

Article

Sound Perception of Blind Older Adults in Nursing Homes

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Abstract: The number of blind older adults is gradually increasing with the aging of world's population, and their needs and perception of sound are specific. This study investigated the behavioral activities of blind older adults and the dominant sound sources through on-site observation of an all-blind nursing home in China, and it used semi-structured interviews to obtain the sound perceptions of blind older adults. The findings showed that the daily behavioral activities can be categorized into basic living activity, leisure activity, social activity; and physical activity. The dominant sound sources included human, equipment, informational, and environmental sounds. This study developed a sound perception model of blind older adults in nursing homes, which takes three levels: sound requirements, acoustic environment, and sound cognition. Firstly, the blind older adults have a basic understanding of sound from the perspective of their living needs, then they feel the sound environment from the perspective of the living environment, and finally, they perceive the acoustic environment from the dimension of sound cognition in conjunction with contextual memory. This study sheds a light on the aural diversity of older adults, which is expected to support the inclusive design of nursing homes for older adults with visual impairments.

Keywords: blind older adults; nursing homes; acoustic environment; sound perception; aural diversity; inclusive design



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1. Introduction

With at least 2.2 billion people suffering from vision impairment [1], an estimated 1.8 billion suffering from presbyopia [2], and 196 million having age-related macular degeneration, which is expected to increase to 288 million by 2040 [3], vision impairment along with aging has become a global public-health concern. In addition to congenital anomalies and accidents, the cataract, glaucoma, age-related macular degeneration, diabetic retinopathy, and presbyopia are common causes of vision impairment [4]. The number of people with vision impairment is gradually increasing with the increase of aging population, with 43.3 million people worldwide expected to be blind in 2020 [5].

To address the difficulties that visually impaired or blind people have in mobility [6–10], non-verbal sounds and/or speech, such as musical cues, are often used to convey shapes and figures [11,12], because visually impaired people acquire spatial information through hearing to deal with various challenges, especially in unfamiliar environments [13–15]. Miura et al. examined the mobility situation and mobility needs of visually impaired people and found that they could deal with impairment through acquiring auditory information with various strategies, such as rotating the head to hear environmental sound more clearly, or tapping the floor hard with a cane or foot to enhance reflective or reverberant sounds [16]. However, sound has both positive and negative effects on visually impaired people: footsteps and stick echoes can complement acoustic signals, and certain continuous sounds make orientation easier, while noise can interfere with sounds that

provide directional guidance [17]. Rychtarikova suggested that the known indoor sound sources are preferred by blind people and argued that the acoustic environment could help people to extract unfamiliar indoor space information, while excessive noise affects positioning [18]. In conclusion, the architectural acoustic environment is significant for people with vision impairment.

A poor indoor acoustic environment can not only harm the health of older adults [19–21], but may also hinder their everyday life in nursing homes [22]. Zeng studied the living environment of older adults in different functional rooms in 11 nursing homes in Guangzhou, China, and found that the acoustic setting had the most significant impact on the subjective evaluations of the older adults among all the physical settings of nursing homes [23]. Some studies, however, found that the acoustic quality of the building environment designed for the general population was largely inappropriate for the disabled and the elderly with hearing loss [24]. Other studies also found that the acoustic environment was the second crucial environmental parameter, just after the light, affecting the behavior and health of dementia patients [25], and a good acoustic environment was vital in helping to delay the onset and progression of Alzheimer’s disease [26,27].

Soundscape first proposed in 1929 [28] was later defined as the study of the effects of the acoustic environment on the physical responses or behavioral characteristics of creatures living within it [29]. The research on soundscape was gradually applied to the urban and architectural design, and formally introduced in the 16th International Congress on Acoustics [30]. And International standard ISO 12913-1 (2014) defines soundscape as “[the] acoustic environment as perceived or experienced and/or understood by a person or people, in context” [31]. Due to the important progress of soundscape research in both the natural and social sciences in recent years, many studies have explored the understanding and perception of soundscape in urban construction [32–35] and building type [36–40], and investigated the subjective perception of soundscape in specific populations such as children [41,42], the elderly [43,44], and people with disabilities [45,46]. In terms of the soundscape perception of blind people, Rychtarikova used in-depth interviewing with blind adults to understand their experience of the built environment and discussed the issue of the inclusiveness of soundscape [47], and reviewed the studies on topics related to sound and soundscape perception of blind people, and concluded that blind people perceive the reality also in a multisensory way [18]. Mediastika et al. found that the dimension of eventfulness of park soundscape and the dimensions of pleasantness and space of mall soundscape were the most prominent factors and suggested that the visually impaired used hearing to perceive the danger and direction of the soundscape [48,49]. Hearing differences lead to auditory diversity, and researchers have found differences in hearing levels among infants, adolescents, adults and older adults. We do not yet know how blind older adults perceive sound differently from others?

Generally, blind older adults can only choose to stay at home or live with other older adults in nursing homes [50,51], which brings up the needs to study the inconveniences of the environment for blind older adults. This study examined the only nursing home in China that provides the environmental and service support for blind older adults. As shown in Figure 1, this study first investigated the architectural environment and space of the nursing home, then observed the daily behavioral activities of the blind residents in the nursing home, and finally conducted semi-structured interviews with the blind residents on their sound perceptions, aiming to answer two main questions: 1. How do the blind older adults behave and what are the sound sources in nursing homes for them? 2. How do the blind older adults in nursing homes perceive sounds? This study expects to help nursing homes provide the better environmental support for blind older adults.

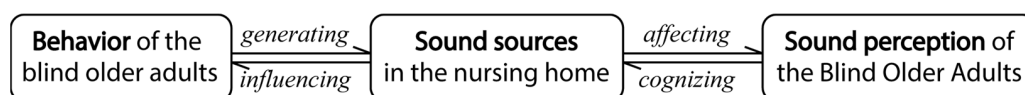


Figure 1. Research framework.

2. Materials and Methods

2.1. Field Survey

The all-blind nursing home where the study was conducted is located in Shenyang, Liaoning Province, Northeast China. It has five floors with a total of 96 care units. As shown in Figure 2, the first floor of the building composes of a multifunctional hall, activity rooms, office rooms, and rooms for other purposes, mainly for the daily activities of the blind older adults and the staff, the second to fifth floors of the building are for care units where the blind older adults live. In addition to the rooms for their daily activities, there are other care units for them to engage in social interaction and the corridors for them to stroll during inclement weather. There were about 30 to 50 blind older residents and 12 staff members at the time of study.

