the corresponding SPL.

The RT was measured at night while the activity room was closed and unoccupied, and thus the environment was very quiet. An OS002 omni-directional sound source was used to play white noise at the five sound source points (as shown in Figure 1, S1–S5) to avoid measurement errors. After stabilization, the sound source was suddenly turned off, and the time it took for the sound to decay by 30 dB(A) (T30) was recorded in order to determine the RT (after extrapolation to 60 dB(A) (Bautmans et al., 2007). Since the activity hall was a large space, T30 instead of T60 was measured. The equipment selection and measurement process followed the ISO3382 standard.

2.3 Observation of the elderly participants' behaviour

As people age, their skeletal muscle mass declines, which results in decreased energy and grip strength (Bautmans et al., 2007; Wensveen et al., 2017) adversely affecting elderly people's ability to perform daily activities (Wang et al., 2009). An effective activity space can support the daily activities of the elderly, thereby improving their physical functioning and overall health (Cutler, 2007).

Image recording is an important research method used to observe and study human behaviour; for example, a camera was used to record the behaviours of children at different locations in a playground by Meng and Kang(2020). We placed HD video cameras around the activity hall and the ring corridor on the second floor, as shown in Figure 1(H1–H5), to prevent the elderly residents' normal activities in the activity hall being influenced by the experimental process and to avoid blind spots. The recordings took place between 8 a.m. and 6 p.m., every 10 min, and lasted for 5 min. At each recording point, H1–H5, a minimum of 15–20 recordings were taken for every activity to ensure the stochastic behaviour was accounted for in the measurement.

From the observations of the activities in the activity hall, the activities of the the elderly were divided into three types based on the SPL: 1) (near-) silent activity such as rest and reading, with SPL < 35 dB(A); 2) low-dB(A) activities such as meeting, talking, walking, and playing chess, with SPL < 50 dB(A); and 3) high-dB(A) activities such as playing music, TV sounds, singing, and dancing, with SPL > 60 dB(A) (Berglund et al., 1999). When the third type of activity was conducted, it was usually accompanied by the sound of foreground music. The elderly residents' activities in the hall were not limited to one type of activity, and the area in which activity took place also changed.

The recording and observation continued throughout the survey, and the recording time for each activity type was set at 15 min (Meng and Kang, 2020).

In the questionnaire, the attitudes of the elderly were measured using a seven-point Likert-type scale (Table 1), which has been widely used in survey research on the environmental effects of subjective comfort (Sanchez et al., 2017; Liu and Kang, 2018; Liang et al., 2014). The reliability coefficient of the questionnaire was estimated at 0.81 (Cronbach's alpha).

Table 1. Questionnaire and scales

Category	Questions	Scale
Background information	Gender; age; education level; pension; length of residence, usage duration, usage frequency	
Subjective evaluation	Evaluation of the overall sound environment	1 being very noisy and 7 being very quiet
	Acoustic comfort of the overall sound environment	1 being very uncomfortable and 7 being very comfortable
	Subjective impression of reverberation	1 being very long and 7 being very short
	Acoustic comfort of various sound sources	1 being very uncomfortable and 7 being very comfortable
	Loudness of various sound sources	1 being very low and 7 being very high
	Intelligibility of various sound sources	1 being very clear and 7being very unclear
	Noise level of various sound sources	1 being very noisy and 7 being very quiet
	Preference degree of various sound sources	1 being highly disliked and 7 being highly liked

The nursing home was populated by a total of 384 elderly people. Considering that the elderly need approximately 20–30 min to adjust to the sound environment in a given space (Meng and Kang, 2013) the elderly that were in the activity hall for < 30 min were not interviewed, making the total number of participants 320. The questionnaires were taken using a one-to-one method and completed within five minutes, and at least 10 interviews were conducted at each survey point. The residents that participated in the survey were considered qualified to participate according to the frailty scales proposed by Rockwood et al. (2005) belonging to the scale range of 1–4. This range ensured that the participants had the appropriate physiological and psychological status to enrol in the study. Since the questionnaire survey was taken one-on-one, the researchers were attentive to the hearing of the elderly while communicating with them, and the elderly who displayed poor hearing were excluded from participating in the questionnaire as well as the observation experiment. A total of 320 questionnaires were distributed, of which 307 were found valid.

In the survey, the elderly were asked to record the sound sources they heard at each time point. Repeated sound sources needed to be recorded repeatedly while simultaneously recording the sound source that had the greatest impact on them (Meng and Kang, 2020). The sounds in the hall were divided into five categories: activity sounds, speech sounds, machine sounds, background music, and foreground music. The background music was the music played in the activity hall, and the foreground music was selected and played by the elderly people themselves or referred to music played during a group activity such as dancing or singing (Yi and Kang, 2019). Seat and table moving sounds, such as dragging chairs and table relocation, belonged to the sound type activity sound, since these sounds are related to activities (e.g. dining). Table 3 consists of a detailed specification of the five sound types and the sound sources for each.

2.4 Statistical analysis

SPSS 20.0 was used to establish a database of the subjective and objective results (Zhang et al., 2018). Pearson's correlation coefficient was used to determine the factors and dominant sound sources that affected the elderly's comfort evaluations of the sound environment, and the mean differences were used to investigate the influence of the existence or nonexistence of dominant background sound sources on the elderly. Pearson's correlation and multiple regression analysis were then used to determine the factors affecting the acoustic comfort of the dominant sound sources from the sound source characteristics. The factors affecting the elderly's acoustic comfort evaluations were discussed from the perspective of their demographic and social factors.

3 Results and analysis

3.1 The acoustic environment in the activity hall

The physical environment of the activity hall was first measured by the SPL and RT in an attempt to discover the behavioural habits of the elderly and the acoustic environment of the hall.

As shown in Figure 2, there are obvious differences in the RT in different areas. The fan-shaped sunshine hall's monitored RT was more than four seconds longer than that of the rectangular living area (corridor), and the RT of the corridor was less than two seconds.

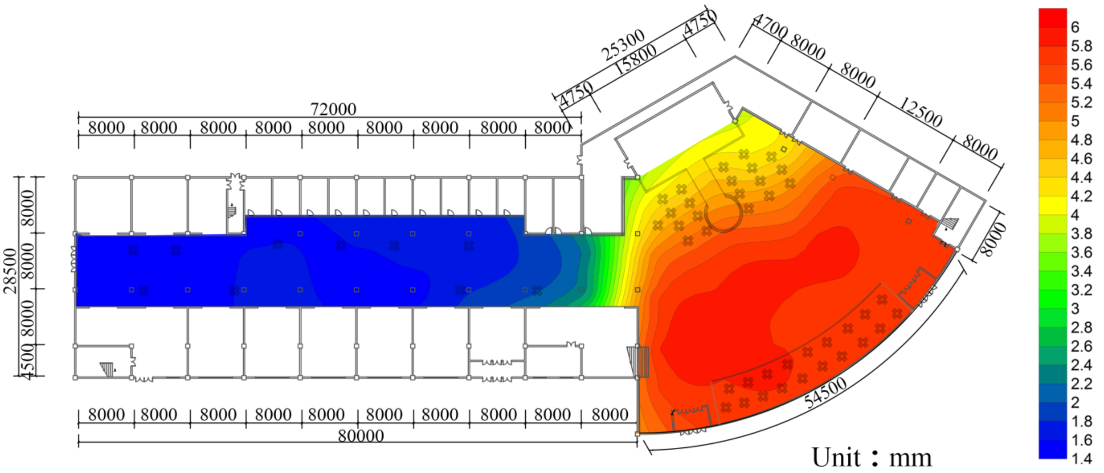
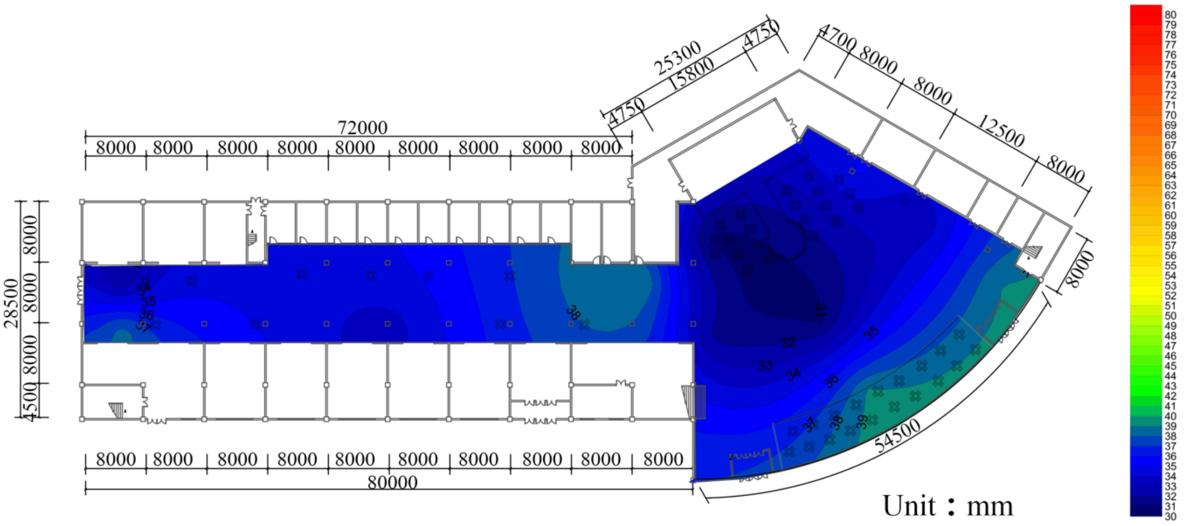
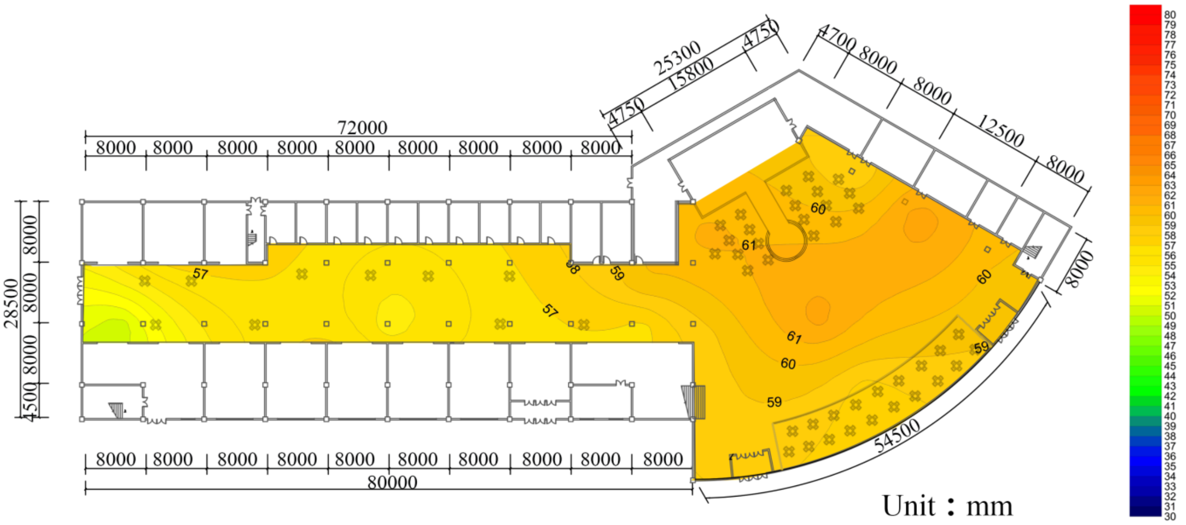


