SOUND PERCEPTION AND THE WELL-BEING OF VULNERABLE GROUPS

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SOUND PERCEPTION AND THE WELL-BEING OF VULNERABLE GROUPS

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Editorial: Sound Perception and the Well-Being of Vulnerable Groups

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Editorial on the Research Topic

Sound Perception and the Well-Being of Vulnerable Groups

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INTRODUCTION

Sound environment is a significant factor to be considered in building sustainable and healthy urban communities and cities (Kang and Schulte-Fortkamp, 2018). The International Organization for Standardization (ISO) defines soundscape as an acoustic environment that is perceived or experienced and/or understood by a person or people in context (ISO, 2014). In general, the current soundscape researches have mainly focused on urban spaces (e.g., parks, open spaces, and streets) and functional buildings (e.g., hospitals, schools, offices and residences). The experience of environment can result in either positive or negative perceptual outcomes, which are in turn related to people's well-being and emotion state. In terms of a positive soundscape, for instance, natural environment as well as music can induce positive emotions and help restoring attention and reducing mental fatigue. On the other hand, as the World Health Organization (WHO) Environmental Noise Guidelines report (WHO, 2018), noise is a considerable public health issue which would lead to hearing loss, annoyance, sleep disturbance, and even cardiovascular and metabolic disease.

In most cases, the related experiments have discussed individual differences on soundscape evaluations such as comfort, tranquility, capacity for restoration and soundscape quality according to people's different demographic and social characteristics (such as age, gender, and income level), as well as their behavior status (such as sitting, resting and strolling). However, the differences between groups are not often given enough prominence in environmental psychology studies, particularly research on vulnerable groups.

Vulnerable groups involve human samples considered particularly susceptible to stress or undue influence in a research setting. Existing researches show that the elderly have special challenges for hearing in noise; noise would disturb patients' sleep and the noise level should not exceed 30 dBA at night inside the hospital; noise would even disturb children's cognitive development; and people with high noise sensitivity are more susceptible to noise (Xie et al., 2009; Zeng et al., 2021). Besides, a Review of Evidence in the WHO European Region which analyzed articles published between 2010 and 2017 (Dreger et al., 2019) indicated that there was a trend of higher environmental noise exposures in groups with lower socioeconomic position. However, there are still so many questions in sound perception of vulnerable groups, such as, "What kind of people are the vulnerable groups in urban or building sound environments?," "What are the differences between vulnerable groups and general persons in sound perception?," and "What sound environment is the best choice for different vulnerable groups?"

Therefore, this special issue aims at gathering articles talking about soundscape perception of vulnerable groups (including but not being limited to the aged, children, patients, and the low-income). The focus included theoretical aspects (e.g., relationships between sounds and psychological, physiological as well as behavioral pattern aspects, for instance, human health, psychological/physiological restoration, and emotion changes) and methodological aspects (e.g., protocols and procedures to gather acoustic and psychological data).

RESEARCH THEMES

Considering the broad scope of the call for papers, the topics and research questions addressed by the submissions we received were very diverse. Looking retrospectively at them, we tried to identify common themes and eventually clustered them under three main categories. There were: (1) adverse effects caused by noise on vulnerable groups, (2) potential benefits brought by soundscape for vulnerable groups, and (3) restoration of the sound environment in patients. The experience of the environment can result in either positive or negative perceptual outcomes, which are in turn related to well-being and emotional state on vulnerable groups. Thus, contributions to this particular research strand were particularly welcome to advance the scientific conversation on these issues.

Adverse Effects Caused by Noise on Vulnerable Groups

Benito et al. described the relationship between the traffic noise level and the perceived annoyance in the inhabitants of a city on the Northern Border of Mexico. The results show that the population is desensitized to traffic noise and does not perceive it as an annoyance. The flow of vehicles and the type of vehicles are the significant factors for the propagation and increase in the traffic noise levels. Women present a considerable appreciation of traffic noise perception instead of younger people who demonstrate a higher tolerance to high-level exposure. Yang, Feng et al. conducted a 7-month noise level (L_{Aeq}) measurement on a construction site of a reinforced concrete structure high-rise residential building in northern China. It was done to explore the acoustic environment on the construction site, the environmental experience of construction workers, the impact of noise on hearing and on-site communications, and the corresponding influencing factors. Qu and Tsuchiya investigated the relationship between wind turbine noise (WTN), noise perception, and self-reported health of people, and controlled for background characteristics of the residents in urbanized areas. The dose-response relationship was found between WTN and annoyance, moderated by age and degree of education. Cai et al. investigated the acute physiological effect of different noise-sensitive groups by indoor-level noise stimulus experiments under laboratory conditions, by observing heart rate variability (HRV) indicators, including Standard Deviation of NN intervals (SDNN), Low Frequency/High Frequency (LF/HF), and Heart Rate (HR).

Potential Benefits Brought by Soundscape for Vulnerable Groups

Yang, Wang et al. focused on the usually neglected acoustic environment and its effect on drivers' physiological state and driving behaviors. The results indicated that different sound scenarios in the highway tunnel showed significant differences in vehicle speed and steering wheel angle. Zhu et al. compared through soundscape evaluation including an analysis of the dominance of various sound sources, noise annoyance, and the perceptual dimensions of soundscape. Jiang et al. proposed a three-dimensional pleasure arousal dominance (PAD) emotional model to indicate whether the perception of one's music environment has influences on college students' emotion during communication in different indoor conditions including spatial function, visual and sound atmospheres, and interior furnishings. Zhang Zhang et al. conducted an independent sample non-parametric test to determine the significance of the differences between environmental evaluation results for each evaluation dimension and to summarize the compositions of sound and space elements in the positive and negative influence spaces. Liu, Xu et al. explored the reality of the soundscape preferences of Chinese urban residents in the general public landscape in the post-pandemic area, and then proposed design recommendations to meet the practical needs of people s preferences for landscape especially soundscapes in the post-pandemic area. Zhang, Kong et al. distributed questionnaires to believers and tourists inside and outside several well-known Han Chinese Buddhist temples in China to analyze the relationship between evaluations of temple soundscapes (including the overall acoustic environment and preferences for typical sounds) and mental health and the role of religious belief-related factors in this relationship.

Restoration of Sound Environment in Patients

Cui et al. used the methods of field observation, sound measurement, and questionnaire survey to explore the sound perception and preference of the elderly in the main indoor public space of a nursing home in Harbin. The results revealed that in terms of the temporal and spatial distribution of sound pressure level (SPL), the unit living space had the highest SPL, which was above 60 dBA. The reverberation time (RT) of the unit living space, medical and health care center corridor, was 2.15 and 2.13 s, respectively. Liu, Wang et al. used facial expression recognition software (FaceReader) to explore the influence of different sound interventions on the emotions of older people with dementia. The field experiment was carried out in the public activity space of an older adult care facility. The results showed that, in the music intervention, the valence in the first 80 s helps to predict dominance and acoustic comfort; in the stream sound intervention, the first 40 s helps to predict pleasure and acoustic comfort; for the birdsong intervention, the first 20 s helps to predict dominance and arousal.

CONCLUDING REMARKS

While the three themes discussed above certainly do not cover the full range of questions being discussed in the soundscape studies on vulnerable groups, they do detect a few "hot topics" and areas of interest for researchers and practitioners in the field. The psychological theory underpinning the environmental sounds perception processes could still be considered (at least) as evolving. There is a clear interest in making a connection with health and well-being frameworks and also an outlook toward the design and co-creation of open public spaces. Virtual reality techniques are now commonly used in perceptual experiments, together with onsite surveys and the analysis of "big data" from public sources. Going forward, it will be essential to include all possible stakeholders in the debate: the public, researchers, practitioners, artists, and professionals with different skills and expertise. This will help generate and test new hypotheses and triangulate methodologies and results.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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ORIGINAL RESEARCH
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Traffic Noise Annoyance in the Population of North Mexico: Case Study on the Daytime Period in the City of Matamoros

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Aim: The presence of noise in urban environments is rarely considered a factor that causes damage to the environment. The primary generating source is transportation means, with vehicles being the ones that affect cities the most. Traffic noise has a particular influence on the quality of life of those who are exposed to it and can cause health alterations ranging from annoyance to cardiovascular diseases. This study aims to describe the relationship between the traffic noise level and the perceived annoyance in the inhabitants of a city on the Northern Border of Mexico. The work carried out in a city represents the vulnerability characteristics: economic, social, and migratory of its sizable portion of the inhabitants. Due to that, it is impossible to identify precisely the number of residents as the number of vehicles in circulation.

Methods: The streets and avenues with an annual average daily traffic of more than 1,000 vehicles were considered for the measurement of traffic noise. The equipment used was a vehicle gauge with non-invasive speed radar; type I integrating sound level meters, with their respective gauges and tripods. A questionnaire was applied to people living within 250 m of the streets and avenues in which the noise was measured.

Results: The noise measurement found a parameter of LA_{eq} estimated for 12 h during the day, exceeding 70 dBA. The data received from the questionnaire were statistically tested by using Pearson's correlation tests. A total number of 2,350 people were participated, of whom 1,378 were women (58.6%) and 972 were men (41.4%). The age of participants is ranged from 18 to 75 years. The overall perception of traffic noise annoyance identified that 1,131 participants (48.1%) responded "Yes" as they considered the noise annoying. Participants who responded "No" as well as those who responded "Do not know" resulted in a total of 1,219 people (51.9%).

Conclusion: The results show that the population is desensitized to traffic noise and does not perceive it as an annoyance. The flow of vehicles and the type of vehicles are the significant factors for the propagation and increase in the traffic noise levels. Women present a considerable appreciation of traffic noise perception instead of younger people who demonstrate a higher tolerance to high-level exposure. This reflects the lack of information of the population around the noise problem and its effects.

Keywords: traffic noise, annoyance noise, perception, noise, urban soundscape

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INTRODUCTION

Technological advances, industry, and everyday activities influence noise in the urban regions. In addition, transport, construction sites, and rapid population growth are responsible for generating acoustic variations in urban centers. This means that all these activities break the natural balance of the environment, causing damage to any individual with a particular time and exposure level. The environmental noise is currently one of the main types of pollution in large cities, regardless of the development level (Echeverry Velasquez, 2011; Cohen and Castillo, 2017). Therefore, it is essential to recognize that as the population is concentrated in a particular area, in addition to the type of activities they carry out, the presence of environmental noise also increases (Zamorano González et al., 2015).

The population faces an environmental problem that is rarely conscious. Unlike other environmental pollution types, it is characterized by its progressiveness and the generation of adverse, direct, and cumulative effects on health. Daily exposure to loud sounds, even those of short duration, causes damage to the auditory threshold of humans, which increases with age (Alvarado et al., 2019). Some studies describe some health alterations caused by noise, which aim to explain the consequences of exposure to noise for a long time, particularly noise generated through transport, such as trains, planes, cars, and motorcycles (Vienneau et al., 2015; Christensen et al., 2017; Mueller et al., 2017; Park and Lee, 2017; Oh et al., 2019). Other proposals explain that transport noise can influence intellectual activities, disrupting reading, comprehension, and even memorization (Halin, 2016).