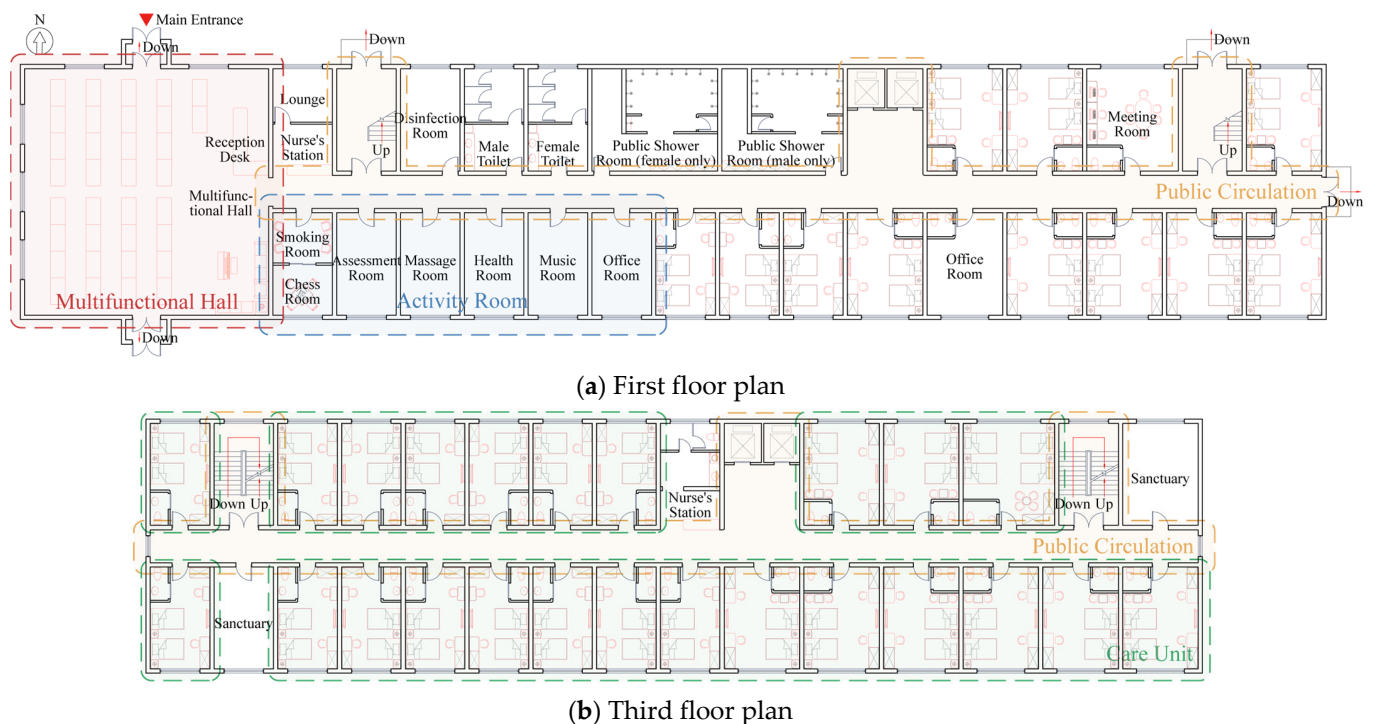


Figure 2. Floor plan of the nursing home. (Note: - - - Multifunctional Hall - - - Activity Room - - - Public Circulation - - - Care Unit).

Image acquisition is an important research method for observing the behavior of the observed [52–56]. To avoid the collision between the camera and the blind older adults, this study was conducted during the period from 5:00 to 20:00 when the residents were awake [21], on 20 July 2021 and 27 December 2021, with typical summer and winter weathers, respectively. The number and type of activities performed by the blind older adults in the six types of spaces—multifunctional hall, activity room, outdoor space, public circulation, and personal and other care units—were monitored and recorded in the nursing home. In addition, during the two days of the study, the researcher circled the nursing home every hour and recorded the sound sources that could be perceived indoors.

2.2. Field Interviews

In this study, the semi-structured interviews were conducted with the blind older adults and the staff members living in the nursing home in terms of the sound perception of the nursing home. The interview questions were:

- Q1. What do you think of the acoustic environment of the nursing home?
- Q2. What are your sound perceptions in the nursing home in your daily life?
- Q3. What sounds do you think need to be added to, or subtracted from, the nursing home?

The researchers took down in shorthand in the memos the participants' answers to the questions, and their own findings and reflections; afterwards the memos were transcribed; finally the transcripts were coded and entered into the Nvivo 11 software for analysis.

The definition of blindness was based on the criteria in Chinese National Standard on Disability Classification and Classification of Persons with Disabilities [57]. Two field interviews were conducted on 21 July and 28 December 2021, followed by the two behavior observations on the next days, respectively. And the data from 37 interviews and the basic information of the participants were collected, as shown in Table 1 and Figure 3. In order to not cause psychological stress to the blind older adults and to reduce their vigilance, the researchers were introduced by the nursing workers into the care units, to explain the purpose of the study and obtain the consent of the participants before conducting the interviews. The interviews were relayed and recorded. In accordance with local legislation and institutional requirements, this study was ethically reviewed by the Harbin Institute of Technology. Afterwards, the interview data were coded, induced, and clustered based on classical grounded theory [58–63] to construct a sound perception model of the blind older adults in nursing homes.

Table 1. Respondent profiles.

Measures	Items	The Blind Older Adults	Staff	All Respondents
Gender	Male	14	3	17
	Female	17	3	20
Age	50–	3	3	6
	50–59	12	3	15
	60–69	7	0	7
	70+	9	0	9



Figure 3. Age and sex distribution of the respondents.

3. Results

3.1. Behavioral activities and Sound Sources

3.1.1. The Behavioral activities of the Blind Older Adults

As shown in Figure 4, the blind older adults living in the nursing home have a consistent schedule for their activities. They usually wake up one after another at 5:00 a.m. Breakfast is served from 7:30 a.m. to 8:00 a.m. Before breakfast, the blind older adults rest

in their rooms or stroll in the courtyard. In the morning, they may spend time in activity rooms doing activities, such as singing, dancing, massaging, and playing cards, etc., or in their living rooms for entertainments, such as surfing the Internet, listening to songs, news, playing musical instruments, etc., and may also move to others' rooms to gossip together. After lunch, some blind older adults take a walk outside to digest food, while the others rest in their rooms. After a while, the residents nap in their own care units. From 14:30 to 16:30, most of the blind older adults gather in the multifunctional hall for some group activities, such as performing, playing games, and making dumplings, while the others entertain in their own rooms. After dinner, most of the blind older adults choose to walk, work out, or talk outside, while some remain in their rooms. After 19:00, all the residents retreat to their rooms to rest, and most of the blind older adults take their shower in the public shower room. After 20:00, the nursing home is quiet, for the residents fall sleep one after another. In winter, the cold weather reduces the residents' willingness to go outside, so most of them choose to walk back and forth in the corridors for exercise, wake up later in the morning and spend more time in the care units.