Figure 1. The measurement of RT in the activity hall, units in mm and RT in s.

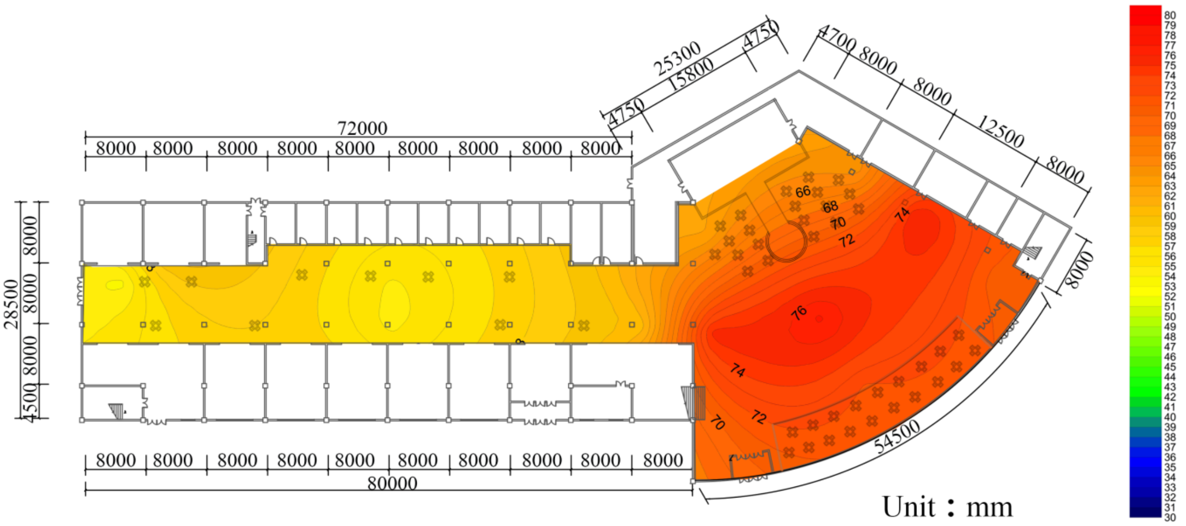
Changes in SPLs between 8 a.m. and 6 p.m. are shown in Figure 3. The SPL measurement results in the fan-shaped sunshine hall show significant changes. The SPL in the morning was the lowest throughout the day: below 40 dB(A) at each detection location. The two peak SPLs were between 11 a.m. and 12 p.m. (before lunch) and between 4 p.m. and 5 p.m. (before dinner), at 74 dB(A) and 76 dB(A), respectively. As many elderly people have the habit of taking a nap, SPL tended to be flat at a low level in the afternoon between 40 dB(A) and 50 dB(A). In general, the results of the SPL measurement show that changes in the SPLs in the activity hall correlated with the activities of the elderly.



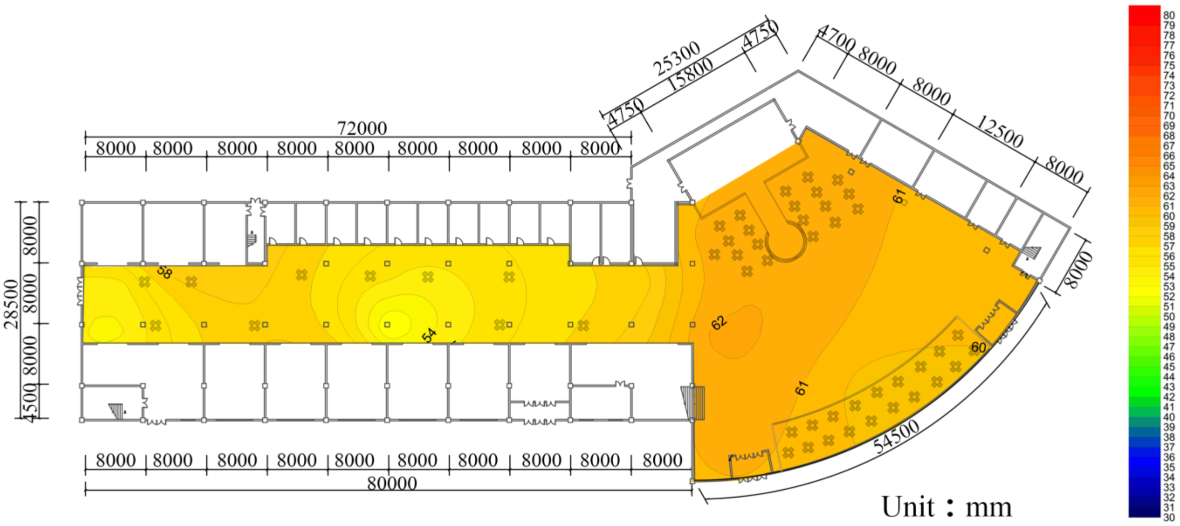
a) 8.00 a.m.



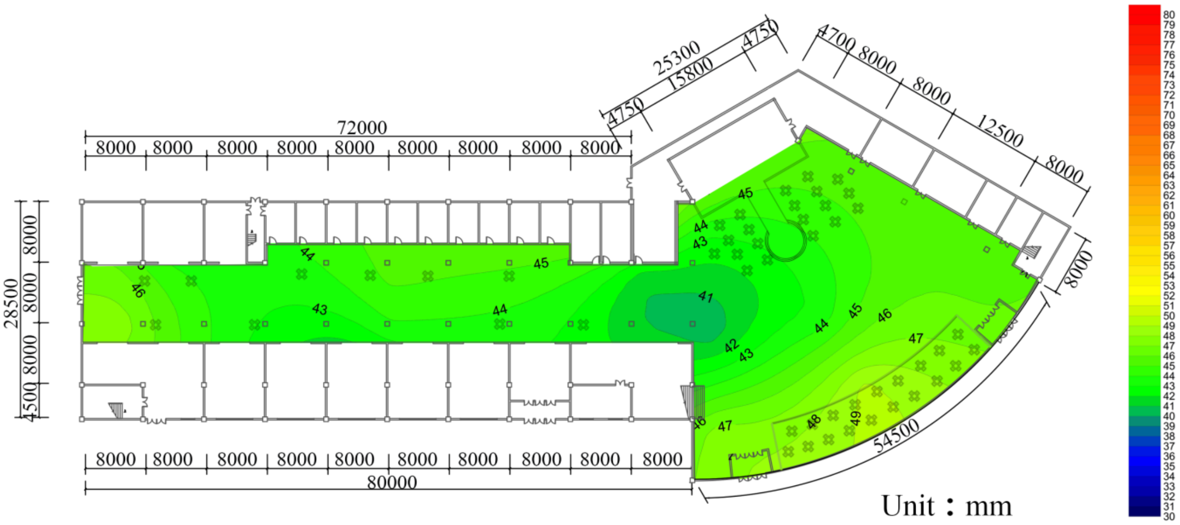
b) 9.00 a.m.