The literature review describes the need to identify health hazards and relate them to a hearing problem. Even the World Health Organization highlights the influence that vehicular traffic noise has on irritability, interference in communication, the sensation of annoyance. It can even affect the work performance due to fatigue caused by disrupting sleep. Insight of these consequences, noise is an environmental problem that is generally detrimental to the lifestyle and quality of life (Fyhri and Aasvang, 2010; World Health Organization, 2011; Zamorano González et al., 2015; Guski et al., 2016; Gasco et al., 2020). In this way, other studies agree that noise affects the quality of life, well-being, and mental health but require the inclusion of other transport means, as well as a greater methodological depth to improve their findings (Clark and Paunovic, 2018).

In the context of Latin America, the work of some authors stands out. In Brazil, studies on acoustic comfort and quality of life have been carried out in the following areas (Levandoski and Trombetta Zannin, 2020): noise annoyance perception (Paiva et al., 2019), the development of noise maps (Kirrian Fiedler and Trombetta Zannin, 2015), design of prediction models (Oliveira do Nascimento et al., 2021), and the noise generated by different means of transportation (Bunn and Trombetta Zannin, 2016). In Chile, studies focus on the elaboration of noise maps (Suárez and Barros, 2014), noise mapping methods (Bastián-Monarca et al., 2016), road noise estimation (Rey Gozalo et al., 2020), and the design of smartphone applications for noise monitoring (Aumond et al., 2020).

In case of Mexico, the work reported in English is minimal. For example, the study describes the noise level above 96 dBA in commercial areas (Environmental Noise in Mexico City, 2019). Another study defines the environmental noise as annoying but included it in a set of environmental aggressors without performing the measurements (Sánchez-Arias et al., 2019). While there are other studies, its diffusion in Spanish limits its dissemination at the international plane. Some examples are the qualitative study of different noise types exceeding 70 dBA (Rodríguez-Manzo and Juárez González, 2020), noise pollution generated in a border town center (Zamorano González et al., 2015), as well as noise associated with sleep quality and performance (Zamorano González et al., 2019). The previously mentioned evidence is the need for studies on noise, especially the noise generated by traffic and the impacts it has on the population, which are the results of the limited effort by a few authors in a country such as Mexico with a large population and geographical dimensions.

The regulatory framework in Mexico attempts to reduce the noise generation; however, the laws presented are particular to a specific sector, as is the instance of the standard that regulates noise inside workplaces (NOM-011-STPS-2001, 2001). Mexican Official Norm 081 defines the study and control of noise from fixed sources in the environmental aspect, published in 1995. According to the type of noise source, they only update the table of maximum noise exposure levels over the years (NOM 081 SEMARNAT, 1994, 2013). Other types of noise standards evaluate the levels generated by the automobile vehicles. However, their measurement must be performed in the verification centers, leaving aside the soundscape when the vehicles are in circulation.

In addition to the normative limitations, the social and cultural aspects of the populations located in border cities present a cultural diversity, a consequence of the migratory movements between the United States and Latin America. In this sense, the towns give a gap of inequalities, both in social rights and economic development, becoming vulnerable areas due to their lower level of well-being and quality of life (Consejo Nacional de Evaluación de la Política de Desarrollo Social, 2018).

Therefore, it is common for people to express distrust toward the institutions derived from ethnic and linguistic differences, representing an attitudinal barrier on the part of the participants (Calva Sánchez and Alarcón Acosta, 2018). This shows that the cultural differences can influence when carrying out any intervention or studies that address the environmental landscape (Zijlema et al., 2020).

The importance of carrying on the environmental noise studies concerning social aspects allows determining the quality of life of the inhabitants in a particular area (Paiva et al., 2019). The perception of noise nuisance of the population can be altered by personal variables, such as health status, age, and gender. Nevertheless, certain external conditions also influence the number of neighbors and the type of housing construction. For this reason, the population should be aware of being able to determine the objectives and subjective variables that influence the presence of noise, but likewise of its consequences (Koprowska et al., 2018).

The present study intended to cover a part of the research gap in Mexico and to join the effort of other authors in Latin America to study the environmental noise problem. This main objective of this study is to describe the relationship between the traffic noise level and the perception of annoyance in the inhabitants of a city on the Northern Border of Mexico.

MATERIALS AND METHODS

The research was developed during the period April to September 2016, in H. Matamoros, Tamaulipas, located in the northeast of Mexico and has a territorial extension of 4045.62 km^2. According to the data registered in the last available census, the city has 520,367 inhabitants, where 51.3% were women. The vehicle registry indicates a total of 132,938 cars (Instituto Nacional de Estadística y Geografía, 2015). These quantities could triple due to the migratory characteristics of the city; the first is due to the number of people who have the objective of crossing to the United States and do not achieve it, who remain indefinitely in the city. The second characteristic is a consequence of the deportation processes. A group of people establishes their residence "temporarily" with the firm desire to return to the United States; however, the wait could last for years. The third characteristic of importance of this study is the lack of control for foreign-origin vehicles since many cars cross the border but do not return to the United States (Figueroa-Hernández and Pérez-Soto, 2011).

At the time of this study, it was impossible to obtain the official records to allow random sampling. For this reason, an intentional procedure was followed for the selection of the assessment areas. The intersections with the highest traffic flow in the diverse sectors of the city were selected, considering the opinion of the research team. These streets possess the characteristics to be classified as secondary streets or roads because they are utilized for small length and with speeds in the range of 25–62 m/h. According to the law, it is essential to emphasize that this categorization refers to the antiquity of more than 15 years (Secretaría de Comunicaciones y Transportes, 2006).

The ideal scenario for vehicle capacity is to perform them continuously during a year, i.e., 24 h a day. However, it represents a significant consumption of resources, so the traffic samples are used as a strategy to optimize them. In this study, we installed a non-invasive speed camera, model SafePace, from the brand Traffic Logix, which records the data in the internal memory and allows it to be transferred to a computer via Bluetooth, with the software SP-Data. The measured vehicle capacity at each intersection was counted for 1 week. Initially, traffic dense identified 15 intersections, but the observation discarded four roads due to the maintenance and road repairs.

The present study used a reference for the measurement of traffic noise, the ISO-1996-1-2016 standard (International Standards Organization, 2016), in the absence of a national standard describing the environmental noise assessment procedures. It is worth mentioning that the standard points out the installation of type I sound level meters, which must be installed at the height of 5 m and 1½ m away from any facade. Besides, it describes the premise that noise levels may be evaluated at the height of 1½ m in open spaces, ensuring no noise reflecting barrier (Barrigón Morillas et al., 2016).

For this purpose, Quest 3M integrated the type I sound level meter with their respective calibrators. Due to the difficulty of locating the sound level meters at the height described previously, tripods of 4 m in height were used and located at a distance of 3 m from any facade or wall that could reflect the sound. In this case, the position will not represent a risk for the field personnel, and we tried to ensure that the measurements were as close as possible to those described by the standard.

Noise measurement is carried out in three periods of the day, from Monday to Friday: the first period is from 6.30 to 7.30 a.m.; the second is from 12.30 to 1.30 in the afternoon; and the third is from 5.30 to 6.30 p.m. The field measurements allowed to obtain the acoustic parameters as follows: equivalent continuous sound pressure level (LA_{eq12}), the maximum sound level (LA_{max}), and the minimum sound level (LA_{min}), which were transferred directly from the sound level meter through an USB connection to a computer.

In addition, during the fieldwork, the research team verified that, in the noise evaluations, the weather conditions were free of rain and thunder; the device also used a portable anemometer to verify that the wind speed was <3 m/s. When the weather conditions were different, the measurement day was canceled and rescheduled.

A questionnaire was used to obtain the information from the population about traffic noise perception, with seven questions used and requesting specific demographic information. The application of the questionnaire was carried out through the visits of the surveyors to each home within a radius of 250 m from the road intersection where the field personnel took the noise measurement. **Figure 1** shows the distribution of the evaluation points of this study.

RESULTS

Table 1 represents the information obtained from the vehicle gauge. It is observed that the values calculated for the average weekly traffic (AWT) and the values of the annual average daily traffic (AADT) exceed 1,000 vehicles on the different roads. Similarly, the data obtained from the sound level meter are presented, where it is observed that, in all zones, the LA_{eq} parameters estimated for 12 h during the day exceed 70 dBA, as well as the minimum values fluctuate between 51.8 and 61.8 dBA, while the maximum values are between 86.7 and 103.9 dBA.

As part of the fieldwork, we visited people living within the area to collect data. The questionnaire used requested the sociodemographic information such as gender, age, marital and school status, and work situation. Of note, 2,350 participants were interviewed in their homes, of which 1,378 were women (58.6%) and 972 were men (41.4%). The age of those with the highest participation was within a range of 18–30 years with a total of 867 participants (36.9%), while those over the age of 61 years were 252 participants (10.7%), being the range with the lowest participation. Due to many participants under the age

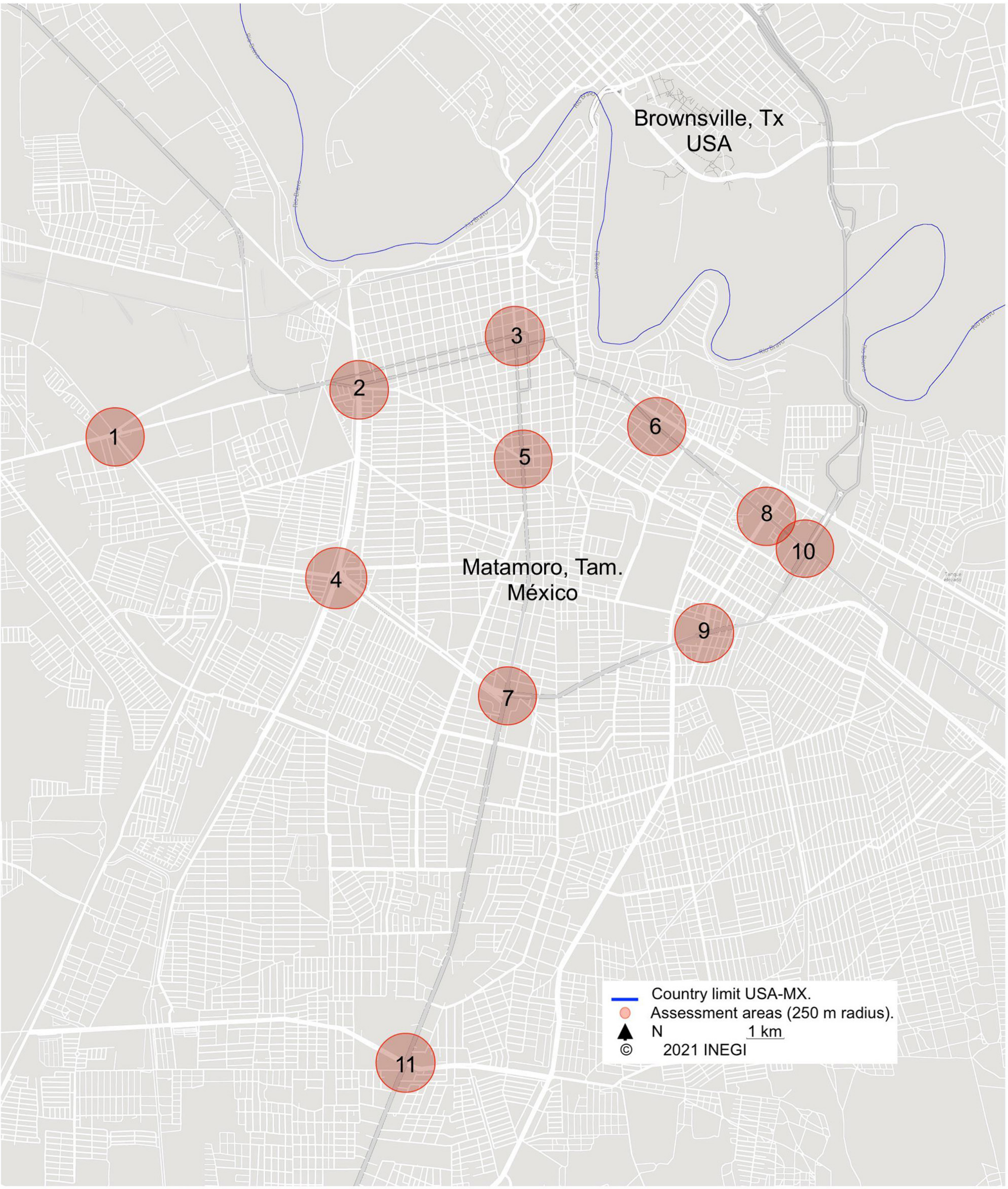

FIGURE 1 | Assessment areas.

of 30 years, the single marital status presented the involvement of 931 people (39.6%), unlike the widowed marital status, i.e., a total of 134 people (5.7%). The educational attainment level is represented by 561 people (23.9%) at the secondary level, while 58 people (2.5%) responded that they have some graduate degree. The employment situation of the participants found

TABLE 1 | Measurement results.