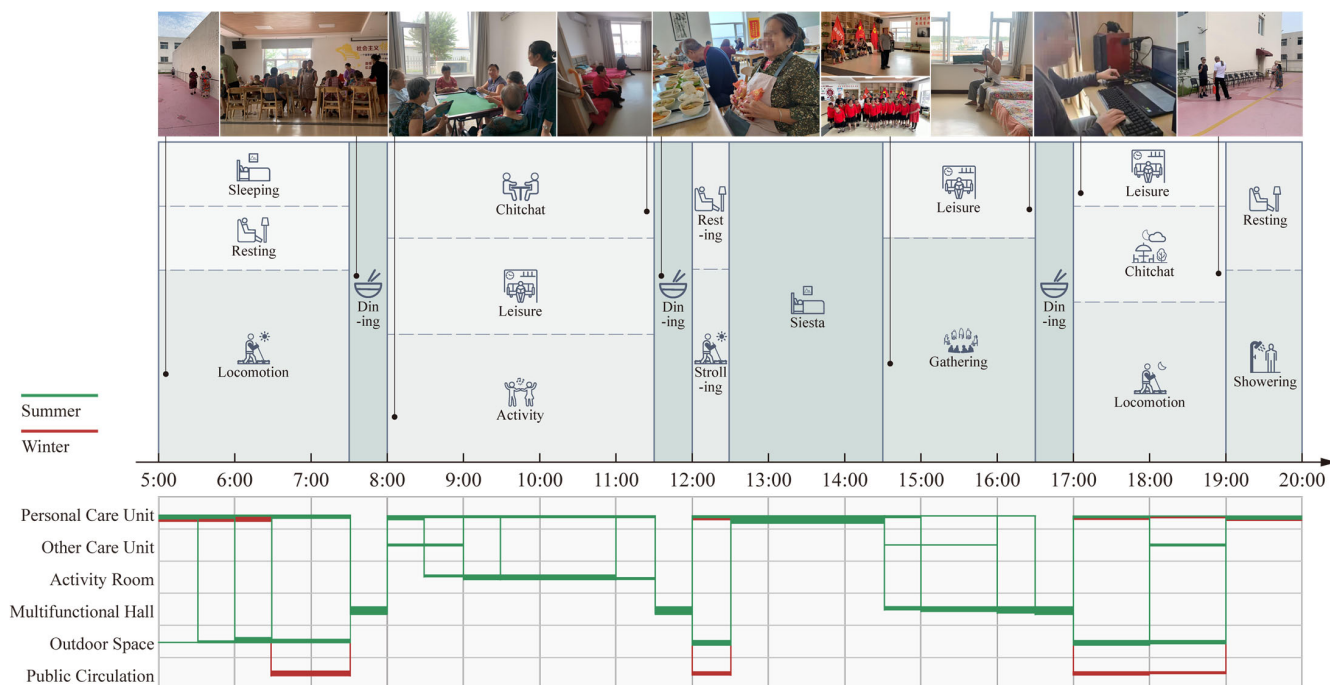


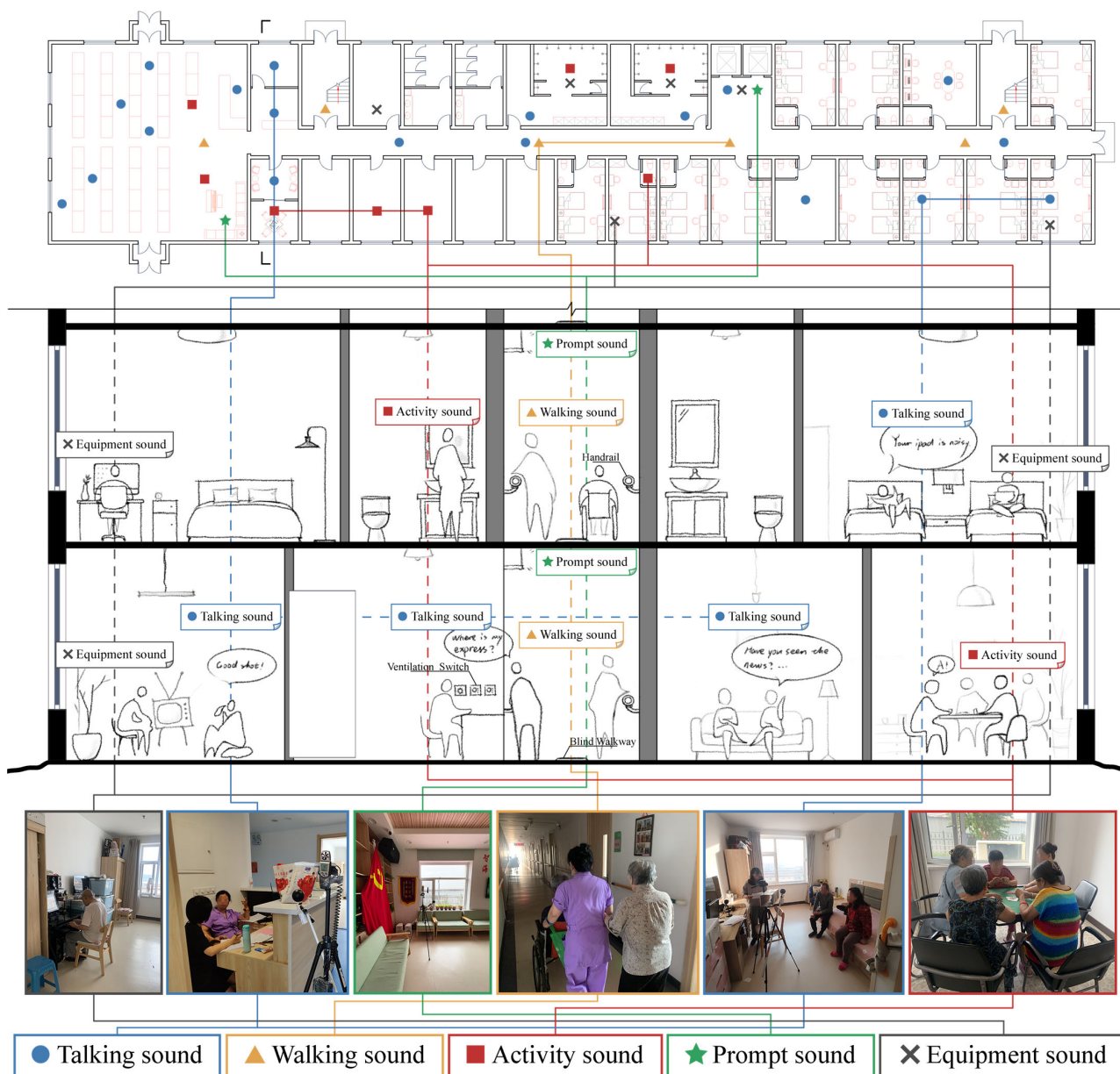
Figure 4. The daily behavior and space utilization of the blind older adults.