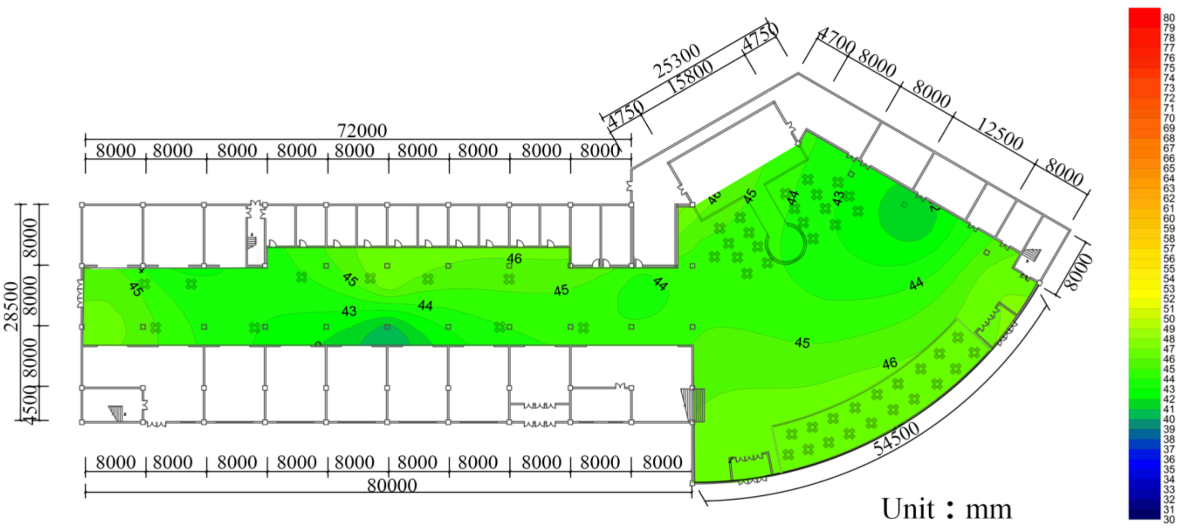
c)10.00 a.m.



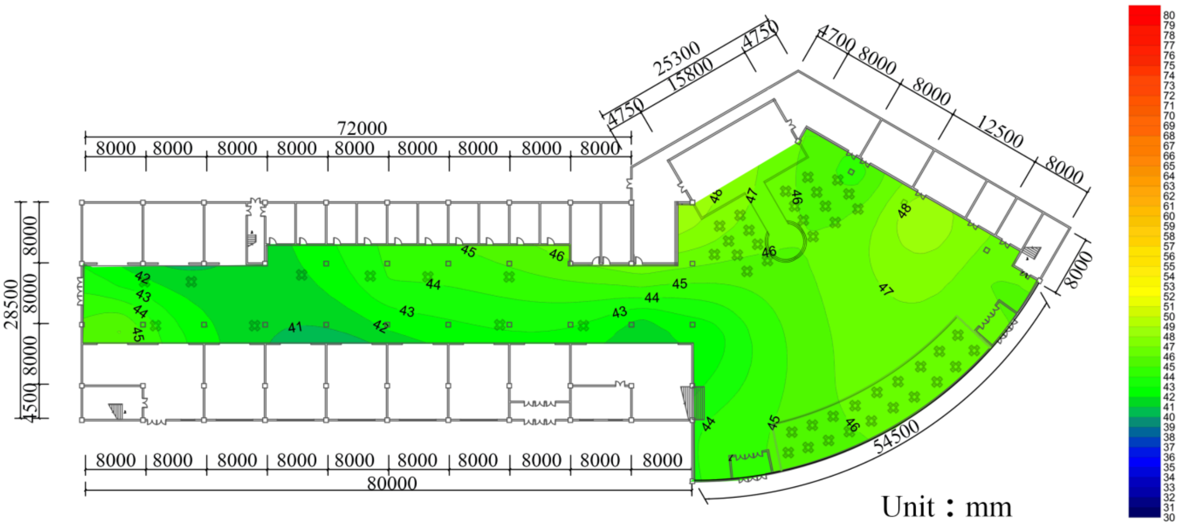
d) 11.00 a.m.



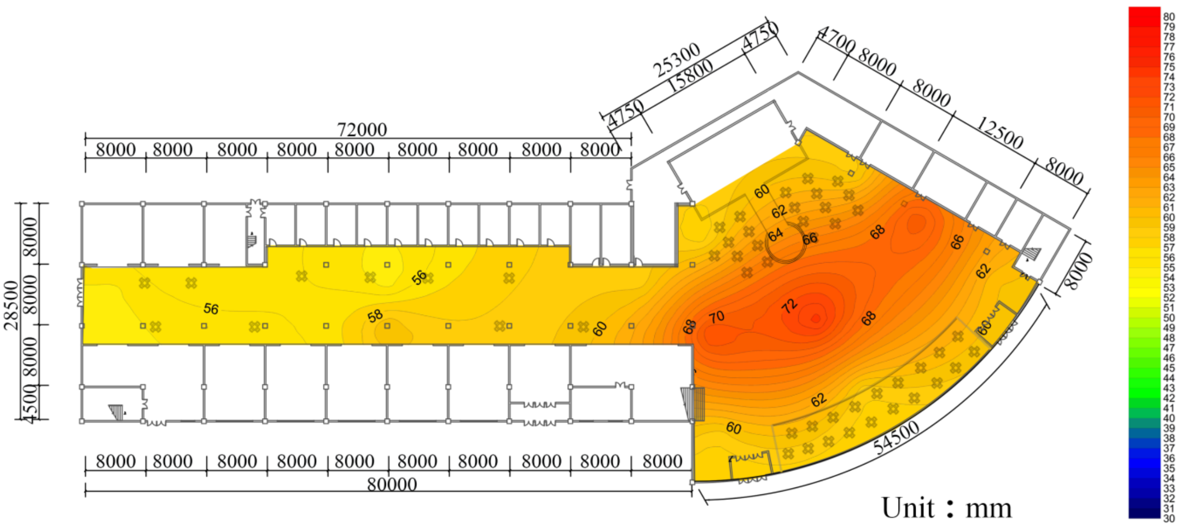
e) 12.00 a.m.



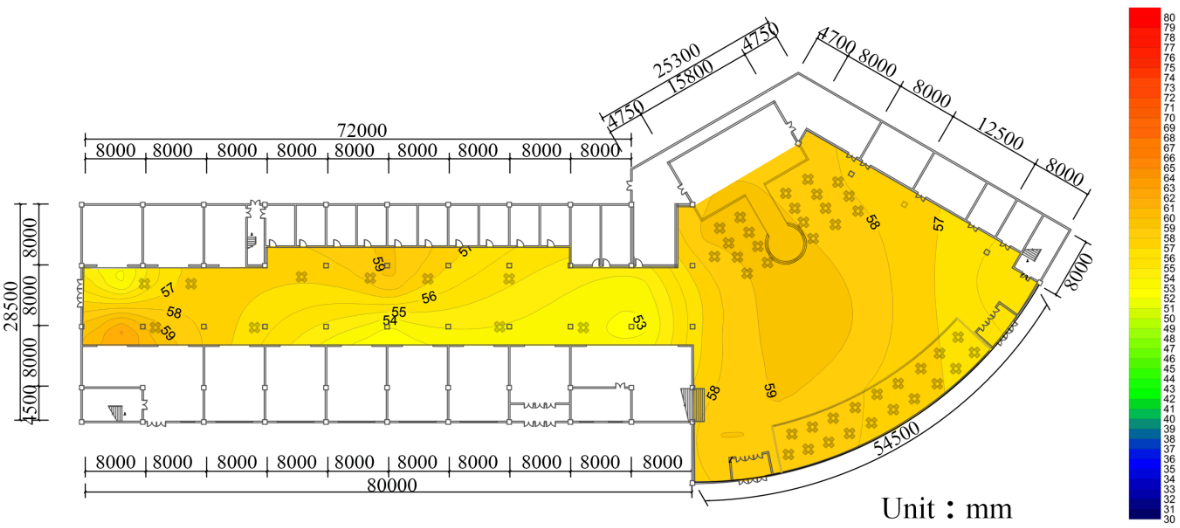
f) 1 p.m.



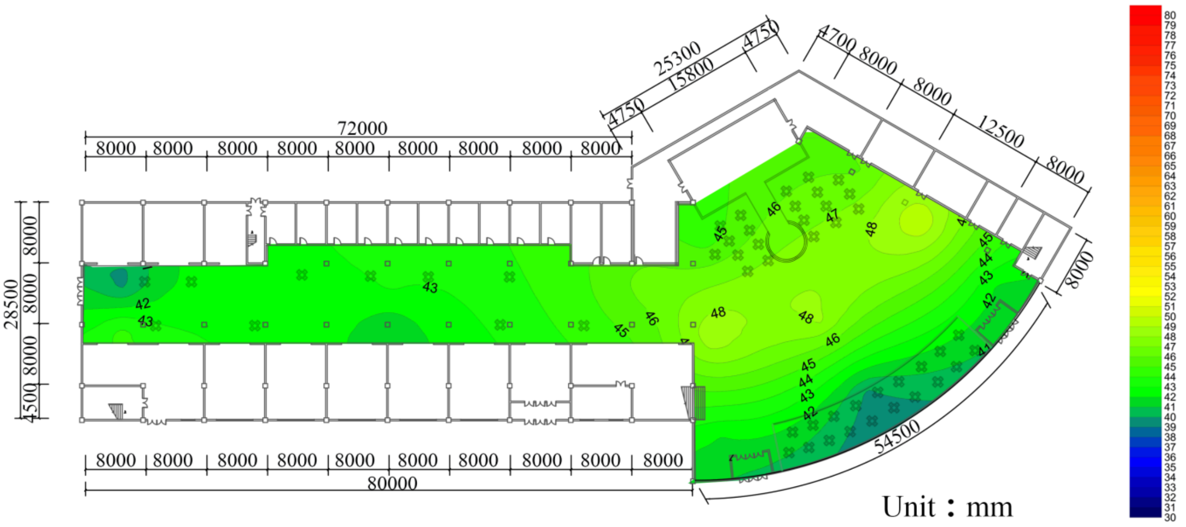
g) 2 p.m.