Area	Vehicles type		Traffic volume		Noise parameters		
	Lightweight	Heavy	AWT	AADT	L_{Aeq}	L_{AMin}	L_{AMax}
1	1,545	178	1,723	1,617	72.3	51.9	97.8
2	2,375	170	2,545	2,305	74.7	60.4	98.2
3	1,246	42	1,288	1,175	70.5	51.8	94.9
4	1,904	187	2,091	1,935	74.5	58.7	98.5
5	2,437	47	2,484	2,228	74.7	60.4	98.2
6	1,461	25	1,486	1,394	71.9	56.8	103.9
7	2,164	258	2,422	2,210	75.6	58.3	97.9
8	1,885	48	1,933	1,793	71.7	58.6	86.7
9	1,408	47	1,455	1,344	73.2	61.8	99.1
10	2,168	150	2,318	2,025	72.1	59.7	94
11	1,832	361	2,193	2,059	74.8	60.4	95.2

Extracted values of sound level meter and vehicular gauging device.

that 1,153 people (49.1%) have some employment, while only 7 people (0.3%) are unemployed or on strike. **Table 2** represents a cross-tabulation between the demographic data and traffic noise.

The traffic noise perception found that 48.1% of the participants responded that they do perceive it. The answer NO was identified in 38.8% of the participants, while those who responded that they Do Not Know resulted in 13.1%. The last two values stand out as a whole, which reveals that slightly more than half of the participants, 51.9%, do NOT identify or perceive the presence of noise, despite living in areas exposed to values higher than 70 dBA.

The demographic data allow us to identify the characteristics of the population that perceives traffic noise. Due to gender, 28.8% of women and 19.3% of men responded that they perceive traffic noise, representing 48.1% of the participants.

In the different age groups, 18–30 category (16%) of the participants responded that they do NOT perceive traffic noise, while in the other categories, 31–45 (12.8%); 46–60 (13.9%); >60 (6.1%), the highest response was YES. Such results demonstrate that the younger population has a lower appreciation of traffic noise.

In the schooling of the participants, the categories High School (8.9%) and University (7.3%) stand out, in which the participants responded that they do not perceive traffic noise. In the other educational levels, namely, Uneducated (9.1%); Elementary (11.1%); Junior High School (10.8%); and Post-graduate (0.5%), the participants responded that they do perceive the noise. Therefore, the results show that for the participants at a medium–high educational level, noise does not represent a factor that causes any type of displeasure or annoyance.

According to the occupation categories of the participants, namely, Unemployed (6.5%); Worker (22.3%); Retired (3.6%); Housewife (12.0%); and Student (3.7%), the participants responded that they do perceive traffic noise. Only in the Strike category (0.2%), they responded that they do not perceive the noise. This evidence that the different occupation categories of the participants, especially those employed and housewives are more accustomed to noise perception due to their daily activities.

In all marital status categories, namely, Married (22.1%); Single (20.0%); Widower (3.1%); and Divorced (0.9%), the participants responded that they do perceive noise. In this way, it implies that marital status may be related to some occupation, and consequently they have a better appreciation of the noise around them.

To describe the relationship between the variables, the Pearson's correlation test was used, finding that the noise levels and traffic noise perception represent very low correlations but with significant values of <0.05. The detailed results are discussed in **Table 3**.

The noise levels evaluated exceed 70 dBA in contrast to the perception of noise of the participants denotes a very low correlation, despite being significant. This implies that people do not pay attention and are even accustomed to the problems they are exposed to daily derived from vehicular traffic.

The variables "considering exterior noise" and "interior noise" also presented low, although significant correlations. Hence, this may imply that people confuse noise coming from different sources, impacting their perception of noise.

The variable concerning the time of the day they find noise most annoying represents a very low significant correlation with noise levels. However, a perfect positive correlation was found with noise perception.

Considering their street compared with the previous years showed no significant correlation concerning noise levels but did show a low significant correlation in terms of perception. Similarly, is the consideration of their street compared with the rest of the city? Therefore, people neither have a clear idea on the effect of traffic noise in previous years, nor do they have an evident appreciation of the noise of their street compared with other places in the city.

The annoyance or disturbance of street noise when inside or outside the home presented a significant negative correlation concerning noise levels and noise perception; this means that

TABLE 2 | Demographic data and noise perception.

	Noise perception							
	No		Yes		I don't		Total	
Gender	#	%	#	%	#	%	#	%
Male	394	16.8	454	19.3	124	5.3	972	41.4
Female	518	22	677	28.8	183	7.8	1,378	58.6
Total	912	38.8	1,131	48.1	307	13.1	2,350	100
Age	#	%	#	%	#	%	#	%
18–30	376	16.0	361	15.4	130	5.5	867	36.9
31–45	252	10.7	300	12.8	79	3.4	631	26.9
46–60	201	8.6	326	13.9	73	3.1	600	25.5
>60	83	3.5	144	6.1	25	1.1	252	10.7
Total	912	38.8	1,131	48.1	307	13.1	2,350	100
Education level	#	%	#	%	#	%	#	%
Uneducated	95	4.0	215	9.1	55	2.3	365	15.5
Elementary	189	8.0	262	11.1	90	3.8	541	23.0
Junior High School	234	10.0	254	10.8	73	3.1	561	23.9
High School	210	8.9	193	8.2	57	2.4	460	19.6
University	172	7.3	169	7.2	24	1.0	365	15.5
Post-graduate	12	0.5	38	1.6	8	0.3	58	2.5
Total	912	38.8	1,131	48.1	307	13.1	2,350	100
Employment status	#	%	#	%	#	%	#	%
Unemployed	114	4.9	152	6.5	63	2.7	329	14.0
Worker	486	20.7	523	22.3	144	6.1	1,153	49.1
Strike	4	0.2	2	0.1	1	0.0	7	0.3
Retired	34	1.4	85	3.6	15	0.6	134	5.7
Housewife	189	8.0	282	12.0	59	2.5	530	22.6
Student	85	3.6	87	3.7	25	1.1	197	8.4
Total	912	38.8	1,131	48.1	307	13.1	2,350	100
Marital status	#	%	#	%	#	%	#	%
Single	314	13.4	471	20.0	146	6.2	931	39.6
Married	497	21.1	519	22.1	130	5.5	1,146	48.8
Widower	51	2.2	74	3.1	9	0.4	134	5.7
Divorced	50	2.1	67	2.9	22	0.9	139	5.9
Total	912	38.8	1,131	48.1	307	13.1	2,350	100

the participants cannot distinguish exposure to traffic noise, regardless of their location at home, and the perception of the problem.

DISCUSSION

The vehicular traffic noise is an essential factor in noise annoyance perception (Dzhambov and Dimitrova, 2018). When the perception of noise annoyance is very high, traffic noise, especially from heavy vehicles or ambulance sirens, is easily identified as annoying (Cramer et al., 2019). Sensitivity to traffic noise annoyance is higher in those exposed to noisier streets (Kishikawa et al., 2006). In the study, more than half of the participants do NOT perceive or identify noise as an annoying factor. This conclusion is essential because the participating population lives in areas close to high-traffic roads. The traffic noise levels evaluated throughout the study exceeded 70 dBA. Such assumption suggests that the population does not consider traffic noise as a problem they should be affected. A potential explanation could be that people are desensitized to the adverse conditions of the traffic noise due to the impossibility of changing their environment or changing their residence.

The first consideration in the perception of annoyance should be the age of the participants, i.e., for those who are younger have less problem with the sounds, while those who are older, traffic noise does represent an annoyance (Dzhambov et al., 2017).

TABLE 3 | Correlations.

	Level noise	Noise perception	C.1	C.2	C.3	C.4	C.5	C.6
Level noise	1							
Noise perception	0.080**	1						
C.1 Considering outside noise	0.045*	0.519**	1					
C.2 Considering indoor noise	0.150**	0.384**	0.318**	1				
C.3 What times do you find the noise most annoying?	0.080**	1.000**	0.519**	0.384**	1			
C.4 Do you consider that your street, compared to previous years, is on average...	0.012	0.263**	0.405**	0.148**	0.263**	1		
C.5 Do you consider that your street, compared to the rest of the city, is on average...	−0.039	0.299**	0.281**	0.329**	0.299**	0.200**	1	
C.6 The street noise annoys or disturbs you the most when you are...	−0.103**	−0.180**	−0.113**	−0.167**	−0.180**	−0.134**	−0.082**	1

Pearson correlation.
***Correlation is significant at the 0.01 level (2-tailed).*
**Correlation is significant at the 0.05 level (2-tailed).*

Our results identify that those under the age of 30 years do not perceive traffic noise, while the rest recognize it. Consequently, it reflects that age is an aspect that affects the comprehension. As age increases, the perception of traffic noise increases. It is common for younger people to frequent leisure places that are noisier. Therefore, they become desensitized to noise from any source, which does not recognize it as something annoying or harmful to their health, but these assumptions will have to be evaluated in a subsequent study.

That is why the urban centers are the ones with the highest traffic noise, where levels of 55 dBA are exceeded by far during the day and 45 dBA at night (Kim et al., 2012). Some studies conclude that in areas exposed to vehicular traffic, noise can exceed 73.1 dBA, while in quiet or low-traffic areas, the noise levels oscillate around 64 dBA (Paiva et al., 2019). The outcomes of this research address the traffic noise generated during the day, and it can be seen in **Table 1** that the different areas evaluated have the values above 70 dBA. It can also be noted that the highest noise values include the most increased traffic of heavy vehicles.

The research reflects the opinion of those participants who do identify it, but at the same time, consider that the street where they live is less noisy than the rest of the city, which would imply that the participants do not have a clear idea of the intensity of traffic noise. This statement coincides with other works where they describe that people who demonstrate high annoyance from traffic noise are those living in areas with noise above 65 dBA (Di et al., 2012). Even the perception of annoyance does not change if a range of 45–95 dBA is considered. However, categories could be established in the intensity of annoyance, such as minor annoying, annoying, and very annoying, depending on the intensity of the noise (Camusso and Pronello, 2016). Likewise, noise levels found in dense traffic areas vary within the range of 80–85 dBA, while interviews found that 48.4% of the population expressed a high degree of noise annoyance (Paiva et al., 2019).