3.1.2. Sound Sources in the Nursing Home

Based on the data about the building layout, site conditions, user behavior, and sound sources in the nursing home, the study categorized four main types of sound sources: human sound, equipment sound, informational sound, and environmental sound. Firstly, the human sound refers to the sound generated by the behavioral activities of the blind older adults, such as talking, walking, and doing activities. Secondly, the equipment sound refers to the sound generated by the equipment and machinery in supporting the normal operation of the nursing home and the recreation of the blind residents. Thirdly, the informational sound refers to the sound generated to signal the movement and activities of the blind older adults, for example, a variety of audible messages set up at key points both indoors and outdoors in the nursing home. Finally, environmental sound refers to the sound in the surroundings of the nursing home, which can be heard inside the nursing home, such as traffic and natural sound. The types of sound sources in the nursing home are shown in Figure 5.

As shown in Figure 5a, the indoor sound sources in the nursing home are:

- Talking sound: It is generated in transport, activity and living spaces to meet the living, recreational, and social needs of the blind older adults.
- Walking sound: It is caused by walking with whistles, bells, claps, and other actions to avoid a collision; or moving with crutches and in wheelchairs.
- Activity sound: It is caused by the acts of singing, working out, playing musical instruments, and washing clothes, etc., in addition to the sounds of entertainment in the activity room.
- Prompt sound: It is equipped at the multi-function hall and corridors of the nursing home to deliver notices of meals and gatherings, in addition to the voice in the lifts that indicate the floor.
- Equipment sound: It is the mechanical sound generated by machinery that supports the operation of the nursing home and small appliances for the residents, such as the screen-reading sounds from electronic devices for the blind older adults, and the voice sounds from smart speakers.



(a)

Figure 5. Cont.

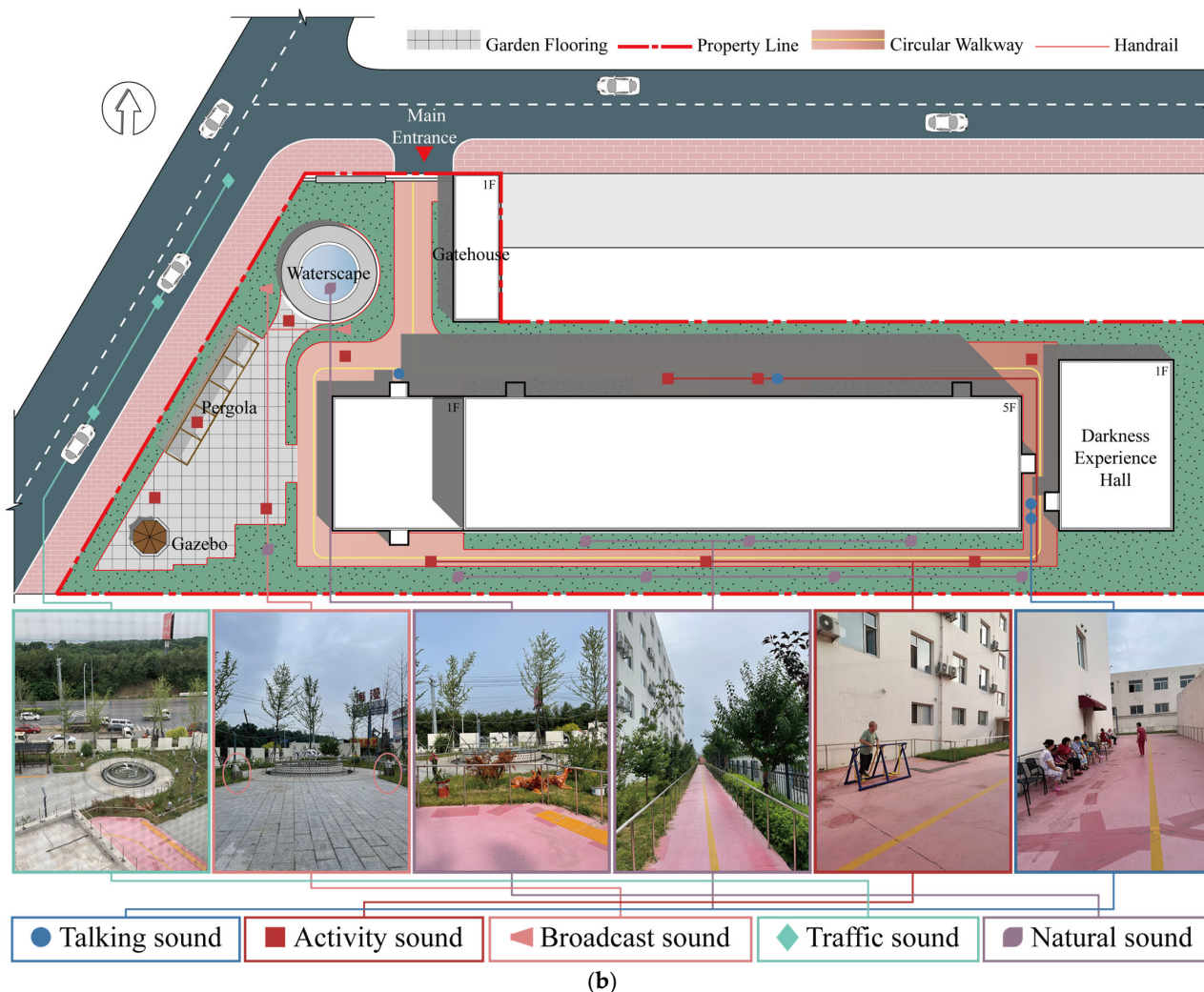


Figure 5. (a) Indoor sound sources in the nursing home; (b) outdoor sound sources in the nursing home.

Moreover, as shown in Figure 5b, the outdoor sound sources that can be heard indoors in the nursing home are:

- Talking sound: It refers to the sound of talking when the blind older adults gather together, before breakfast or after dinner.
- Activity sound: it is the sound generated by the walking or working out of the blind older adults outside before and/or after their three meals, when the weather is good.
- Broadcast sound: It is a music broadcast set up next to the waterscape in the northwest of the nursing home; to help the blind older adults orient themselves and count laps.
- Traffic sound: It is generated by moving vehicles and alternating signals, from the western and northern sides of the nursing home which are adjacent to traffic roads.
- Natural sound: It refers to fountain sound on the waterscape platform in the northwest of the nursing home, and the rustling or birdsong from the greenery and trees around the nursing home.