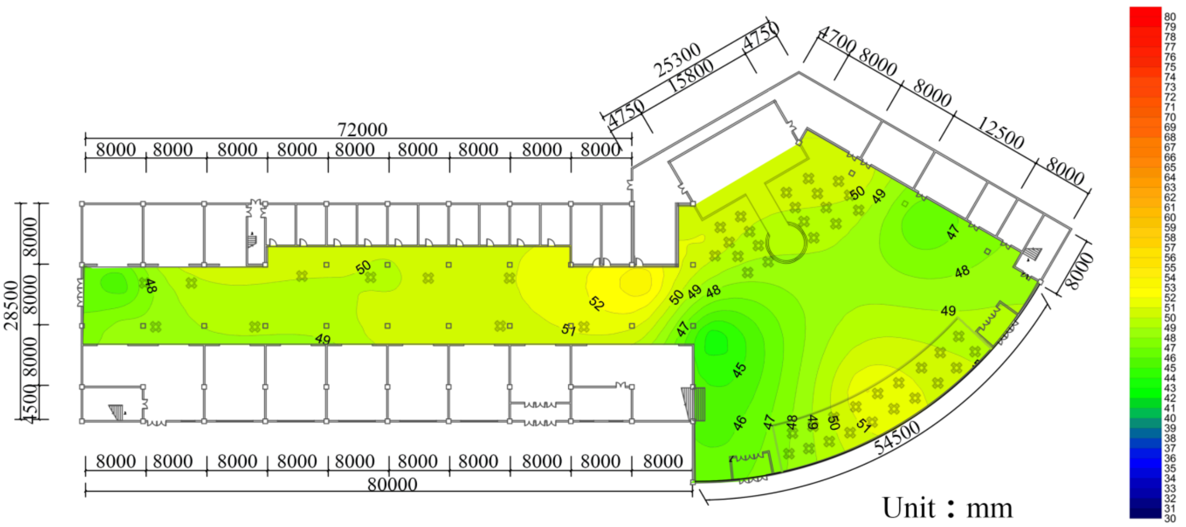
h) 3 p.m.



i) 4 p.m.



j) 5 p.m.

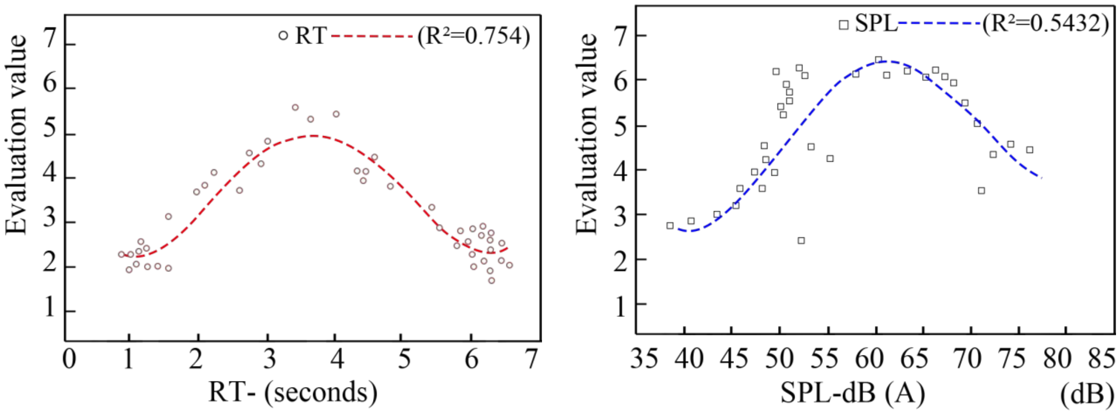


k) 6 p.m.

Figure 3(a-k). Changes in and distribution of SPL, units in mm and SPL in dBA.

3.1.1 Relationship between the acoustic evaluation and the test results

The changes in the acoustic environment evaluation along with the measured RT and SPL are shown in Figure 4, where it can be seen that there is a non-linear relationship.



a) RT b) SPL

Figure 4. Relationship between the acoustic evaluation and the measured RT and SPL.

Figure 4 a) shows that the acoustic environment evaluation rises with the increase of RT. When the RT is four seconds, the sound evaluation is the highest, at four points. According to research by Wu et al. (Wu et al., 2020)when RT exceeds 4.5 s, it can be perceived by a participant. In this survey, when RT exceeded four seconds, the background noise increased, and the participants felt frustrated due to the interference with their communication, which ultimately led to a reduction in the evaluation of the sound comfort. The evaluation values in Figure 4 b) show the same trend. As SPL increased, the sound evaluation presented earlier increased, and later decreased, when exceeding 65 dB(A).

3.2 Evaluation of the sound environment based on the sound types and sources

3.2.1 Characteristics of the dominant sound types

Previous studies have shown that various sound sources in background noise can have different effects on people (Cheng and Kang, 2017; MacKenzie and Galbrun, 2007). This study divided the activity sounds of the nursing home residents into three categories: (near-) silent, low-dB(A), and high-dB(A) activities. The evaluation indicators of sound characteristics included acoustic comfort, loudness, noise level, intelligibility, and preference level.

Figure 5 shows the characteristics of each sound type by averaging the scores of the four evaluation indicators: loudness, intelligibility, noise level, and degree of preference towards the five different sound types: activity sounds, speech sounds, mechanical sounds, background music, and foreground music. As they were affected by subjective factors, the participants gave a median rating for the loudness and intelligibility of all sound types, which was around four points, indicating that they felt that their surroundings were acceptable or a little loud. Simultaneously, the evaluation of the noise level and preference for each sound type were low. The four indicators had a significant correlation with acoustic comfort ($p < 0.001$), while the highest correlations were for preference level and intelligibility at 0.473 and 0.51, respectively. Overall, the acoustic comfort of the elderly is more affected by their subjective preferences and audibility. To further explore the impact of the four subjective evaluation indicators (preference degree, loudness, noise level, and intelligibility), the independent variables, on the dependent variable, acoustic comfort, multiple regression analysis was carried out. The results are shown in Table 2and indicate a positive relationship between the variables. All four evaluation indicators are statistically significant, $p < 0.05$, which means they each have a significant impact on acoustic comfort. Of the four indicators, intelligibility has the highest coefficient value at 0.459, which again confirms a significant correlation with acoustic comfort. This result is in accordance with a study by Wu et al. which indicated that SPL and speech intelligibility are the factors that have the most influence on the acoustic environment (Wu et al., 2020).

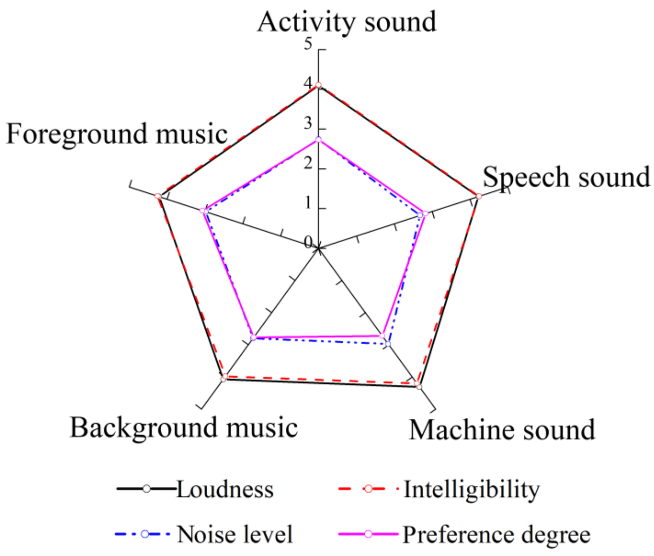


Figure 5. Sound characteristics for each sound type.

Table 2. Multiple regression coefficients, *p<0.05

	Unstandardized Coefficients		Standardized Coefficients	t	95% Confidence Interval
	B	Std. Error	Beta		
(Constant)	-0.128	0.188		-0.683	0.495
Preference degree	0.144	0.058	0.116	2.473	0.014*
Loudness	0.228	0.052	0.205	4.362	0.000*
Noise level	0.217	0.055	0.185	3.947	0.000*
Intelligibility	0.459	0.058	0.418	7.891	0.000*

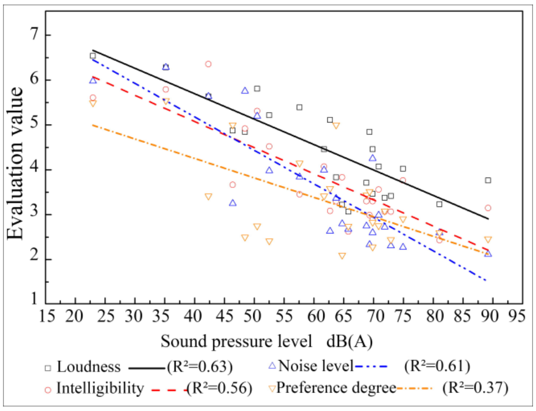
Table 3. Correlation between sound sources and acoustic comfort