The sensitivity to traffic noise is greater during the night periods, as it causes an interruption of sleep; however, the annoyance by traffic noise is perceived during the day, when the inhabitants are inside their homes, in rooms, or in rest areas close to the street (Jakovljevic et al., 2009). Thus, the inhabitants cannot be at ease inside their homes (Camusso and Pronello, 2016). Some proposed models describe that inhabitants consider traffic noise above 70 dB as a highly annoying problem outside their homes. When the traffic noise level is higher than 76 dB, inhabitants consider the noise to be highly annoying when they are indoors (Fyhri and Klæboe, 2006). The previously described factors coincide with the present results. It can be identified that people recognize that the annoyance noise is more significant when being in the interior of their house during the night periods. Probably, it is because the traffic noise interferes with the tranquility of the people when they are inside their homes to dedicate part of their time to rest.

LIMITATIONS

This research was carried out with developed activities during the day periods, which leaves night periods that allow the development of complete 24-h period calculations unobserved.

It is also required to increase some variables related to the infrastructure of the homes, such as construction materials, isolation, number of windows, bedrooms position, and living rooms concerning the street or noise source.

The results are focused on the noise generated by vehicles in transit, but those areas where high sounds are generated outside their facilities or use sound amplifiers were not considered. Besides, improvements should be made in the description of vehicle flow, such as speed and duration at traffic lights.

CONCLUSION

The vehicle type and flow are the essential elements for the generation and increase of traffic noise levels. The study identifies that more than half of the participants from Matamoros city do NOT perceive traffic noise as a factor that causes them annoyance.

Women show a better appreciation of traffic noise perception, while younger people show a higher tolerance for high-level exposure. The participants do not differentiate between the different types of noise, nor do they recall the noise situation from previous years, making it difficult to determine a pattern for comparison. Thus, it may reflect the evident lack of necessary information among the vulnerable population about the noise problem and the probable consequences for health in the short, medium, and long terms.

Due to the questioning performed and the results of the very low correlations, the simple opinion of the perception of traffic noise is not sufficient to make predictions or generalizations.

The development of ongoing socioenvironmental studies related to traffic noise must have advantages in different aspects. First, it allows describing the vehicular flow in certain areas, which allows the development of better planning of the road traffic. Second, it allows knowing the parameters of environmental noise in their different schedules, which allows the local authorities to have references that facilitate the development of regulations and, in their case, the verification of the established limits.

In contrast to what is described in the literature, people in Matamoros do not care about noise pollution, so more multidisciplinary research should be conducted to comprehend the possible reasons behind that issue, allowing novel noise mitigation strategies to be developed. These projects must have the active participation of the authority in urban planning, transportation, and the environment to prevent the future complaints of the upcoming residents, especially in vulnerable areas.

Finally, the voluntary participation of the citizens in the development of this type of project is required since their collaboration is vital, representing a challenge for researchers to find strategies that allow them to expand the sample in subgroups, new variables, and research lines.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Research and Ethics Committee of the Unidad Académica Multidisciplinaria Matamoros of Universidad Autónoma de Tamaulipas. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

BZ-G and FP-C carried out the study design, data analysis, and writing of the manuscript. VP-S and YV-N developed the statistical analysis, participated in the writing, and editing of the manuscript. JV-M designed the database, supervised the correct collection, transcription of data, and reviewed and corrected the manuscript. LR-R and OM-A participated in the supervision of the fieldwork and the correction of the manuscript. All the authors approved the final version of the manuscript. All the authors were involved in different stages of the study.

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SUPPLEMENTARY MATERIAL

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frontiers in Psychology

ORIGINAL RESEARCH
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Sound Effects on Physiological State and Behavior of Drivers in a Highway Tunnel

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Driving behavior in a highway tunnel could be affected by external environmental factors like light, traffic flow, and acoustic environments, significantly when these factors suddenly change at the moment before and after entering a tunnel. It will cause tremendous physiological pressure on drivers because of the reduction of information and the narrow environment. The risks in driving behavior will increase, making drivers more vulnerable than driving on the regular highways. This research focuses on the usually neglected acoustic environment and its effect on drivers' physiological state and driving behavior. Based on the SIMLAB driving simulation platform of a highway tunnel, 45 drivers participated in the experiment. Five different sound scenarios were tested: original highway tunnel sound and a mix of it with four other sounds (slow music, fast music, voice prompt, and siren, respectively). The subjects' physiological state and driving behavior data were collected through heart rate variability (HRV) and electroencephalography (EEG). Also, vehicle operational data, including vehicle speed, steering wheel angle, brake pedal depth, and accelerator pedal depth, were collected. The results indicated that different sound scenarios in the highway tunnel showed significant differences in vehicle speed ($p = 0.000$, $\eta^2 = 0.167$) and steering wheel angle ($p = 0.007$, $\eta^2 = 0.126$). At the same time, they had no significant difference in HRV and EEG indicators. According to the results, slow music was the best kind of sound related to driving comfort, while the siren sound produced the strongest driver reaction in terms of mental alertness and stress level. The voice-prompt sound most likely caused driver fatigue and overload, but it was the most effective sound affecting safety. The subjective opinion of the drivers indicated that the best sound scenario for the overall experience was slow music (63%), followed by fast music (21%), original highway tunnel sound environment (13%), and voice-prompt sound (3%). The findings of this study will be valuable in improving acoustic environment quality and driving safety in highway tunnels.

Keywords: sound effect, driving behavior, physiological state, heart rate variability, electroencephalography

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INTRODUCTION

The highway tunnel is a semi-concealed structure with an abrupt change in the external environment (e.g., lighting and sound), usually built on complex terrain to effectively use mountainous areas and protect the natural environment. Driving through a tunnel is a challenging and risky task for drivers. When driving through a tunnel, drivers need to process lots of information within a short time, and their sensory systems should constantly monitor and immediately respond to many environmental variables, leading to increased workload. Besides, the psychological depression generated by the relatively confined space on drivers could result in irritability and tension (Calvi et al., 2012; Feng and Chen, 2017). Under this stressful situation, drivers are more prone to dangerous and risky driving (Yan et al., 2014), resulting in improper behaviors.

It is reported that 60.1% of driving accidents were caused by the improper behavior of the drivers (Wang et al., 2017). Furthermore, driver behavior in tunnels has increasingly become of concern to promote safety (Calvi and D'amico, 2013). Considerable physiological studies have been conducted concerning three types of indicators: heart rate variability (HRV) indicators, electroencephalogram (EEG) indicators, and vehicle indicators. Typically, HRV is used to detect driver workload (Bortkiewicz et al., 2016), sleep stage (Yamakawa et al., 2017), and driving errors that occur in actual driving tasks (Michail et al., 2008). EEG is used to study driver anger (Ping et al., 2014), fatigue (Jap et al., 2009), and alertness level (Kiymik et al., 2004). After these indicators are determined, they could be measured using some exogenous variables to evaluate driving behavior further. Such variables include vehicle speed corresponding to accident rate (Aarts and Schagen, 2006), steering wheel angle determining whether fatigue driving exists (He et al., 2011), and accelerator and brake pedal depth reflecting a driver's speed control and concentration (Caliendo et al., 2013).

Concerning highway tunnels, the contributing factors to driving behavior focus on traffic environment characteristics, such as light (Song et al., 2018), sound (Akamatsu et al., 2003), and alignment (Rudin-Brown et al., 2013). Especially for the acoustic environment, some researchers demonstrate that music could relieve pressure and aggression in drivers (Dalton and Behm, 2007), thus influencing driving behaviors. Specifically, joyful music can distract attention and reduce speed, while sad music can improve lane-keeping ability (Pêcher et al., 2009), and fast-paced music could easily cause speeding (Brodsky, 2001). Some researchers claimed that natural sounds could enhance driving ability (Febriandirza and Chaozhong, 2017). However, the noise will affect the accuracy (Hartley and Williams, 1977) and reduce the alertness level (Smith, 1988) of the driver. In particular, the noise inside a tunnel is increased drastically at the exit due to the sudden connection of the restricted space and the natural environment's open space (Takagi et al., 2000). There are calls for some solutions to alleviate the influence of noise and improve the acoustic environment to improve highway tunnel safety. Some attempts using sound systems have been made to influence drivers when they are driving in tunnels (Guiyangnet, 2015).

This paper aims to identify the effect of the acoustic environment on the physiological state and behavior of drivers in highway tunnels using a scenario-based approach. Five sound scenarios are set in the driving simulation experiment. All objective parameters (HRV, EEG, and vehicle parameters) that might reflect the mental state and subjective judgment of the driver, were analyzed and compared to reveal how driving behaviors vary according to different sounds. The purpose of the study was to provide a practical reference for improving the driving safety level in highway tunnels through the control and management of the acoustic environment.

MATERIALS AND METHODS

Experiment Design

Experimental Scenarios

The experimental road scenario is specific to one direction of a two-way four-lane highway tunnel: one-way two-lane single-hole, as shown in **Figure 1**. The lane width is 3.75 m and the speed limit is 80 km/h. The study section's total length is 5100 m, where the length from the starting point to the tunnel entrance is 1000 m, the length of the tunnel is 4000 m, and the distance from the tunnel exit to the endpoint is 100 m. The traffic flow in the experimental scenario was randomly generated using passenger cars. The total traffic volume on all lanes was 400 passenger car units per hour. The traffic was not evenly distributed on the lanes. The cars' speed ranged from 80 km/h to 100 km/h. The road alignment is a s-shaped curve with large radius (R = 2000 m), with a longitudinal slope of 2.9%, and horizontal slope of 2%. There is no central reserve set.

The scenario demonstrates the same sound environment from the actual tunnel called the control sound. Four different sound sources were separately mixed with the original sound to form comparative scenarios: slow music, fast music, siren, and voice prompt. The voice prompt was from a woman's voice saying, "Please turn on the lights, slow down, and no-overtaking" and "Here is an accident blackspot, please turn on the lights and slow down." The siren sound was from special effects generated from the software. The fast music was "Croatian Rhapsody" with 96 beats per minute (BPM), and the slow music was "Canon" with 72 beats per minute (BPM). Before the vehicle entered the tunnel, the usual road noise was played through the speakers connected to the driving simulator. Once they entered the tunnel, the specific sound scenario was played. The sound pressure level was

FIGURE 1 | Experimental scenarios of the study highway tunnel.

controlled at 70 dB, which was a volume that was loud enough but did not cause discomfort to the driver. To avoid the influence of irrelevant variables on the independent variables, the traffic flow and lighting conditions in the tunnel in each scenario were the same. The experiment was conducted indoors with lights on, and curtains are drawn to control the environmental brightness.

Experimental Apparatus

Sim Lab Driving Simulator

The main parts of the Sim lab driving simulator are the driving simulator motion platform, a console, four high-definition projectors, and front and rear curtain walls. This equipment was used to collect the vehicle characteristics, such as the depth of the accelerator pedal and brake pedal, steering wheel angle and speed, and acceleration.