3.2. Sound Perception of the Blind Older Adults

3.2.1. Sound Perception Model Development

1. Open coding

This study did the open coding, which is the process of coding data line by line and conceptualizing and categorizing them, and breaking, crushing, and re-integrating

them through continual comparison [64]. The 25 sets of raw data from the first interview were summarized to the level of concepts and categories, as shown in Table 2. The initial extraction of memos was carried out, resulting in 74 labels (aa); then, the 74 labels generated 22 initial concepts (a) through the process of grouping the labels with the same content into one concept; finally the results obtained from the conceptualization were re-refined, resulting in nine initial categories (A). During the iterative process of comparing the categories, three core categories emerged, in terms of the sound perception of the blind older adults in nursing homes: “sound requirements” (A2, A5, A6), “acoustic environment” (A3, A7, A8), and “sound cognition” (A1, A4, A9).

Table 2. Open coding scheme of the sound perception.

Labeling (aa)	Conceptualizing Data (a)	Categorizing Data (A)
Equipment noise	Noisy feeling (aa1, aa19, aa20, aa41, aa56, aa68)	Sound perception (a1, a2)
Outdoor sounds can be heard when windows are opened	Sounds heard (aa2, aa51)	Noise controls (a3, a4, a17)
No outdoor sound can be heard with windows closed	Noise prevention (aa3, aa7, aa8, aa42)	Room assignment (a5, a16)
Affected by talking sound	Noise annoyance (aa4, aa5, aa6, aa38, aa45, aa46, aa52, aa54, aa60, aa62, aa69)	Soundscape memories (a6, a9, a14)
Affected by equipment sound	Acoustic layout (aa9, aa24, aa49)	Lifestyle needs (a7, a13, a15)
Annoyed by the sound of traffic signals	Emotional trigger (aa10, aa59)	Sound functions (a8, a11, a19, a21)
Closing doors can block sound	Sound insulation needs (aa11, aa67)	Loudness design (a10, a18)
Playing sounds to mask other sounds	Recreational means (aa12, aa13, aa16, aa31, aa36, aa37, aa44, aa53, aa55, aa57, aa64)	Sound source settings (a12, a20)
North room noisy	Sound preference (aa14, aa15, aa32, aa30)	Sound context (a22)
Traffic sound could cause fear	Moderate loudness (aa17)	
Good sound insulation may delay calling for help	Wayfinding role (aa18, aa21, aa34, aa35, aa43, aa65)	
Listening to news for entertainment	Sound source needs (aa22, aa52, aa66, aa71)	
Singing for pleasure	Quiet demand (aa23)	
Enjoying birdsong	Psychological dependence (aa25)	
Enjoying the sound of flowing water	Space requirements (aa26)	
Listening to novels for entertainment	Zoning methods (aa27)	
Broadcast sound should be designed to be just audible	Rule constraints (aa28, aa48, aa72)	
Prompt sound for residents who do not know Braille when finding their way	Excessive loudness (aa29, aa41, aa58)	
Others talking loudly	Information transfer (aa39, aa40)	
Others playing loudly	Sound source impact (aa33, aa47)	
Orientation by sound	Avoiding danger (aa50, aa63, aa70)	
... *	Lively atmosphere (aa61)	

* The rest of the labels are detailed in Appendix A, Table A1.

2. Selective coding

After the core categories were preliminarily determined, the data obtained for the second time underwent selective coding. In the process, only the content related to the core categories of the blind older adults’ sound perception in nursing homes was encoded [65]. As shown in Table 3, three new initial concepts were extracted and grouped into the categories of “sound perception” (a1, a2, a23), “sound source setting” (a12, a20, a24), and “sound context” (a22, a25); no new core categories were created.

3. Theoretical coding

This study also did the theoretical coding, to organize the implicit relationships between the categories formed in the process of substantive coding to build a theory [66]. In this study, three core categories of sound requirements, acoustic environment, and sound cognition were identified in the substantive coding process, and these core categories were found in a recursive relationship: first, the blind older adults obtain a basic understanding of

sound from the starting point of their living needs; then they feel the acoustic environment of nursing homes from the perspective of the living environment, and finally; they perceive the acoustic environment from the dimension of sound cognition in combination with contextual memory. The sound perception model of the blind older adults in nursing homes is shown in Figure 6.

Table 3. Selective coding scheme of the sound perception.

Labeling (aa)	Conceptualizing Data (a)	Categorizing Data (A)
Sharp sound will stimulate the heart of old adults	a12. Sound source needs (aa22, aa33, aa52, aa66, aa71, aa75, aa79, aa86) *	A1. Sound perception (a1, a2, a23)
Old residents are light sleepers and need quiet at night	a13. Quiet demand (aa23, aa76)	A8. Sound source settings (a12, a20, a24)
Broadcast sound for positioning and counting laps	a11. Wayfinding role (aa18, aa21, aa34, aa35, aa43, aa65, aa77, aa82)	A9. Sound context (a22, a25)
Staff greet each other with as little noise as possible	a17. Rule constraints (aa28, aa48, aa72, aa78)	
Prompt sound should be added to public shower	a23. Becoming habits (aa80)	
Getting used to loud noises	a20. Sound source impact (aa47, aa81)	
People who do not need a prompt sound will feel noisy	a24. Seasonal influences (aa83)	
Positioning wind chimes in canteens for orientation	a2. Sounds heard (aa2, aa51, aa84)	
No fountain broadcast in winter	a9. Sound preference (aa14, aa15, aa32, aa30, aa85)	
No nature sound can be heard	a6. Emotional trigger (aa10, aa59, aa87)	
Enjoying natural sound	a4. Noise annoyance (aa4, aa5, aa6, aa38, aa45, aa46, aa52, aa54, aa60, aa62, aa69, aa88)	
Equipment noise cannot be avoided	a22. Lively atmosphere (aa61, aa89)	
Annoyed by equipment noise	a25. Social environment (aa90)	
Affected by talking sound while resting		
Lively with sound		
The sound of cars means that people are nearby		

* Bolded parts are newly-emerging codes.