Name of area	Sound types	Sound sources	A:Average value/variance	B: Correlation coefficient/p value
Rest area	Activity sound		3.060/1.348	0.596/0.000 （***）
		Playing card sounds	3.262/1.701	0.342/0.006 （**）
		Seat and table moving sounds	2.962/1.746	-0.023/0.815
		Dancing sounds	3.01/1.943	-0.036/0.718
		Chess sounds	2.933/1.224	0.335/0.001 （**）
	Speech sound		3.167/1.511	0.539/0.000 （***）
		Talking sounds	3.644/1.645	0.206/0.000(***)
		Explanation sounds	2.869/1.674	-0.209/0.033(*)
		Talking sounds of staff	2.923/1.863	0.031/0.757
		Talking sounds of onlookers	2.933/1.829	0.098/0.323
	Mechanical sound		2.703/1.328	0.245/0.113
		Air conditioning sounds	3.058/1.683	0.017/0.863
	Background music		2.77/1.638	0.494/0.001 （**）
		Background music	3.172/1.448	0.452/0.000 （***）

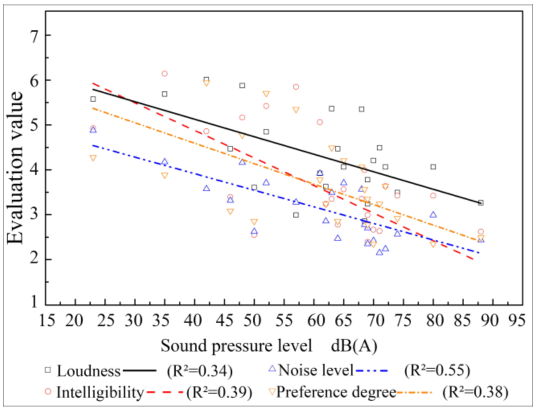
		TV sounds	2.262/1.779	-0.095/0.340
	Foreground music		3.542/1.401	0.541/0.000（***）
		Dance music	3.748/1.585	0.269/0.002(**)
		Singing sounds	3.462/1.689	0.351/0.000(***)
Activity area	Activity sound		2.956/1.032	0.187/0.172
		Walking sounds	2.926/1.885	0.17/0.063
		Dancing sounds	3.841/1.637	0.426/0.000(***)
		Chess sounds	2.917/1.860	0.066/0.047
	Speech sound		3.162/1.411	0.588/0.000（***）
		Talking sounds	3.273/1.812	0.145/0.112
		Talking sounds of onlookers	3.066/1.252	0.19/0.000(***)
	Mechanical sound	Trolley sounds	3.033/1.288	0.342/0.09(*)
	Background music	Background music	2.63/0.924	0.222/0.104
	Foreground music		2.846/1.278	0.624/0.000（***）
		Dance music	3.725/1.544	0.319/0.000(***)
		Singing sounds	1.982/0.683	0.119/0.193
Quiet area	Activity sound		3.365/1.765	0.459/0.000（***）
		Seat and table moving sounds	3.570/1.296	0.395/0.000（***）
		Walking sounds	2.860/1.823	0.227/0.003(**)
		Chess sounds	3.041/1.923	0.276/0.000(***)
		Using computer sound	2.959/1.733	0.272/0.000(***)
		Dancing sounds	2.959/1.829	0.154/0.054
	Speech sound		3.147/2.028	0.640/0.000（***）
		Talking sounds of staff	2.591/1.731	0.225/0.000（***）
		Talking on the phone sounds	3.281/1.763	0.155/0.003(**)
		Talking sounds	3.058/1.651	0.044/0.565
	Mechanical sound		3.352/1.704	0.350/0.000（***）
		Trolley sounds	3.547/1.641	0.220/0.000（***）
		Air conditioning sounds	3.041/1.646	0.175/0.022(*)
	Background music	Background music	3.362/2.028	0.440/0.000（***）
	Foreground music		3.062/2.073	0.615/0.000（***）
		Singing sounds	3.170/1.766	0.258/0.001(**)
		Dance music	3.023/1.598	0.261/0.000（***）
Corridor	Activity sound		2.765/1.255	0.324/0.021（*）
		Walking sounds	3.197/1.031	0.315/0.014(*)
		Seat and table moving sounds	2.297/1.433	0.222/0.086
		Playing card sounds	3.049/1.784	0.149/0.003（**）
	Speech sound		2.386/1.077	0.188/0.186
		Talking sounds	2.195/1.764	0.008/0.952
		Talking sounds of staff	1.966/0.636	0.226/0.08
		Talking sounds of onlookers	2.731/1.836	0.151/0.009（*）
	Mechanical sound		2.451/1.246	0.420/0.002（**）
		Air conditioning sounds	2.470/1.287	0.058/0.655
		Trolley sounds	2.547/1.241	0.220/0.004(**)
	Background music	Background music	2.41/1.344	0.426/0.002（**）

	Foreground music		2.296/0.999	0.409/0.003 （**）
		Music from electronic devices	3.023/1.598	0.261/0.001(**)
		Singing sounds	1.728/0.557	0.223/0.084
Small event space	Activity sound		2.236/0.826	0.133/0.566
		Walking sounds	2.331/0.839	-0.037/0.713
		Playing billiards sounds	2.165/0.880	-0.045/0.653
	Speech sound		1.973/0.915	0.411/0.030 （*）
		Talking on the phone sounds	1.902/0.510	-0.069/0.487
		Talking sounds of onlookers	2.123/1.066	-0.242/0.013(*)
	Mechanical sound	Air conditioning sounds	2.50/1.036	0.663/0.000 （***）
	Background music	Background music	2.46/1.401	0.691/0.000 （***）
	Foreground music	Music from electronic devices	2.14/1.044	0.359/0.061

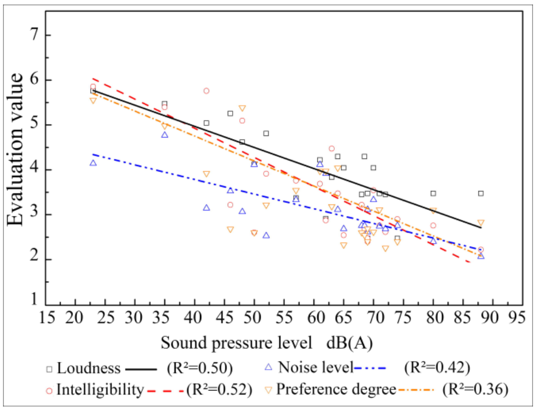
Due to these characteristics, the main sound types may have different effects on SPL and acoustic comfort. Therefore, this section also analysed the relationship between the comfort level of different sound types and SPL, as shown in Figure 6. This figure involves linear regression and correlation coefficients to obtain the changing trend in how comfort is affected by the SPL and the correlation between sound type and SPL.



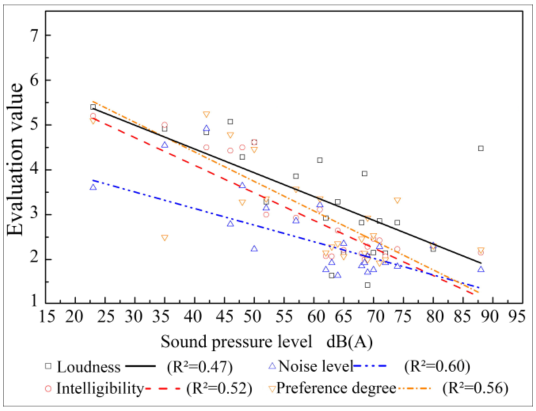
a) Activity sound



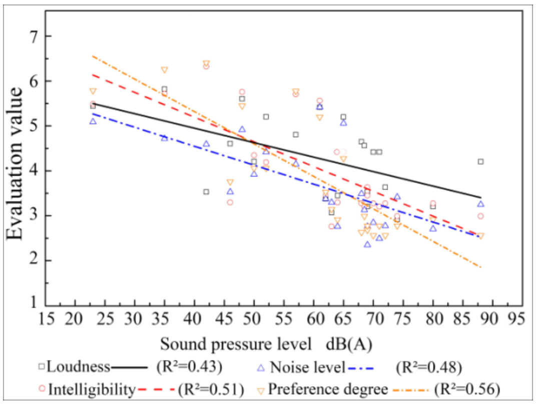
b) Speech sound



c) Mechanical sound



d) Background music

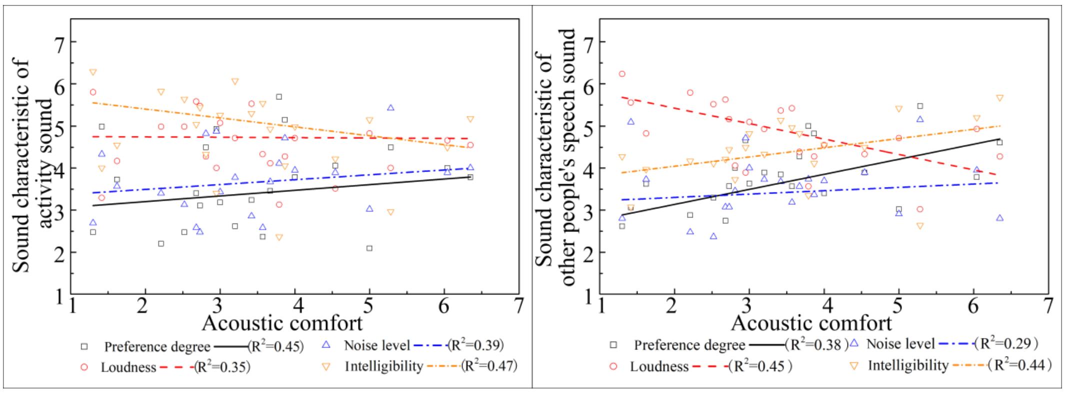


e) Foreground music

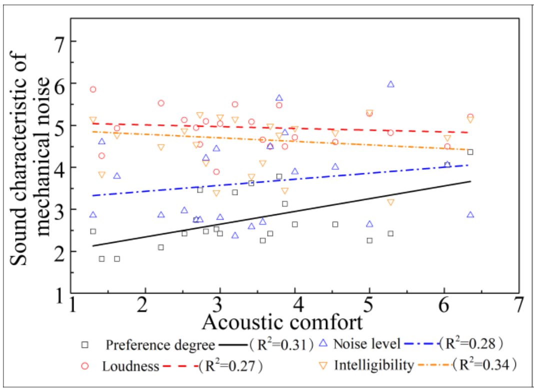
Figure 6(a-e). Relationship between SPL and the sound characteristics of the dominant sound types.