ErgoLAB Man–Machine Environment System

The ErgoLAB man–machine environment system consists of ECG wireless sensor, photo plethysmo graphic (PPG) wireless blood volume pulse sensor, and electro dermal activity (EDA) wireless skin sensor. The system uses synchronization technology, such as radio frequency physiological recording, which can record, track, and analyze real-time data, including individual physiological, psychological, and behavioral changes simultaneously or within the same period. Also, it could be used for analyzing the physiological data of the individual's driving behavior. The equipment includes three types of metrics, as follows:

(1) ECG wireless sensor metrics: measuring range: −1,500 to +1,500 μV, maximum transmission rate: 500 kbps, noise: 1.6 μV (RMS), sampling rate: 256–4,096 Hz, resolution: 16 bits, and accuracy: up to 0.026 μV.
(2) PPG wireless blood volume pulse sensor metrics: measuring range: 25–240 bpm, sampling rate: 32–256 Hz, resolution: 1 bpm, and accuracy: ±3 bpm.
(3) EDA wireless skin sensor metrics: measuring range: 0–30 μs, sampling rate: 32 Hz/Channel, and resolution: 0.3 μt.

Neuroelectrics Wireless EEG

Neuroelectrics Wireless EEG is a wearable wireless EEG system. The recording data can be wirelessly transmitted to the PC software in real time. It can be used to compare and analyze the brain wave changes of the drivers in a specific situation in real time and then analyze the change in his/her mental state. The metrics are as follows: number of channels: 8, 20, 32, bandwidth: 0–250 Hz, sampling rate: 500 SPS, resolution: 24 bits−0.05 μV, and noise: <1 μV RMS (0–250 Hz).

Subjects

This experiment hired 45 drivers with valid driving licenses. The subjects were undergraduate or graduate students selected from the university campus, between 20 and 25 years of age, with normal auditory and vision levels, and similar driving age and driving mileage. Before the formal experiment, the subjects were informed to ensure that they get adequate sleep. They could not drink or do other activities that could affect driving before the experiment. Thus, they were all in good physical condition when participating in the experiment. The time of the experiment was scheduled and informed to the subjects to avoid waiting for too long for their turn and to prevent irritability. Their uncorrected visual acuity or corrected visual acuity of both eyes was above 4.9 in the logarithmic visual acuity chart. Their hearing was certified using the tuning fork vibration test. Besides, to avoid the expectation effect of the experiment, the subjects who understood the purpose of the experiment were excluded. After data screening, 38 sets of valid data from 20 male drivers and 18 female drivers were finally obtained. **Table 1** shows the average and SD value of age, driving age, and driving mileage of subjects.

Experimental Procedures

The experimental procedures were as follows:

- To ensure that the equipment was in regular operation, the test experimental road scenario was loaded, and the subjects were allowed to be familiar with the simulator operations without wearing the experimental equipment.
- After the subject was familiar with the simulator, the subject could wear the EEG cap and the physiological collection instrument, as shown in **Figure 2**. After the instrument was in a stable recording state, the subject could sit in the driving position.
- When the subject was ready, the subject was informed to start the experiment, and the data were recorded at the same time. If the subject had an uncomfortable reaction, the experiment would be stopped and continued after the subject felt normal again.

TABLE 1 | Information of subjects.

	Age (yr)	Driving age (yr)	Driving mileage (km)
Average	23.3	2.7	13947.4
SD	1.1	1.3	6704.1

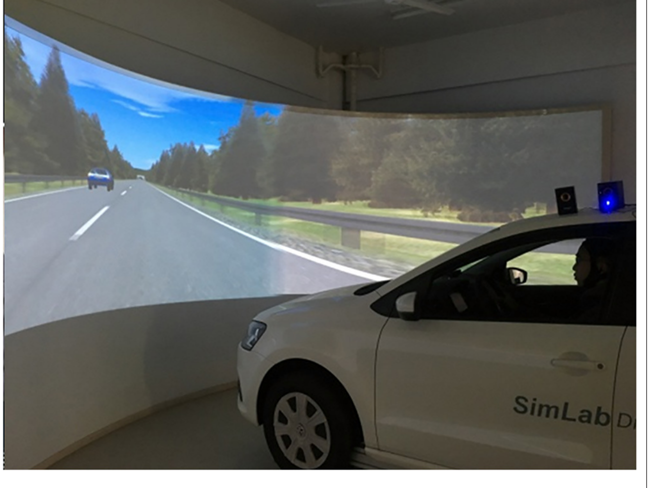

FIGURE 2 | Subject in SimLab driving simulator.

- The experiment time was controlled to avoid excessive fatigue in the subjects. The driving time for a single scenario was ∼4 min. The average time for switching between the scenarios and the instrument's re-adjustment was 1–2 min. The driving scenarios were provided to the subjects in random order to avoid the memory effect (Ali et al., 2020; Onate-Vega et al., 2020; Vollrath et al., 2021). The duration of the entire experiment was 25–30 min.
- After all the scenarios were completed, the participants got off the car and took off the experimental equipment. Then, they were asked to fill in a questionnaire survey based on their experimental experiences.

Objective Evaluation of the Mental State of the Driver

Based on previous studies, 14 indicators from three categories (HRV index, EEG indicators, and vehicle indicators) were selected to evaluate the sound effects on the mental state of drivers in a highway tunnel, as shown in **Table 2**.

Subjective Evaluation of Driving Behavior

The subjective feeling of the drivers under different sound scenarios was collected through a questionnaire survey. They were immediately asked to fill in the questionnaire based on their real feelings in the experiment after they finished all the driving scenarios. The questionnaire measures the physiological and psychological feelings of the drivers in four aspects, including driving safety (Q1), driving comfort (Q2), driving load (Q3), and driving fatigue (Q4), using a Likert five-level scale. The main questions of the questionnaire were as follows:

Q1: Please describe your perception of your speed and vehicle spacing in the process of driving under different sound scenarios.

Q2: How comfortable are you when driving under different sound scenarios?

Q3: Please describe the urgency you feel of driving out of the tunnel under different sound scenarios.

Q4: How tired are you when driving under different sound scenarios?

Q5: In your overall driving experience, what is the best one of the five sound scenarios?

Data Screening

In the driving simulation experiment, the loose earlobe or weak acquisition signal would cause inaccuracy or missing data. Among the 38 sets of HRV data of each scenario, up to 23 sets of incomplete or bad data were excluded from the analysis. The EEG data were first filtered, and then the noise with ICA (independent component analysis) algorithm was removed (Makeig et al., 1996; Lee et al., 1999; Jung et al., 2000). The stability of the signal, number of artifacts, sufficiency of the markers, and mutual signal influence with the heart rate monitor were also considered. Vehicle operational data were obtained from the driving simulation platform. Vehicle operational data of the subjects familiar with the experiment and those of the pre-experiment were removed.

RESULTS

Sound Effects on HRV

Analysis of HRV Indicator

In terms of the emotional level, a previous study showed that it was positively correlated with emotional level (Mather and Thayer, 2018). The emotions are in the tensest state under the siren sound stimulus, followed by the voice prompt. The emotional level under the fast and slow music scenario is lower than the original sound scenario.

A previous study showed that SDNN, RMSSD, and PNN50 were all reduced when driving fatigue and stress increased (Lee et al., 2007). It is indicated in **Figure 3** that AVHR, SDNN, RMSSD, and PNN50 show similar trends under different sound scenarios, all of which reached the lowest level in the siren scenario. Under the slow music scenario, the three types of indicators were at the highest level, and it could be considered that their emotional level and workload as the most stable.

The ratio of LF/HF under different sound scenarios is obviously different, as indicated in **Figure 3**. According to previous study results, the lower the emotional level, the higher the LF/HF ratio, and the degree of fatigue and workload were negatively correlated with the LF/HF ratio (Michail et al., 2008). This research showed that the LF/HF ratio of the drivers was the lowest under the slow music scenario. The emotional level was stable, followed by fast music, original sound, voice prompt, and siren.

Relationship Between Scenarios and HRV

One-way repeated measure ANOVA was used to analyze the effects of different sound scenarios on the HRV. The test results of Mauchly sphericity and the within-subject effect are shown in **Table 3** and **Table 4**. As noted, different sound scenarios have no significant difference on HRV, as indicated by the p-value of the significance test (all $p > 0.05$), mainly because of the limited sample size (15).

Sound Effects on EEG

Analysis of EEG Energy

α-Wave

Regarding α-waves, a previous study showed that they appear when the brain was awake and could be used to measure the soberness degree of the brain (Eoh et al., 2005). The higher the average α-energy, the higher the soberness of the driver. The results in **Figure 4** show that:

(1) Under the original sound scenario, when the drivers entered the tunnel, the average energy of the α-wave was significantly reduced. Therefore, when driving in the tunnel, it is more likely to cause driving fatigue.

(2) Fast and slow music have similar effects compared with the original sound. Under the fast and slow music scenarios, the energy of α-wave was higher than that of other scenarios without music, indicating that music can effectively increase the soberness of the drivers.

(3) The comparison shows that the α-waves in drivers under the siren scenario are much higher than the other scenarios. Therefore, although the siren makes the driver

TABLE 2 | Driver's physiological state and driving behavior indicators.

Indicator type	Indicator name	Index characteristics	Unit
Heart rate variability indicators (HRV)	AVHR	Average heart rate value, when the heart rate value rises, it can indicate the drivers' tension (Lee et al., 2007).	BPM
	SDNN	Standard deviation of the cardiac interval. It can be used as an indicator of the drivers' nervousness (Miller and Boyle, 2013).	–
	RMSSD	Average value of the difference between adjacent RR intervals. It can be used as an indicator of driving fatigue (Lee et al., 2007).	–
	PNN50	Difference between adjacent R-R intervals is >50 MS as a percentage of the total, which can be used as an indicator of driving fatigue (Lee et al., 2007).	%
	LF/HF	Ratio of low-frequency and high-frequency power. It can be used as an indicator of mental load (Michail et al., 2008).	–
EEG indicators	α-wave (the percentage of α wave to the total energy)	Low-amplitude synchrowave. It is the main waveform recorded in the awake and quiet state. It is generally considered to be related to the brain's preparation activities. This rhythm of brain waves appears when the brain is awake and relaxed (Eoh et al., 2005).	%
	β-wave (the percentage of β wave to the total energy)	High-frequency and low-amplitude asynchronous fast wave. It reflects the alertness of the brain, usually appears when a person's mental state is nervous or excited. When it appears, the brain is prone to fatigue (Ping et al., 2014).	%
	θ-wave (the percentage of θ-wave to the total energy)	Low-to-medium amplitude slow waves. It appears when people turn to sleep from calm and relaxation. It is a manifestation of the central nervous system's inhibited state and is related to working memory load (Lin et al., 2011).	%
	θ/β	When the θ-wave energy increases and the β-wave energy decreases, the ratio increases, which is usually used to characterize drivers' fatigue (Jap et al., 2011).	–
	(θ + α)/β	Composite index of (θ + α)/β energy, which can be used to characterize driving fatigue (Jap et al., 2009).	–
Vehicle indicators (VB)	Vehicle speed	Distance traveled by the car in a unit of time. It can be used to study the emotions of the drivers (Aarts and Schagen, 2006).	km/h
	Steering wheel angle	Angle at which the steering wheel is turned. It can be used to study distractions and drivers' emotions (He et al., 2011).	rad
	Accelerator pedal depth	Depth of the drivers' accelerator pedal. It can be used to study the stability of the drivers (Caliendo et al., 2013).	rad
	Brake pedal depth	Depth of the driver's brake pedal can be used to study the stability of the drivers (Caliendo et al., 2013).	rad

feel uncomfortable, it can improve brain soberness, thereby increasing driving safety.

From the above analysis, siren appears to be the most effective sound influencing the α-waves in the drivers when driving inside the tunnel.