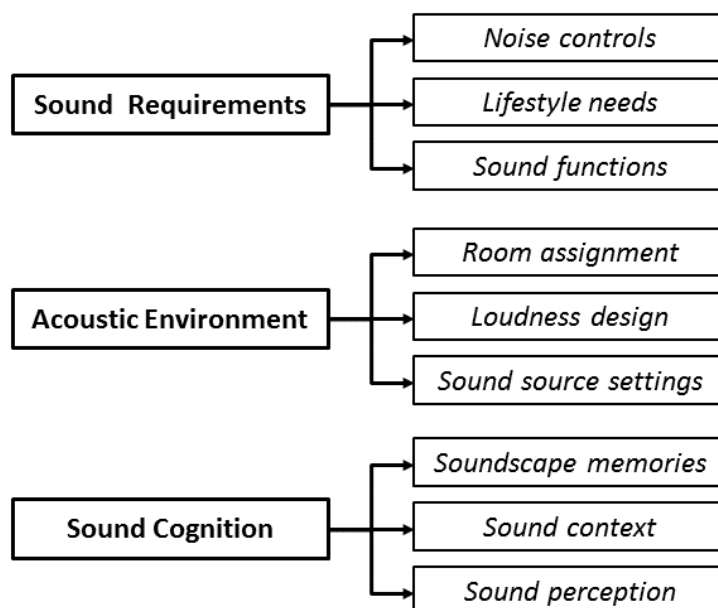


Figure 6. Sound perception model of the blind older adults in nursing homes.

3.2.2. Sound Perception of the Blind Older Adults in Nursing Homes

1. Sound requirements

Participants in the interviews indicated that sound was a vital ingredient in their daily lives, helping them to access information about the language and the environment, to avoid danger, and to be a constant companion and a major means of entertainment. However, sound, for example noise, may interfere with the life and rest of blind older adults. In addition, some participants stated that “I need a quiet environment when I speculate (aa23)”, “Blind people make more noise than normal people, so we need a separate space (aa26)”, and “We need to hear the outside world to make sure we are in a social environment (aa73)”. They also emphasized that “The sound insulation of nursing homes should not be too good, otherwise it will block old residents’ calls for help (aa11)”. It can be seen that the sound requirements of the blind older adults vary with the demands of life.

2. Acoustic environment

It was found that the acoustic environment influenced the sound perception of blind residents through the room allocation, sound source, and loudness setting in nursing homes. Since the blind older adults relied on the acoustic environment to understand and remember their current living environment [13], nursing homes created sound sources at particular points to convey key messages. For example, some staff members stated, “The sound of music broadcast makes it easy for the residents to determine their position relative to the building as they walk around the outdoor circular walkway, and can help them remember roughly how many laps they have taken (aa77). The music broadcast is not played in the winter when older adults will go out less (aa83)”. However, one resident stated that “Broadcast sound is too loud and affects the judgement of orientation (aa47)”. Therefore, the sound source setting and loudness design need to complement each other to achieve the best possible delivery. In addition, some participants would like to have “more audible warnings in public showers (aa79), in places difficult to walk (aa22) and when others pass by (aa50)”, and some stated that “Some places have prompt sound but I don’t know how to turn (aa66)”. These statements revealed the problems existing in the set-up of sound sources used to suggest the routes and warn of dangers in the acoustic environment of the nursing home which needs to be optimized.

The allocation of rooms by the managers was also found impact the acoustic environment of the nursing homes. For example, some participants felt that “the eastern part of the home is too noisy”. It may be because the east side of the nursing home is close to the traffic road, or may also be due to the managers placing in the east the senior residents who tend to make more noise because of their hearing loss and reduced mobility. However, a noisier environment is not necessarily bad, for some blind residents expressed their preference to a livelier environment. Therefore, conducting relevant investigations would benefit optimizing the layout of the acoustic environment and reasonably allocating rooms for the residents of nursing homes.

3. Sound cognition

The analysis revealed that sound cognition in the nursing homes was related to sound perception, soundscape memory, and sound context in minds of blind older adults. Wang investigated the acoustic demands in facilities for the elderly, and found that the most common unwanted sounds in general among older adults were people talking and other noises [67]. In the current study, most of residents interviewed expressed their understanding and acceptance, even though they often sensed the talking sound of others and felt the noise in the nursing home. And some residents interviewed even considered the sound of people talking a blessing stating that “We chat together in a good atmosphere (aa61)”, and “There are sounds that will feel lively (aa89)”. Since talking can be used to avoid loneliness [68], talking sound can make blind older adults feel that they are in a social environment.

The subjective preferences, personal history, and life experiences of the blind older adults produce different subjective perceptions of sound, and some perceptions were

combined with the scene at the time to form a soundscape memory [35]. However, there are individual differences in soundscape memory. Taking traffic sounds as an example, some residents felt “fearful of traffic sound (aa10)” and “annoyed by the sound of traffic signals (aa6)”. However, some reported that “hearing traffic sound makes us feel safe (aa59)”, “the sound of cars means that people are nearby (aa90)”, or “traffic sound makes me feel that we are living in a busy urban area (aa74)”. Therefore, in designing the soundscape to optimize the acoustic environment, the blind residents’ sound perception and soundscape memory and the context in which the sound is represented, need to be seriously considered. The reasonable control in the soundscape dimension and the enhanced soundscape design would enhance the health and well-being of the blind older adults living in nursing homes.

4. Discussion

4.1. The Relationship between Behavior, Sound, and Space

According to the behavioral findings in Section 3.1, the daily behavioral activities of blind older adults in nursing homes can be categorized into basic living activity, leisure activity, social activity, and physical activity [56]. As shown in Figure 7, firstly, the basic needs of the blind older adults were met in the care unit (living) and the multifunctional hall (food) in the nursing homes; secondly, their leisure and recreation generally occurred in their personal care units or activity rooms, while social activities mostly occurred in the multifunctional hall, outdoor space, and others’ care units; finally, the physical activities occurred in the outdoor space and public circulation of the nursing homes.

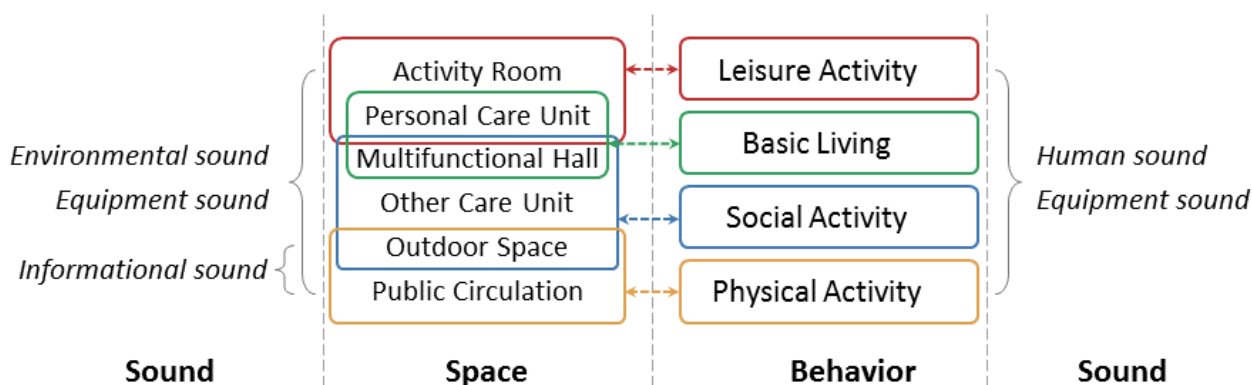


Figure 7. The relationship between behavior, sound, and space in nursing homes.