As Figure 6 indicates, as SPL increases, all evaluation indicators decline. The indicators of activity sound, loudness, intelligibility, and noise level are highly correlated with SPL. As the measured SPL increased, the noise level of speech sounds decreased (0.55). The indicators of speech sound, loudness, intelligibility and preference degree were weakly correlated with SPL. Mechanical and activity sounds show similar results, except for preference degree, which shows only weak correlation with SPL, while the other indicators (noise level, loudness and intelligibility) show a stronger correlation. The correlation between background music, foreground music, and SPL is similar; except for the weak correlation of noise levels, all the indicators (loudness, intelligibility, and preference degree) are correlated. These results show that the participants' evaluation of the acoustic environment as satisfactory declines as SPL increases. The decline in their evaluation of music is slower than that of other sound types, and their satisfaction with and preference for music sounds are higher than for the other sound types.

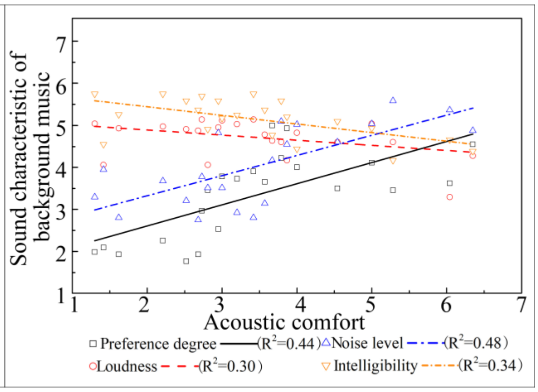
In general, the evaluation of most of the sound types is either weakly related or unrelated to acoustic comfort (< 0.5) as shown in Figure 7. However, when the evaluation of loudness decreases, sound comfort will increase, and the most obvious source of it is foreground music (= 0.61). This indicates that the elderly do not like foreground music when it is too loud.



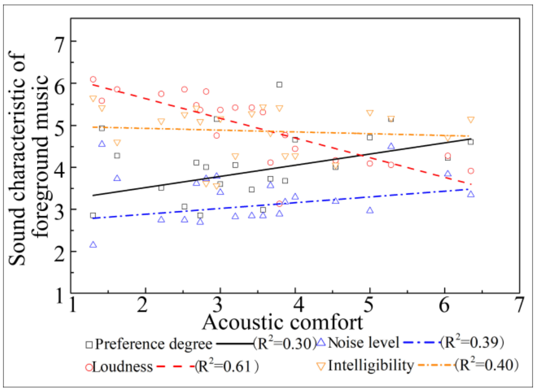
a) Activity sound b) Speech sound



c) Mechanical sound



d) Background music



e) Foreground music

Figure 7(a-e). Relationship between acoustic comfort and the sound characteristics of the dominant sound types hall.

3.2.2 Correlation between acoustic evaluation and sound source in different areas

The elderly were asked about their subjective feelings when they heard different sound sources in different areas to investigate whether there is a correlation between sound environment evaluations and sound types in different areas. The activity hall of the nursing home is divided into several activity areas (Figure 1), but activities are relatively free and do not have to be limited to specific areas. Therefore, there could be many different sound sources in the rest area, and these sound sources may also come from other areas.

Column A in Table 3 shows the mean and standard deviation of the elderly residents' acoustic comfort evaluations. Among them, the quiet area was rated higher than all the other areas for all sound types, with an average close to 4 points. The reason may be that the elderly primarily conduct (near-) silent activities in this area, such as reading, resting, and viewing the outdoor landscape through glass to relieve stress. This confirms Davies et al.'s contention that a pleasant landscape or appealing visual scene can improve hearing comfort (Davies et al., 2013). It is worth noting that speech sounds were most annoying to the elderly, with a minimum rating of 1.86 points in all areas. Respondents in the corridor stated that they felt that speech sounds came from all directions, sounded noisy, and caused extreme discomfort. This may be due to the complicated structure of the corridor and its walls, which cause the sound to be refracted multiple times, thus making the participants feel like the sound is amplified and coming from different directions (Davies, 1978; Lam, 1996). Due to the poor overall sound environment in the activity hall, residential facility managers and employees have to speak loudly to ensure correct communication and work effectively. Elevated SPLs cause frustration in the elderly residents, and some of the elderly stated that they did not like the managers to shout, as it causes them headaches and heart discomfort. Activity sounds are more complicated, as there are more sound sources and the elderly provided unclear descriptions of them. Therefore, the overall evaluation of activity sounds is higher than that of other sound types and is second only to mechanical sounds (which had an average of over 3 points), at a moderate sound level, which is slightly uncomfortable. In terms of sound sources, talking and singing sounds are the lowest rated in comparison, with scores in some areas of below 3 points. The activity hall, the rest area, activity area, corridor, and small event space are affected by the sounds of talking; the louder noises arise from activities such as talking, singing, and dancing. Most the elderly rated speaking sounds worst but could tolerate mechanical sounds and activity sounds. Previous studies have described how older people generally cannot perceive high-frequency sounds and are less sensitive to low-frequency sounds (Van Hoof et al., 2010). Since different type of sounds were recorded by the participants in the questionnaire it is safe to assume that they were able to perceive low-frequency mechanical sounds; however, since they evaluated them more positively compared to activity sounds, it could indicate that were are less sensitive to them and that the low frequency did not affect them too much. Meanwhile, the poor evaluation of activity and in particular speech sounds, could indicate a negative impact of these sounds on elderly residents' activities and emotional state. Overall, the elderly evaluated the activity hall's acoustic environment with low ratings.

As shown in column B in Table 3, the acoustic comfort evaluation of the rest area is affected by activity sound, speech sound, background music, and foreground music. In this area, almost no mechanical sounds can be heard, as a result of the conversation, music, and activity sounds. According to the evaluation of the various sound sources shown in column A in Table 3, the worst evaluation is for TV sounds and the best is for dancing sounds.

In the activity area, foreground music and speech sounds have the highest correlations with sound satisfaction (0.624 [$p < 0.01$] and 0.588 [$p < 0.01$], respectively), because these activities require communication such as talking sounds from both participants and onlookers. Music can help elderly people exercise and enjoy themselves. As the residents are focused on their activities in the activity area, they pay less attention to external activity sounds and background sounds; thus, the correlation between these two sound types and satisfaction is low. The most preferred sound sources in the area are dancing sounds and music during the dancing sessions. The most unpopular sound source is singing, which may be because it can easily affect and interfere with other types of activities.

The quiet area received a higher overall evaluation of the acoustic environment; it is affected by all sound sources, with the highest correlations for speech (0.64, $p < 0.001$) and foreground music (0.615, $p < 0.001$). It is interesting to see that the respondents in the quiet area rated all sound sources at a moderate level, and that most of the sound sources have a rating of > 3 points. Obviously, the participants are relatively accustomed to or accept these sound sources.

Due to the short time people spend in the corridor, the sound sources may be multi-directional, and the elderly have a poor ability to capture sound (Müsch, 2008). Therefore, the survey results show that the correlation between the sound sources of activity and speech and the satisfaction with the corridor is low. Mechanical sound and musical sound with a longer duration, such as trolley sounds and music from electronic devices, have a greater impact on the corridor area.

In the small event space, mechanical sound and background music have the highest correlations with sound satisfaction. This is due to the subjective influence of the elderly participating in high-decibel activities in this area. The lowest-rated sound source in this area is speech sounds. Since the evaluation of each sound type in the small activity room is shown to be at a low rating, it can be assumed that the small activity room is a small space with noisy sounds.

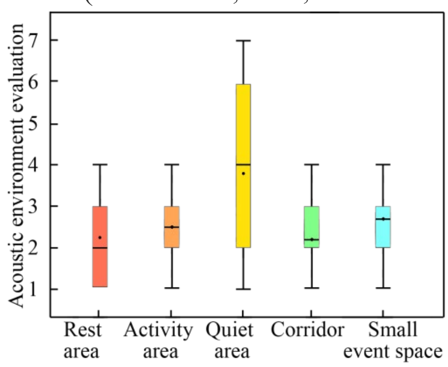
Overall, the elderly gave a low evaluation of the acoustic environment in the activity hall of the nursing home and were uncomfortable with the sound environment. This could be caused by several factors, such as the activity hall's building materials, and interior decorations, which cannot meet the different demands of residents (Drotleff and Zhou, 2001; Frisina and Frisina, 1997). It has been demonstrated that the age-related hearing decline can affect people's perceptions of speech, especially when the surroundings are noisy (Frisina and Frisina, 1997). In this study, when voices were combined with background music, elderly residents' ability to perceive and differentiate the sounds was affected (Van Hoof et al., 2010; Müsch, 2008). In general, the evaluation of music was rated lower, which might be caused by the size of the space. It can be assumed that in a large, multifunctional space, different sounds are mixed together, and when (e.g.) the elderly people are unable to recognise and judge the content of sounds, they may become anxious and this may lead to a lower level of comfort. Therefore, the evaluation of the various sound sources in the rectangular living area (including the corridor and small activity room) was lower than that in the fan-shaped sunshine hall (activity area, quiet area, and rest area). The air-conditioning sound and background music can be heard in all areas, but in the fan-shaped hall they are slightly louder than the living area. Therefore, for the same sound source, the relatively noisy area received a slightly higher tolerance and evaluation of sound than the relatively quiet area.