β-Wave

β-Waves usually appeared when people's mental state was nervous or excited, and the brain was prone to fatigue (Prinzel et al., 1995; Hong et al., 2005). As noted in **Figure 4**, both original sound and slow music can reduce a driver's mental tension, and the effect of slow music is better than the original sound. Voice prompt, siren, and fast music all increase the nervousness of driving in the tunnel. The siren sound has the most significant effect on β-wave, followed by fast music and voice prompt. When a driver's mental state is nervous and excited, he/she is more prone to dangerous behaviors, such as speeding and overtaking (Gabany et al., 1997; Hennessy and Wiesenthal, 1999; de la Fuente et al., 2017). If the nervous level is increased to a certain extent, it is easy to cause fatigue.

θ-Wave and θ/β

When a driver went from a normal state to a fatigued state, the θ-wave significantly increased, and the β-wave decreased significantly, and the θ/β value increased significantly (Kiymik et al., 2004; Ping et al., 2014). The smaller the value, the closer to the normal emotional state. As shown in **Figure 4**:

(1) Under the voice-prompt scenario, the drivers were sober, and their mental state was stable. This conclusion was mutually confirmed with the α-wave energy.

(2) Under the slow music scenario, the θ/β value in the tunnel was the highest among all scenarios, indicating that this type of music has a specific effect on causing driving fatigue.

$(\theta + \alpha)/\beta$

When the value of (θ + α)/β is large, the alertness and fatigue of the driver were high. As noted in **Figure 4**, the alertness and fatigue of the driver were at the lowest level under the original sound scenario.

Figure 5 is a schematic diagram of the sound changes in three dimensions based on the three brain wave energies, where the α-wave stands for soberness, the β-wave stands for alertness, and

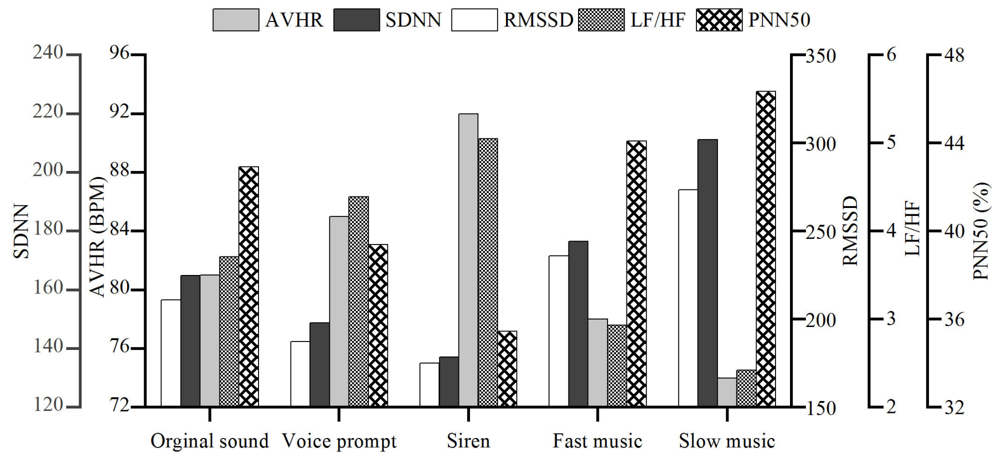

FIGURE 3 | Change of heart rate variability (HRV) indicator for different sound scenarios.

TABLE 3 | Mauchly's test of sphericity of HRV, EEG, and vehicle behavior indicators.

Variable	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon Greenhouse-Geisser
AVHR	0.514	150.603	9	0.076	0.736
SDNN	0.085	570.619	9	0.000*	0.431
RMSSD	0.140	460.094	9	0.000*	0.495
PNN50	0.230	340.399	9	0.000*	0.552
LF/HF	0.011	56.493	9	0.000*	0.369
α-wave	0.646	16.348	9	0.060	0.833
β-wave	0.459	29.159	9	0.001*	0.709
θ/β	0.006	191.621	9	0.000*	0.341
(θ + α)/β	0.006	188.510	9	0.000*	0.336
Vehicle speed	0.392	35.014	9	0.000*	0.672
Steering wheel angle	0.053	110.108	9	0.000*	0.450
Brake pedal depth	0.155	69.717	9	0.000*	0.482
Accelerator pedal depth	0.649	16.201	9	0.063	0.859

Greenhouse-Geisser correction is used when it does not meet the hypothesis of Mauchly sphericity ($p < 0.05$).
$^*p < 0.05$.

the θ-wave stands for fatigue. As noted, the siren can increase the driver's soberness and arouse the driver's alertness when driving in the tunnel, but it will cause the most driver fatigue. Slow music appears to produce the lowest alertness, although it causes the least fatigue. The driver's alertness of the slow music is lower than that of the original sound. This is possibly due to driver distraction when driving under slow music. However, slow music produces a little more soberness than the original sound. In conclusion, considering only EEG indicators, the siren is the most effective sound for increasing alertness and soberness when driving in the tunnel.

Relationship Between Scenarios and EEG

According to the EEG indicators, the significance of the influence of different scenarios was analyzed using the one-way repeated measured ANOVA. According to the test results of Mauchly sphericity and the within-subject effect (**Table 3** and **Table 4**), different scenarios had no significant difference in drivers' EEG (all $p > 0.05$). However, different sound scenarios could possibly affect the β wave ($p = 0.072$, $\eta^2 = 0.059$).

Sound Effects on Vehicle Behavior

Analysis of Vehicle Indicators

Vehicle indicators, including average speed, steering wheel angle, and acceleration and deceleration pedals of the driving vehicle, were selected to analyze different sound scenarios.

Vehicle Speed

The driving speed change was the most direct response when a driver was subjected to any stimulus caused by the driving environment. It is indicated in **Figure 6** that, under the voice prompt scenario, the drivers could control the vehicle speed most closely to the tunnel speed limit of 80 km/h. The reason might be that the direct command, such as the voice prompt, enabled

TABLE 4 | Test results of within-subject effects on HRV, EEG, and vehicle behavior indicators for different sound scenarios.

Variable	Inspection type	Type III sum of squares	df	Mean squares	*F*	Sig.	Partial eta squared
AVHR	Assumed sphericity	326.892	4	81.723	0.137	0.968	0.004
SDNN	Greenhouse-Geisser	103547557.8	1.724	60069780.5	0.277	0.726	0.011
RMSSD	Greenhouse-Geisser	108469991.0	1.982	54741080.4	0.215	0.805	0.009
PNN50	Greenhouse-Geisser	527.3	2.209	238.7	0.369	0.714	0.015
LF/HF	Greenhouse-Geisser	129800.8	2.153	60293.8	2.484	0.089	0.090
α-wave	Assumedsphericity	0.005	4	0.001	1.245	0.294	0.033
β-wave	Greenhouse-Geisser	0.046	2.833	0.016	2.433	0.072	0.059
θ/β	Greenhouse-Geisser	119.8	1.365	87.7	1.437	0.244	0.036
(θ + α)/β	Greenhouse-Geisser	161.1	1.342	120.1	1.574	0.219	0.039
Vehicle speed	Greenhouse-Geisser	4588.7	2.687	1708.0	7.844	0.000*	0.167
Steering wheel angle	Greenhouse-Geisser	0.000045	1.802	0.000025	5.606	0.007*	0.126
Brake pedal depth	Greenhouse-Geisser	0.015	1.927	0.008	3.128	0.051	0.074
Accelerator pedal depth	Assumed sphericity	0.001	4	0.000	1.985	0.099	0.048

*$p < 0.05$.

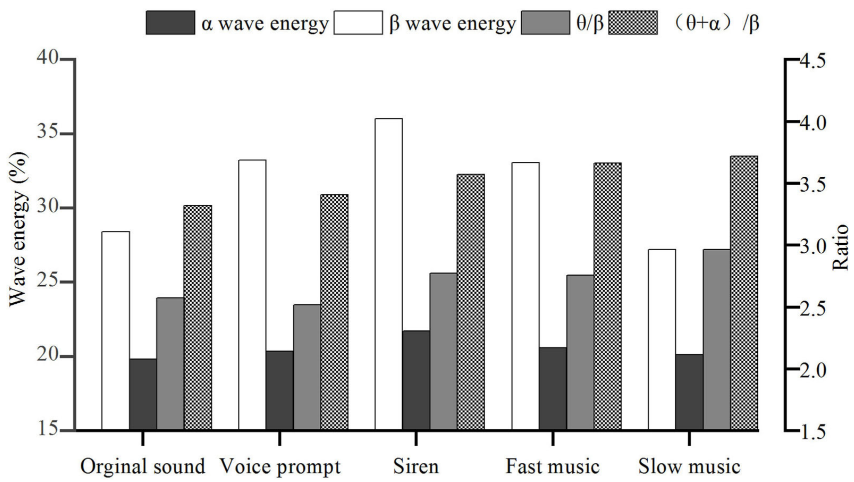

FIGURE 4 | Change of electroencephalogram (EEG) indicators for different sound scenarios.

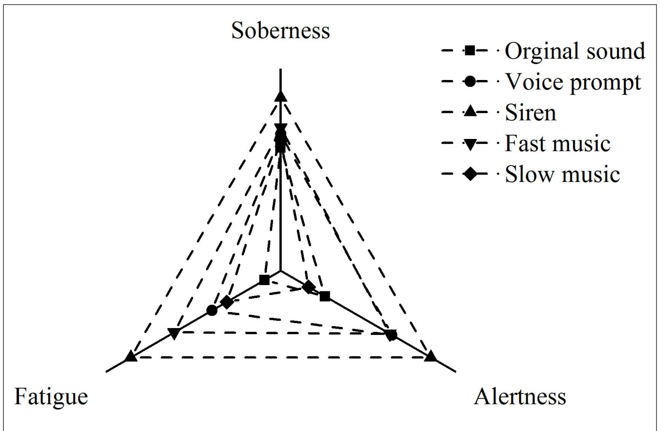

FIGURE 5 | Effect of different sound scenarios on drivers' physiological state considering electroencephalogram (EEG) indicators.

the driver to control the speed better. The siren, which also served as a warning, has the opposite effect. The siren stimulates the drivers' nervous emotion and increases the vehicle speed. Slow music makes the drivers relax but reduces the alertness of speed control. Fast music is most likely to cause vehicle speeding behavior, consistent with a previous study (Brodsky, 2001).