In this study, human, equipment, and environmental sounds were revealed as common sound sources in nursing homes [52,69–73]. Some of these studies found that staff sound was a major sound source in nursing homes, accounting for, for example, 26% [69] or 34% [72] of the total sound. However, the current study revealed that the staff members at the nursing home had already tried their best to avoid making noise around blind older adults so as to not confuse the information, as one staff member stated that “staff greet each other with as little noise as possible (aa78)”. In addition, the nursing homes set up the informational sound at the spatial nodes to provide assistance for the blind older adults, and blind older adults were more dependent on electronic devices for leisure activities. The nursing home that we investigated had more informational and equipment sounds, and fewer staff sounds, than ordinary nursing homes. In conclusion, the daily behavioral activities of the blind older adults generated the massive human sound; the building site environment brought the environmental sound to nursing homes; as such, the normal operation of nursing homes and the equipment and machinery supporting the residents produced equipment sound. And the architectural spaces of the nursing homes helped the blind older adults accomplish the daily life behavioral activities, and these sounds were both indispensable and unavoidable. Meanwhile, exploring the sound perception of the

blind older adults in nursing homes helped to understand the impact of these sounds on blind residents.

4.2. Comparison with the Soundscape Framework from ISO 12913-1

Firstly, Figure 8 shows the differences between the sound perception framework of the blind older adults developed in this study and the ISO soundscape framework. On the one hand, sound not only conveys verbal information and carries recreational activities, but also helps blind people orient, remember, and recognize things. It is a complement to the lack of vision [74,75] and a crucial tool for blind people to perceive the external world. On the other hand, sound may also interfere with the daily activities and rest of the blind older adults, such as noise. Noise can cause not only mental health problems, such as irritability, insomnia, and depression, but also physical health problems such as tinnitus, dizziness, heart disease, and cognitive impairment [76]. Miller systematically reviewed the effects of noise on people and suggested that older adults need a less noisy environment for both communication and sleep [19]. Harris found that adding noise into reverberant conditions resulted in significantly poorer speech recognition in older subjects than in younger subjects [77]. Maschke et al. examined the effect of noise on people of different ages and found that the background noise affects the comprehension of older people about conversation [78]. Moreover, the residents may feel annoyed, when exposed to noise, thereby causing various negative emotions. Noise annoyance, as a major effect of noise, was revealed as a multifaceted psychological concept, including behavioral and evaluative aspects [79]. The blind older adults, therefore, need some sound sources to meet their demands, and avoid the interference caused by unwanted sound sources. In contrast to others, the sound requirements of the blind older adults have to be fulfilled. As for the undesirable sounds, from the perspective of the building users, they presented their response to noise, suggesting the importance of noise prevention and rule constraints. The nursing homes could meet the resident needs for noise prevention and control by reducing noise at the sources (e.g., aa42. purchasing silencing devices), blocking means in transmission (e.g., aa7. closing doors and windows), using sound masking at reception (e.g., aa8. playing sounds to mask other sounds), or adding human intervention (e.g., aa28. establishing management rules and aa48. exercising self-regulation). Moreover, from the perspective of designers, they may consider slope construction, plant greening, water features, and noise barriers around the building site, to block environmental noise from the outside and utilize the internal partition walls indoors to isolate equipment noise and materials such as acoustic cotton, acoustic panels, and felt to retrofit care units with poor sound insulation.

Secondly, some of sound requirements of blind older adults can be fulfilled with the acoustic environment of nursing homes. Since different building materials and reverberation times can indicate changes in the surroundings or space for blind residents, designers can help blind older adults understand their location by varying the reverberation time and footstep echoes caused by changes in the space volume, height or floor material, which managers of nursing homes may add to the interior nodes of nursing homes the wall plants or small ornaments such as wind chimes and birdcages, to create beautiful sounds for blind residents and help blind older adults make orientation judgments. In addition, as for acoustic environments, some designers are more focused on controlling the physical parameters of sound, while others intend to use ideal sounds to create a good acoustic environment [61]. The blind older adults put forward their needs for sound and the acoustic environment from the perspective of users, providing a new design direction for designers. As for the acoustic design of the living environment of the elderly or the disabled, especially the visually impaired, the should reasonable room layout, the sound insulation measures and the special needs of users should also be considered.

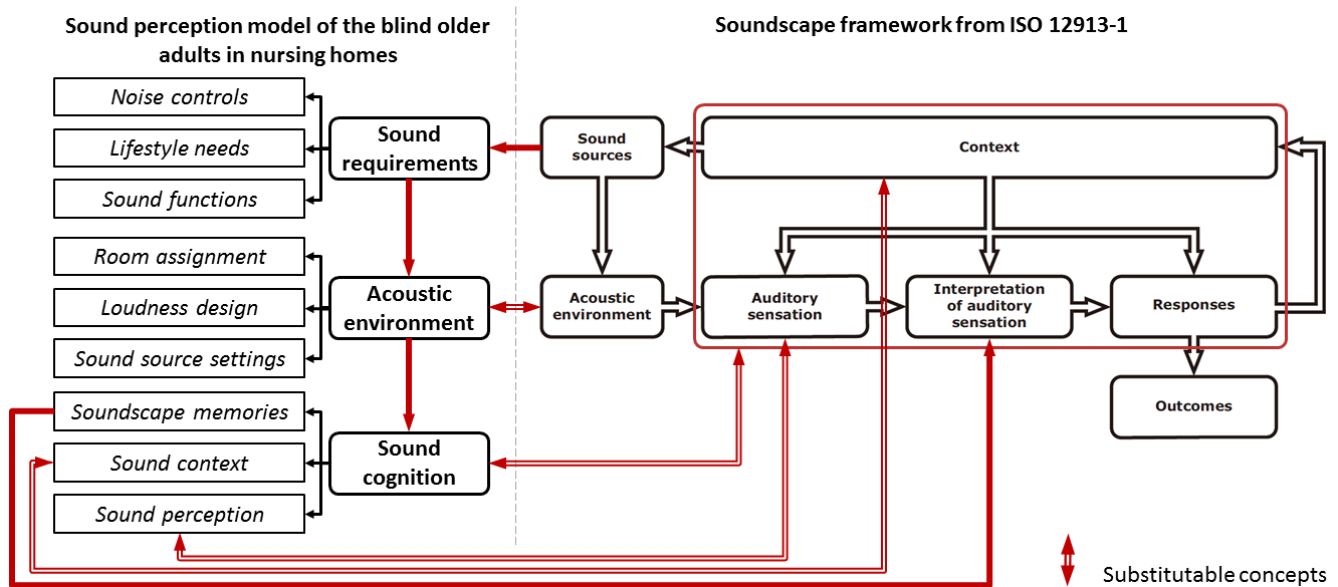


Figure 8. Differences between the sound perception framework of blind older adults and the ISO soundscape framework [31].