3.3 Evaluation of the sound environment based on behaviours

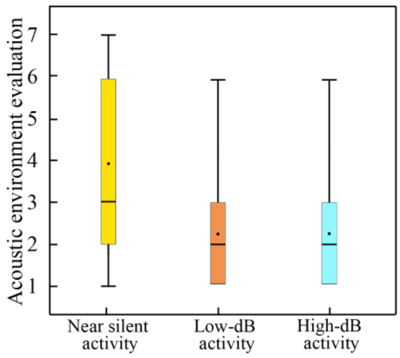
3.3.1 Sound characteristics of the activity types

As mentioned in the previous section, activity sound type and sound sources are more diverse and complex than the others; in this section, activity sounds will be classified to distinguish the impact of different SPLs on sound environment evaluation. A classification of three types of activities was mentioned before, in Section 2.3 ((near-) silent, low-dB(A), and high-dB(A) activity types).

Although the different areas of the activity hall are divided, the elderly residents engage in the same activities in these different areas. Figure 8 illustrates the elderly resident' subjective evaluation of the comfort of the overall sound environment in the activity hall, including sound environment evaluations of different areas and different types of activities. Figure 8(a) shows that the overall evaluation of the acoustic environment of the fan-shaped sunshine hall is low. Except for the 4-points average in quiet areas that are considered as being 'neither comfortable nor uncomfortable', the acoustic environment evaluations in the other areas are generally <3 points. Figure 8(b) shows the subjective evaluations of the acoustic environment when performing different types of activities. The evaluation of the acoustic environment for (near-) silent activities is significantly higher than that of low-dB(A) and high-dB(A) activities, between which there is no difference. This finding is similar to the results of Wu et al. (Wu et al., 2018) who stated that when the SPL increases, sound comfort decreases (Iachini et al., 2012; Wu and Kang, 2019).



a)



b)

Figure 8(a-b). Evaluation of the sound environment in the activity hall.

Table 4 shows the differences in evaluations of acoustic comfort for different types of activities ($F = 28.280$, $p < 0.001$). The mean value of acoustic comfort of (near-) silent activities (3.8 points) is significantly greater than that of low-dB(A) activities (2.28 points) and that of high-dB(A) activities (2.31 points). In addition to acoustic comfort, the evaluation of low-dB(A) activities relying on other characteristics is also significantly higher than for the other two dB(A) levels. This shows that the elderly expect quiet activities and quiet surroundings. However, it is strange that the evaluation of low-dB(A) activities is lower than the evaluation of high-dB(A) activities. This may be because low-dB(A) activities include too many speech sounds; previous surveys found that the elderly give poor evaluations of speech and singing sounds. Among them, the evaluation of low-dB(A) activities' loudness and intelligibility exceed 4.5 points, showing that the elderly thought that low-dB(A) activities were noisy. High-dB(A) activities like dancing and playing music attracted the attention of the elderly residents and received higher evaluations. While research by Meng and Kang has indicated that music can increase people's concentration and improve comfort (Meng and Kang, 2016) this study found that the elderly nursing home residents preferred (near-) silent activity sounds, while the sound evaluation of low- and high-dB(A) activity sounds depended on the degree of participation and personal preference.

Table 4. Comparison of acoustic environment evaluations of the three activity sounds

	(Near-) Silent Activities	Low-dBA Activities	High-dBA Activities	F	p	η_p^2
Acoustic comfort	3.80	2.28	2.31	28.280	0.000	0.157
Loudness	3.65	4.50	3.92	8.932	0.000	0.056
Noise level	3.53	2.77	2.92	8.124	0.000	0.051
Intelligibility	3.78	4.76	4.45	11.540	0.000	0.071
Preference level	3.36	2.72	3.06	5.826	0.003	0.037

3.3.2 Influence of the participation degree on acoustic comfort

There were different evaluations of acoustic comforts between the elderly participants and the onlookers during some of the activities. Meng and Kang stated that activity type has an impact on acoustic comfort. For instance, music-related activities increase the comfort of participants and onlookers, while activities related to human voices reduces the acoustic comfort of onlookers (Meng and Kang, 2016). In order to confirm this statement, four of the most participated-in activities in the nursing home were selected for acoustic environment analysis, as shown in Table 5.

Table 5. Acoustic comfort of participants and onlookers in different activities

Playing chess	Participants	Onlookers	t	p	η_p^2
Acoustic comfort	2.973	2.222	1.532	0.131	0.042
Preference level	3.243	2.500	2.141	0.037	0.051
Loudness	2.784	2.278	1.217	0.229	0.019
Noise level	3.568	2.333	3.482	0.001	0.127
Intelligibility	3.000	2.111	2.334	0.023	0.059
Playing cards	**Participants**	**Onlookers**	**t**	**p**	η_p^2
Acoustic comfort	3.583	2.167	2.550	0.021	0.289
Preference level	4.583	1.667	6.667	0.000	0.735
Loudness	3.417	2.000	3.400	0.006	0.259
Noise level	3.833	2.500	2.126	0.049	0.220
Intelligibility	4.500	2.500	2.579	0.020	0.294
Dancing	**Participants**	**Onlookers**	**t**	**p**	η_p^2

Acoustic comfort	4.143	2.571	2.696	0.01	0.134
Preference level	3.457	2.714	1.434	0.161	0.033
Loudness	4.086	3.000	1.823	0.075	0.066
Noise level	4.057	2.714	2.49	0.016	0.117
Intelligibility	3.514	2.357	2.205	0.035	0.075
Singing	Participants	Onlookers	t	p	η_p^2
Acoustic comfort	4.080	3.038	2.408	0.020	0.106
Preference level	3.520	3.077	0.812	0.421	0.013
Loudness	3.800	2.577	2.964	0.005	0.152
Noise level	3.480	2.654	1.556	0.126	0.047
Intelligibility	3.760	3.231	1.098	0.278	0.024

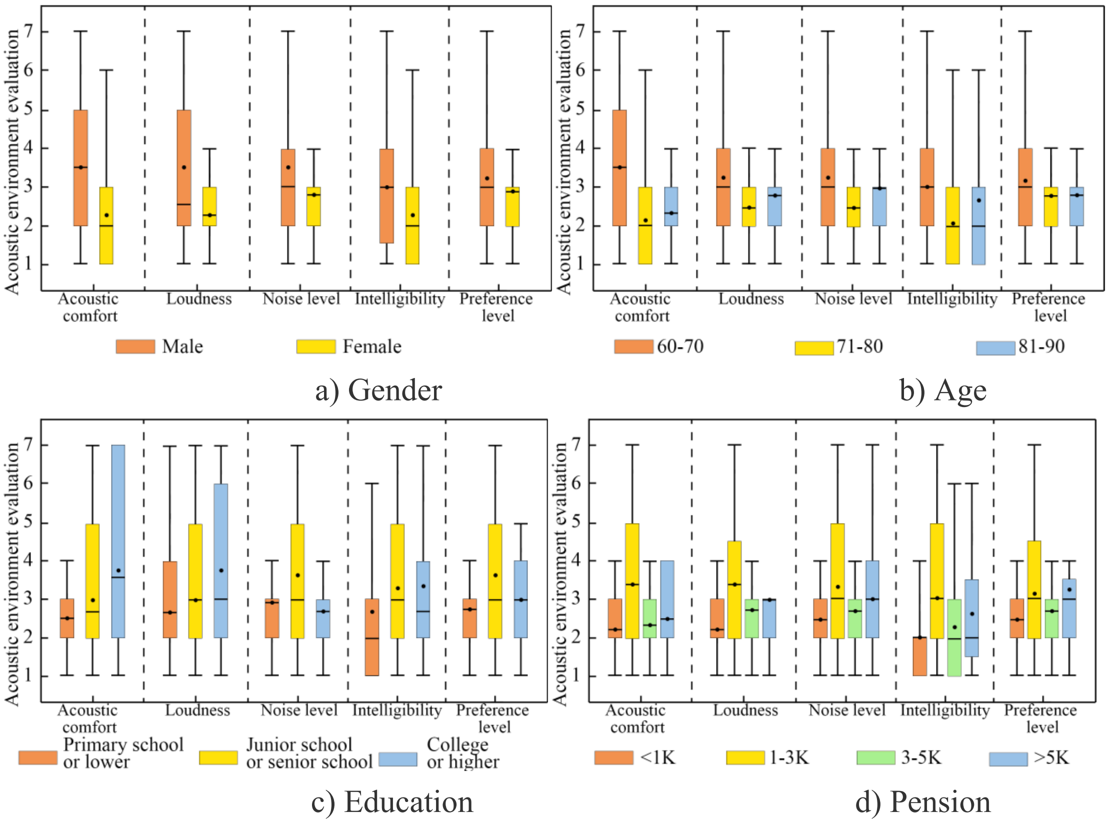
Table 5 shows that except for playing chess ($p=0.131 > 0.05$), there are significant differences in the acoustic comfort of the participants and onlookers in all the other activities. The onlookers have lower acoustic comfort levels than participants, and music-related activities (singing and dancing) are more comfortable than vocal activities (playing chess and cards). However, the noise level of playing chess is higher than the other indicators, which means that participants are susceptible to interference from surrounding sounds. This may be because playing chess requires both concentration and a quiet environment to avoid distractions. In terms of playing cards, the ratings of loudness and intelligibility by participants are higher than those by onlookers ($p < 0.05$). This shows that the onlookers are more relaxed and can communicate with each other, yet that the speech sounds of these onlookers will affect the participants and reduce the participants' acoustic comfort. It is interesting to see that the participants' preference level for playing cards is highest out of all the activities (4.583 points). Subjective preferences for this particular activity may be one of the reasons for the higher comfort levels of the participants when playing cards. In terms of noise levels, there are differences between the evaluation of dance participants and that of onlookers ($p < 0.05$); participants are easily interfered with by other sounds.