The overall vehicle speeds from top to bottom are fast music, siren, slow music, original sound, and voice prompt. In terms of speed change, the largest one is fast music, and the smallest one is slow music. These results indicate that slow music positively affects the smooth increase of the overall driving speed, where the drivers have the largest acceleration under fast music, which is not good for safety. For voice prompt, although the overall speed was the closest to the speed limit, the standard deviation was the largest. The reason could be that the drivers need to accelerate and frequently decelerate to correct the speed as the response to the stimulation caused by the voice prompt. These

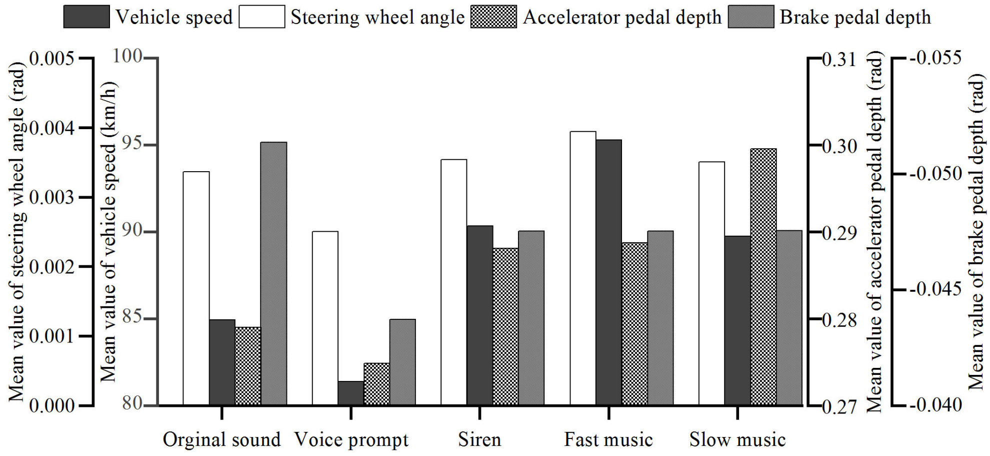

FIGURE 6 | Mean values of vehicle indicators under different sound scenarios.

frequent operations can easily lead to distraction and fatigue in driving.

Steering Wheel Angle

From the analysis in **Figure 6**, the average value of the vehicle's steering wheel angle under the voice-prompt environment was at the lowest level in all different sound scenarios. This was due to the clear "no-overtaking" voice message in the voice prompt, making the driver pay more attention to the steering wheel's control. However, frequent operations lead to a larger deviation of steering wheel angle. The effect of slow music on the steering wheel's control shows no significant difference than the original sound scenario, so nor the siren sound. The fast music scenario shows that the average steering wheel angle is larger, indicating that the driver's mood is relatively high in this environment, and dangerous behaviors, such as overtaking and speeding might occur.

Acceleration and Deceleration Pedal Depth

Compared with the control scenario, the average values of acceleration and deceleration under the voice-prompt scenario were reduced (**Figure 6**), indicating that the drivers paid more attention to the pedal control under a clear voice prompt. The drivers' better pedal control under the voice-prompt sound is good for driving security in the tunnel.

Relationship Between Scenarios and Vehicle Behavior

The significance of scenarios was analyzed using the one-way repeated measure ANOVA. According to the test results of Mauchly sphericity and the within-subject effect (**Table 3** and **Table 4**) different sound scenarios show significant effect on vehicle speed ($p = 0.000$, $\eta^2 = 0.167$) and steering wheel angle ($p = 0.007$, $\eta^2 = 0.126$). Besides, the impact on brake pedal depth is quite close to the significance level ($p = 0.051$, $\eta^2 = 0.074$).

Sound Effects on Driving Behavior Scores

The results shown in **Figure 7** indicate that drivers had a better perception of driving safety under three sound scenarios (original sound, voice prompt, and siren). Among them, the effects from the siren and voice-prompt sounds were more than those of other sounds. The siren sound stimulated the drivers to be alert, and the voice prompt reminded the drivers to pay attention to speed. The speed and distance perception values are the lowest when drivers are driving under fast and slow music. Compared to the original sound, both kinds of music can weaken the driver's alertness, thereby weakening vehicle-driving safety. The siren and voice-prompt sounds are better than the original sound in arousing alertness.

Driving comfort is different under the five-sound scenarios. The siren brings the most uncomfortable experience to the driver. The voice prompt decreases the driver's comfort but increases the drivers' safety performance at the same time. Compared with the original sound of the tunnel, the slow music causes a little more comfortable feeling. For the fast music, the driving comfort might be greatly improved, but at the same time, driving safety might be reduced.

The siren and voice-prompt sounds significantly increase the driver's workload with their high-frequency tones and information volume so that the drivers have a stronger desire to drive out of the tunnel as soon as possible. Compared with the original sound scenario, workload increases slightly under the fast music scenario. Slow music seems to produce the lowest workload.

Under the original sound scenario, the noise composed of natural wind and machine sounds makes the driver feel monotonous and boring, causing fatigue. The siren and voice prompt have a specific promotion effect on the slight reduction of fatigue. Both kinds of music can reduce fatigue and enhance the positive stimulus, while the effect of slow music is more substantial than that of fast music.

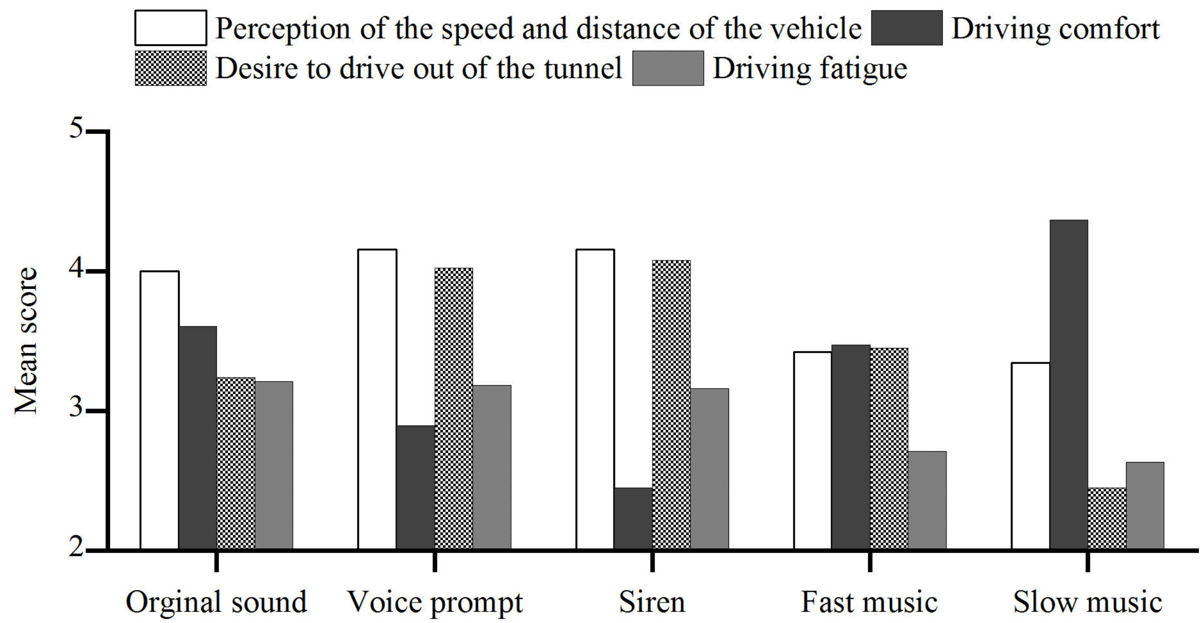

FIGURE 7 | Mean values of the subjective opinions on driving behavior under different sound scenarios.

Besides, most of the subjects (63%) chose slow music as the best background sound in the tunnel, followed by fast music (21%), whereas voice prompt was the least preferred (3%). The selection of slow music as the best sound environment shows that driver's demand for the sound is mainly based on driving comfort and pleasing experience, while safety is a second consideration, which somewhat reflects young people's lifestyle.

CONCLUSIONS

In this paper, the effects of five kinds of sounds on the physiological states and behavior of drivers in a highway tunnel context were studied. A detailed analysis of the drivers' HRV, EEG, vehicle operational data, and questionnaire data obtained from the driving simulation experiment with five different sound scenarios in a tunnel was performed. The following conclusions could be drawn:

The results of HRV indicators showed that slow music had the most effects on increasing driving comfort and reducing driving load, followed by fast music, while voice prompt and siren could generate a negative effect (compared with the original sound). In terms of EEG indicators, inferring from the α-wave energy, all sound scenarios could improve driver's soberness in the tunnel compared with the original sound, with siren having the most effect, followed by voice prompt, fast music, and slow music. For the β-wave energy, it could be inferred that slow music reduced the nervousness than the original sound, but voice prompt, fast music, and siren alarms could increase nervousness. As indicated by the θ/β and according to the $(\theta + \alpha)/\beta$ value, the best sound environment for driving fatigue was voice prompt.

Compared with the original sound, the voice prompt could release fatigue, while the siren, fast music, and slow music produced more fatigue, with slow music having the largest effect. In the schematic diagram based on three brain waves' energy, the siren aroused the highest alertness and soberness levels while it caused enormous fatigue. Slow music would lower the alertness level below driving under the original sound. In terms of the emotional state of the drivers, according to the subjective questionnaire, the best sound was slow music, followed by fast music, siren alarm, voice prompt, where all sounds were better than the original sound. Note that some results are contradictory, e.g., the results of wave radio value and subjective questionnaire. However, the subjective questionnaire results were more reliable, as the indication of different combinations of EEG waves is still being explored. In terms of vehicle indicators, the results showed that the closer to the tunnel speed limit and the smaller the speed SD, the higher the driving safety. Voice prompt was the only sound that could improve the driving safety compared with the original sound. The steering wheel angle, acceleration, and deceleration pedal depth indicators were consistent with the vehicle speed results.

Slow music had the advantage of increasing driving comfort and reducing driving load, making the driver feel better, consistent with the subjective judgment of the driver. At the same time, slow music might distract the driver and draw his attention away from the driving task, thereby weakening driving safety. Fast music might lead to speeding, though it would improve the mental state of the driver. Although the siren showed significant effects on alerting drivers, it is obviously the least preferred sound scenario, and the lasting time and frequency should be carefully controlled to avoid fatigue and discomfort. Voice prompt had the drivers alert on their driving task, but drivers would feel tired following systematic instructions.

Based on the preceding remarks, slow music was the best sound for drivers' pleasant experience when drivers were driving in a highway tunnel, while it had the disadvantage of reducing driving safety. The siren sound could increase drivers' soberness and arouse drivers' alertness when driving in the tunnel, but the drivers will feel tired and uncomfortable if it lasts for a long time (4 min in this study). Therefore, we suggest that slow music could be played while driving inside the tunnel, and when entering and leaving a tunnel, or some emergencies happen, the siren sound could be used to call the driver's attention and focus on the driving task.

This study enriched the research on the effect of different sounds on driver behavior and physiology under a highway tunnel condition. It provided practical references for safety professionals and the formulation of safety rules. However, due to the impact of the COVID-19 epidemic, this study only recruited college students as experimental subjects, and the experiments were conducted using a driving simulator. "Croatian Rhapsody" and "Canon" were chosen as typical "fast music" and "slow music," respectively, mainly because these two sounds have different BPM, and are well-known worldwide. The other elements of music indeed have different effects on driving (Millet et al., 2019). More experiments should be carried out in the future to study the effects of different elements of music.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Ethics Committee of the College of Civil Engineering, Fuzhou University. The patients/participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

YY and WL: study conception and design. XY and YF: data collection. YF, XY, JL, WL, and SE: analysis and interpretation of the results. YF, YY, XY, SE, JL, and WL drafted the manuscript. All authors reviewed the results and approved the final version of the manuscript.