Thirdly, the acoustic environment describes the sound and defines the environment from the level of energy, while the soundscape mainly discusses people's perception of sound energy at the psychological level [80]. People's perception of sound depends on the acoustic environment, their attention, current activities, expectations, and prior knowledge [81]. Soundscape represents the relationship between people and the acoustic environment [82]. Similarly, sound perception refers to auditory sensation in ISO's soundscape framework in this study. Since blind people use known information to form mental maps [83] to support action [13,84,85] and hearing is involved in the perception, processing, and evaluation of information along with mental processes [86]; the soundscape memories forming during this mental process become part of the interpretation of auditory sensation. Furthermore, they are influential factors in the soundscape perception of blind older adults along with the sound context. Therefore, designers can add musical fountains, running water and plants to create a soundscape suitable for the site conditions, for the following reasons: the fountain has strong plasticity and can adapt to different sizes, and the running water can produce a signature sound of linear space. Moreover, plants can not only block the noise, but also create a good auditory feeling with wind or rain, and additional bird feed trees can be planted at the peripheral green belt of nursing homes attracts birds, for the songs of bird can increase the layers of natural sound. In sum, these strategies can be applied to enrich the soundscape layout of nursing homes.

4.3. Limitations

First, only one all-blind nursing home was investigated in this study, and thus the study based on this one case may not be comprehensive enough to explore all aspects of the issue. Second, this study focused on the subjective perception of blind older adults, without considering the physical environment, building materials of nursing homes, and the influence of the building interior decoration on the acoustic environment. Future studies may explore the complex relationship between the physical environment and sound perception of blind older adults living in nursing homes.

5. Conclusions

This study explored the relationship between space, behavior, and sound through on-site observations and semi-structured interviews in the only all-blind nursing home in

China, investigating the sound perception of the blind older adults in the nursing home, and developing a model of sound perception.

The daily behavioral activities of blind older adults in the nursing home can be categorized into basic living activity, leisure activity, social activity, and physical activity. The architectural spaces of the nursing homes help the blind older adults accomplish the daily life behavioral activities the sounds of nursing homes are both indispensable and unavoidable. The dominant sound sources that can be perceived inside the nursing home included human sound, equipment sound, informational sound, and environmental sound. The daily behavioral activities of the blind older adults generated massive human sound; the nursing home produced the informational sound to support the mobility of the blind older adults; the normal operations of nursing homes and the equipment and machinery produced equipment sound; the building site environment brought environmental sound into nursing homes. And the blind home had more equipment sound and less staff sound than other types of nursing homes, for it needs informational sound to provide location information for blind residents.

The blind older adults' perception of nursing home acoustics consists of three levels: sound requirements, acoustic environment, and sound cognition. Firstly, the blind older adults highlighted their needs for sound and their opinions about noise from the perspective of their daily lives. Second, the blind older adults evaluated the current situation of the acoustic environment in the nursing home from the perspective of the residential environment and suggest the improvement. Finally, the sound perception experience of the blind older adults was reflected on the dimension of sound cognition, combining the sound context with the residents' experience. The blind older adults, therefore, need sound sources to meet their requirements, and avoid the interference caused by other sound sources. The sound requirements of the blind older adults need to be fulfilled, especially the need for the setting of the informational sound source. In addition, soundscape memory, as part of the interpretation of auditory sensation, was found affect the sound cognition of blind older adults along with the sound context.

This study shows that older adults having aural- diversity experience and auditory impairments/hearing loss affected their perception of the acoustic environment, and confirms that the visual impairment brought about the differences in sound perception and was related to the differences in the daily behavioral activity and sound requirements of the blind older adults. Since sound is a necessary element for them to perceive direction, activity and other people, silence is not necessary for them during the daytime. Therefore, the aural diversity of the older adults places a higher demand on designers and institution managers for inclusion and refinement to better serve the needs of blind older adults with different visual impairments.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of School of Architecture, Harbin Institute of Technology.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The original data from the study are included in the text and Appendix A; further inquiries can be directed to the respective author.

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Appendix A

Table A1. The rest of the labels in the open coding.

aa22. Add sound in places difficult to walk	aa23. Needing a quiet environment	aa24. Noise in public areas
aa25. Dependence on sound	aa26. Needing a separate space	aa27. Partitioning by demand
aa28. Establishing management rules	aa29. Broadcast sound is too loud	aa30. Do not like the sound too loud
aa31. Chatting in the computer channel for entertainment	aa32. like to listen to sounds	aa33. The external acoustic environment is important
aa34. Sound for direction finding	aa35. Listen to the sound to find the way more convenient	aa36. Like musical instruments
aa37. Likes to play computers	aa38. Human sound has little effect	aa39. Prompt sound does not work after familiarity
aa40. Floor prompt sound is necessary	aa41. The sound of opening and closing the door is loud	aa42. Purchasing silencing devices
aa43. Put the radio to confirm the position	aa44. Listen to book machine entertainment	aa45. Affected by mechanical sound
aa46. Influenced by the sound of others' activities	aa47. Broadcast sound is too loud and affects the judgement of orientation	aa48. Exercising self-regulation
aa49. The eastern part of the home is too noisy	aa50. There should be a prompt sound when people pass by	aa51. There is a talking sound in the morning when the window is opened
aa52. Hope to block the mechanical sound	aa53. Smart speakers' function has defects	aa54. The equipment with the speakers on when opening the door will affect others
aa55. Sound is the main means of entertainment	aa56. Computer screen reading noise	aa57. Daily chat entertainment
aa58. The music broadcast sound is loud	aa59. Hearing traffic sound makes us feel safe	aa60. Traffic sound affects sleep
aa61. Chat together in a good atmosphere	aa62. Wake up at night with sound	aa63. Clap and whistle when I walk
aa64. Chatting with smart speakers	aa65. Sound should be added at the corners	aa66. Some places have prompt sounds but I do not know how to turn
aa67. Poor sound insulation of the door	aa68. The sound of the door opening in the stairwell is particularly noisy	aa69. Affected by walking sound
aa70. Need to add the sound of emergency assembly	aa71. Want more natural sounds	aa72. The equipment with the speakers on will affect others
aa73. Hearing outside sounds to identify myself in the social environment	aa74. Traffic sound makes us feel that we are living in a busy urban area	

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