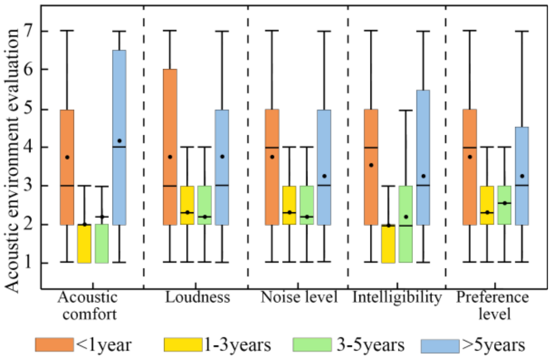
In short, the difference in the acoustic comfort of the elderly residents is only expressed in their degree of participation; that is, whether they are a participant or an onlooker. The acoustic comfort of elderly nursing home residents who participate in music-related activities will be higher than that of residents who participate in other activities, thus confirming Meng and Kang's study (Meng and Kang, 2016). However, for onlookers, the activities have little effect on acoustic comfort. Onlookers prefer to talk with each other and are mostly unbothered by loudness and SPL; only participants will be disturbed by these surrounding sounds.

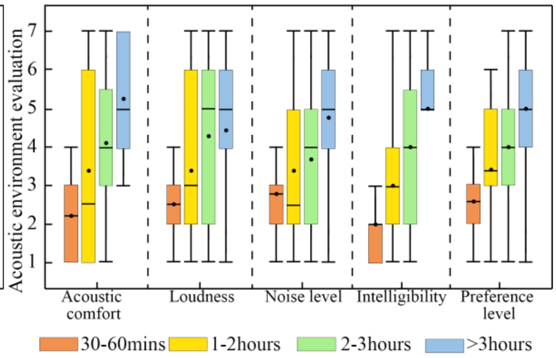
3.4 Effects of demographic and social factors

Many studies have proved that acoustic evaluations have a significant relationship with people's backgrounds (Meng and Kang, 2016; Lercher and Schulte-Fortkamp, 2003; Tamura, 1998; Liu and Kang, 2018; Yu and Kang, 2010) . Background here covers physiological factors (such as gender and age), social factors (such as education and pension), and degree of adaptation to the environment (such as length of residence, duration of use, and frequency of use). This section analysed the impact of these factors on the elderly's evaluation of the acoustic environment.

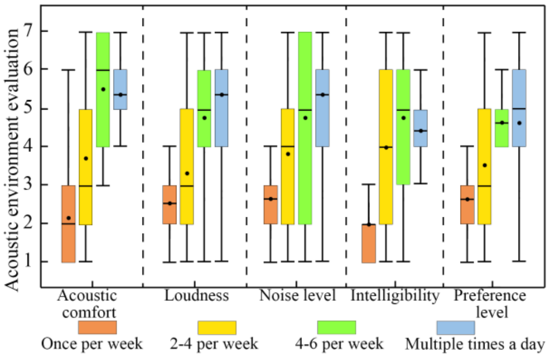
The mean difference between elderly men and women is shown in the acoustic evaluation. According to Figure 9a, elderly men have higher preferences than women in all the listed indicators, especially acoustic comfort. A site-specific survey by Wu et al. (Wu et al., 2020) showed not much difference between men and women with regard to acoustic comfort, which is inconsistent with the results of this study. This may be due to the different research objectives, or because the requirements for sound were not very high in Wu et al.'s study (Wu et al., 2020) . In addition, however, the activities of the elderly in the nursing home in this study are more susceptible to the surrounding environment than in that study. According to Meng and Kang (Meng and Kang, 2016) men were more comfortable with the acoustics than women when engaging in their favourite activities. This is consistent with this study's findings, as recreational activities in nursing homes are more in line with the needs of older men and while participating in their preferred activities, they are more likely to rate their acoustic comfort as higher. In terms of age, this study surveyed the elderly over 60, different from other surveys divided into younger elderly and older elderly people (Du, 2020). Therefore, the comfort of the younger elderly people (60–70 years old) is higher than that of those aged over 70. This may be because the hearing functioning of elderly people aged between 60 and 70 is better than that of elderly over 70 years old, and they may feel anxious and frustrated as their hearing is gradually reduced (Lacerda et al., 2012). Elderly people who attended junior high school education have the highest rated evaluation of sound. And the group of elderly with pensions between 1000 and 3000 yuan/month have a higher acoustic evaluation than the other elderly residents. Figure 9(e) also shows that acoustic evaluation is affected by the length of residence; a longer period of residence in the nursing home resulted in a lower satisfaction level. This indicates that newcomers are relatively satisfied with the environment of the nursing home, but that acoustic environment issues that lead to a decline in acoustic comfort over time. The sound evaluation of the residents who use the activity hall for a long period of time is higher than that of residents who use it for a short time. This shows that as usage time increases, the elderly gradually adapt to the noisy acoustic environment of the activity hall. The acoustic evaluations of usage frequency and usage time are consistent, and the evaluation of the high-frequency users is higher than that of the low-frequency users.







e) Length of residence f) Usage duration



g) Usage frequency

Figure 9(a-g). The relationship between acoustic evaluations and elderly demographics.

4 Conclusions

This research focuses on the elderly residents' evaluation of their acoustic comfort according to a site observation, sound measurements, and a questionnaire conducted for an activity hall in a nursing home in Harbin, China.

In general, the participants evaluated the acoustic environment in the activity hall with a low rating. The SPL measurement found that its two peaks in the event hall were within one hour: before lunch and dinner. When the RT exceeded 4 s and the SPL exceeded 65 dB(A), the acoustic environment evaluation declined.

Regardless of types of sound, the elderly residents' evaluation of their satisfaction with the acoustic environment declined as SPL increased; however, the decline in their evaluation of music was slower than for other sound types, and their satisfaction and preference for music sounds were higher than for other sound types. The questionnaire found that speech sound had the greatest impact on the elderly; thus, this score was the lowest. The results imply that they were unbothered by mechanical sounds in the hall, since they were less sensitive to them and the low frequency did not influence them. The foreground music score was the highest, and so it appears that proper music provision can help improve elderly people's evaluation of an acoustic environment. For the same sound source, a relatively noisy area had a slightly higher tolerance and higher-rated evaluation of sound than the relatively quiet area.

The respondents preferred (near-) silent activities, while the sound evaluation of low-dB(A) and high-dB(A) activities depended on both the degree of participation in the activity and personal preference. Degree of participation will impact elderly people's acoustic comfort, and the participants' acoustic evaluations were generally higher than those of onlookers. Music-related activities (singing and dancing) were more comfortable than vocal activities (playing chess and cards); talking sounds from onlookers affected the evaluations, but this effect was offset by the increase in concentration. There was no reliable evidence to prove that reasons other than the music-related activities caused their acoustic evaluation to decrease or increase.

Acoustic comfort, preference, and noise levels are affected by subjective perceptions, and loudness and clarity are affected by physical conditions. In this study, the acoustic comfort of the elderly men was generally higher than that of the women, and the acoustic comfort of the younger elderly (60–70 years old) was higher than that of the older elderly. Respondents with a junior high school education had the highest-rated evaluation of sounds. The longer the length of residence in the nursing home, the lower the satisfaction, and the acoustic environment of the elderly who occupied the activity hall for a long period of time was higher than those who used the activity hall for a short while.

After investigation, we concluded that the nursing home has a good overall environment and facilities, characterised by its large-scale comprehensive activity hall, but that the acoustic environment in the event hall is not ideal. Although the lobby has designated areas such as rest and activity areas, sounds interfere with each other and 'bleed across' these areas. This shows that large spaces and a diverse type of activities cannot completely eliminate negative effects of sound. Respondents may feel nervous and irritable due to the complex sound environment in large spaces. Therefore, it is recommended that in the design of facilities for older people, large activity spaces should not be included. During the questionnaire, the residents generally showed a willingness to participate, but their understanding and feedback were poor; in the future, the questionnaire's design should be more concise, efficient and suited to elderly people's characteristics, while avoiding technical or confusing words. Moreover, the questionnaire found that the elderly had a higher-rated evaluation of both background and foreground music. Thus, future research could consider adding music more suitable for older adults, as music that annoys them could result in an instant negative evaluation, to investigate their evaluation of large spatial acoustic environments. In addition, future studies could analyse the satisfaction of the residents by comparing the acoustic environment of an open lobby area with that of closed rooms.

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CRediT authorship contribution statement

Jingyi Mu: Investigation, Data curation, Methodology, Formal analysis, Visualization, Writing-original draft, Writing-review & editing.

Jian Kang: Supervision, Writing - review & editing.

Yue Wu: Resources, Investigation, Software.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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