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Soundscape Evaluation Comparison of Outdoor Activity Space Between Gated and Open Communities

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In communities, outdoor activity space is utilized most often by older adults and children, and the soundscape is very important for its quality. For different community planning modes, such as gated and open communities, focus should be on different soundscape enhancement strategies for outdoor spaces. In this paper, typical samples of activity spaces in a gated community and in an open community were used. The comparison was conducted through soundscape evaluation including an analysis of the dominance of various sound sources, noise annoyance, and the perceptual dimensions of soundscape. The results showed that noise annoyance in the gated community was significantly lower than in the open community, although the noise level was of no significance between the two communities. The community planning mode moderated the relationships among the soundscape perception parameters between the gated and open communities. To reduce noise annoyance in the gated communities, each sound source should be considered; in open communities, traffic noise only should be considered. In a gated community, adding natural sounds to reduce noise annoyance may be a feasible intervention; in an open community, this is not necessary. Besides, there was no relationship between noise annoyance and Eventfulness in an open community, indicating that noise annoyance was insufficient to explain the complex sound environment of the community. China's community planning will gradually shift from a gated community to an open community, making the soundscape of outdoor activity spaces likely to change dramatically in the future. The findings will help urban designers and managers to adopt targeted strategies to improve the soundscape and quality of life of community-dwelling older adults and children.

Keywords: soundscape evaluation, sound environment, residential area, gated community, open community, structural equation model

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INTRODUCTION

Exposure to environmental noise can have negative effects on health (Passchier-Vermeer and Passchier, 2000; World Health Organization, 2011), such as the following: potentially developing cardiovascular diseases (Stansfeld and Matheson, 2003; Babisch et al., 2005; Basner et al., 2014), sleep disturbances (Öhrström and Skånberg, 2004; Basner and McGuire, 2018), cognitive impairment (Stansfeld et al., 2005; Ranft et al., 2009; Tzivian et al., 2016), psychological disorders

(Tzivian et al., 2015), having negative effects on the auditory system (Muzet, 2007), and obesity (Christensen et al., 2015; Pyko et al., 2015). These potential negative outcomes are often related to older adults and children (Belojevic et al., 2008; Szalma and Hancock, 2011). Therefore, the sound environment is considered as a critical factor for creating a healthy city (Seidman and Standring, 2010). In China, when comparing various noise sources, a study showed that road traffic noise, as the main source of noise in urban areas, contributed to 61.2% of the noise (Zhang and Kang, 2007).

As an essential part of city planning, community is an important place for urban residents to rest and enjoy leisure. Residents, especially older adults and children, spend a lot of time outdoors to rest, play, talk, or engage in social activities; therefore, they need high-quality sound environments in such outdoor spaces (Brown et al., 2011). Accordingly, traffic noise control in communities has become one of the main objectives for different administrative sectors of the government. In February 2016, the Chinese government was actively promoting a construction model characterized by "narrow roads and dense road networks" and aimed to promote an open community design. In principle, it was decided that new communities should not be developed as gated communities, and the walls of existing gated communities should be gradually demolished. Such demolishing, accordingly, brought an immediate source of noise to the sound environment of many gated communities in China.

To try and reduce the impact of noise on residential buildings, many cities have carried out noise reduction plans by reducing road noise levels (European Parliament and Council, 2002; Ministry of Environmental Protection of the People's Republic of China, 2008; Ng and Chau, 2014; Echevarria et al., 2016). However, the cited studies mainly focused on the change of noise level, giving less attention to perceptual changes. Moreover, many studies have focused on high-noise areas adjacent to roads, whereas less attention has been paid to low-noise areas, which are the main areas of daily activity for older adults and children.

Previous studies have shown that noise level reduction is not completely correspondent to acoustic comfort (Yang and Kang, 2005; Berglund et al., 2006; Meng and Kang, 2015; Gozalo et al., 2018), and sound energy is not highly correlated with soundscape perception (Jambrošić et al., 2013; Ma et al., 2018). Therefore, recently, some scholars have proposed that the quality of communities can be improved through soundscape construction (Vogiatzis and Remy, 2014; Gozalo and Morillas, 2017). Hong and Jeon (2015) developed a structural equation model (SEM) model to determine the relationship among various soundscape perception indicators in communities, proposing that traffic noise and human sound are the main sound sources that affect soundscape perception. Hao et al. (2016) found that the soundscape quality of traffic noise environments could be improved by the masking effects of birdsong. Dzhambov et al. (2018) proposed that a reasonable control of green space perception was conducive to reducing noise annoyance in communities. However, these studies did not distinguish the impact of the differences between diversified community planning modes.

Worldwide, there are two main community planning modes, gated and open communities. Generally speaking, gated communities in residential areas are defined by restricted access, designated parameters, walls or fences, controlled entrances intended to prevent penetration by non-residents, and the external surrounding streets are typically wide arterial roads (Davis, 1990; Roitman, 2010; Sun and Webster, 2019). Open communities are the opposite of gated communities, tending to have gridded road networks (Miao, 2003; Dong et al., 2019). Traffic demand, the distribution of traffic flow, the distances of buildings from the road, building formats, and even the activities and behaviors of people are different in these two modes (Miao, 2003). Thus, the sound environment may also differ.

This study aimed to clarify the effect of community planning mode on soundscape perception parameters. Specifically, it aimed to determine (1) whether there are differences in the soundscape perception between different planning modes; (2) if yes, whether the planning mode affects the relationship among the soundscape evaluation parameters; and (3) if yes, which relationships among the soundscape perception parameters do significantly change between different planning modes? Moreover, in what way will the soundscape enhancement strategies differ? The results may help urban planners and city managers to choose appropriate strategies to improve the sound environment in communities for older adults and children. The selected soundscape evaluation parameters included the perceived dominance of sound sources, noise annoyance, and perceptual dimensions of the soundscape. **Figure 1** presents the conceptual framework of this study. Based on the above review, the following hypotheses are developed.

> *H1*: The relationship between the perceived dominance of the sound source and perceptual dimensions of the soundscape will differ between the gated and open communities.

> *H2*: The relationship between the perceived dominance of the sound source and noise annoyance will differ between the gated and open communities.

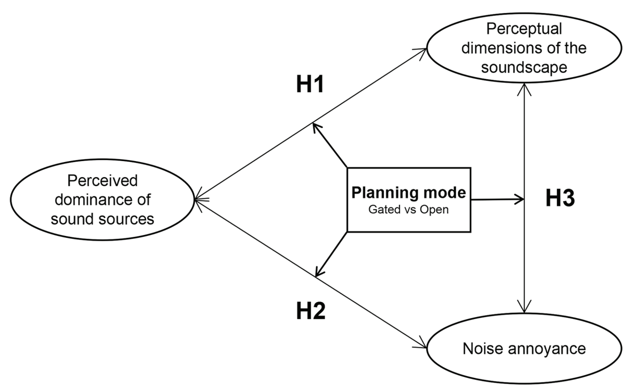

FIGURE 1 | Conceptual framework of the study.

H3: The relationship between noise annoyance and the perceptual dimensions of the soundscape will differ between the gated and open communities.

Owing to the following topics, this study was focused on the sound environment of low-noise areas: because the literature on high-noise areas (about 70 dBA) – which are mainly related to the presence of adjacent, noisy roads – has a plethora of findings (Allen et al., 2009). Most prior research has placed little concern on community planning modes; and low-noise areas (about 50 dBA) are the main activity areas for older adults and children. Two typical communities were selected to represent the gated and open community. Using questionnaires in a laboratory setting, a soundscape perception evaluation was conducted. A structural equation model was used to compare soundscape perception-related results of the gated and open communities.

MATERIALS AND METHODS

Site Selection

The Xinghai Renjia Community and the Xingshe Community, both in Dalian City, China, were selected for comparative research (see **Figure 2**). The first was used to represent gated communities, whereas the latter to represent open communities. The Xinghai Renjia Community comprises an area of 0.21 km^2 with 73 houses, and the Xingshe community comprises an area of 0.17 km^2 with 55 houses; hence, they are similar in size. However, the planning modes of the two communities are different. The Xinghai Renjia community is a typical gated community with obvious boundaries, as the outside is surrounded by arterial roads and the inside exclusively by pedestrian roads, except for a single automobile road. The Xingshe community is a typical open community, with the outside being close to a city branch road, the inside comprising gridded streets, and automobiles being able to transit freely. The study identified seven locations in the gated community and the open community as measurement points, respectively, which were named as GC1–GC7 in the Xinghai Renjia community and OC1–OC7 in the Xingshe community, as shown in **Figure 2**. Photos of the *in-situ* are shown in **Figure 3**. These locations were evenly distributed to reflect the general situation within the community surrounded by buildings, in which there were a variety of noise sources such as traffic, people, and birds.

Measurement of Sound Parameters

The measurement of the studied sound parameters was carried out in the two communities from 9:00–16:00 during a weekday in October. Noise level was measured using an NTI XL2 sound level meter including the A-weighted equivalent continuous sound pressure level (L_{Aeq}), the C-weighted equivalent continuous sound pressure level (L_{Ceq}), and statistical levels (L_{A90}, L_{A50}, and L_{A10}).

To reflect the human binaural auditory system, binaural recordings were conducted, making it possible to reproduce the spatial characteristics of the recorded acoustic environments (Genuit and Fiebig, 2006; Semidor, 2006). Therefore, a 5-min audio recording of the sound environment at each location was taken using a binaural recording device BR2022, which was set at a sampling rate and bit depth of 48 kHz and 24 bits, respectively. Recording levels were calibrated by a sound calibrator B&K4231 (Jeon et al., 2018).

Construction of the Questionnaire

Considering that the sound environment perceived by each person constantly changes in on-site soundscape evaluations, which makes it difficult to rule out the influence of occasional noise, the listening experiment was conducted in a laboratory by playing the recorded files obtained on the spot.

Participants were recruited to engage in the listening experiment and were required to complete a questionnaire, which contained three parts. The first part of the questionnaire

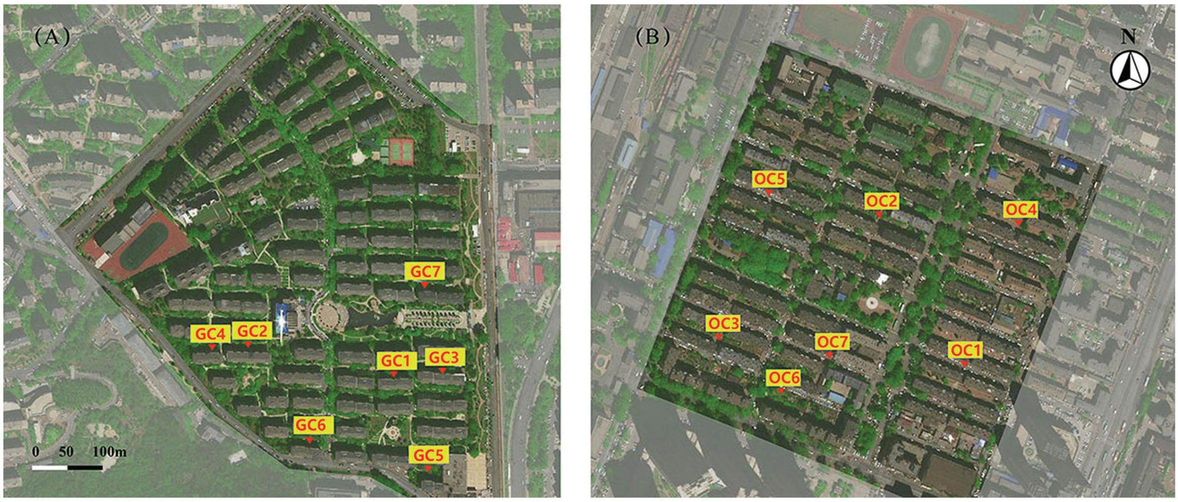

FIGURE 2 | General community planning mode. **(A)** Xinghai Renjia Community (GC); **(B)** Xingshe Community (OC).

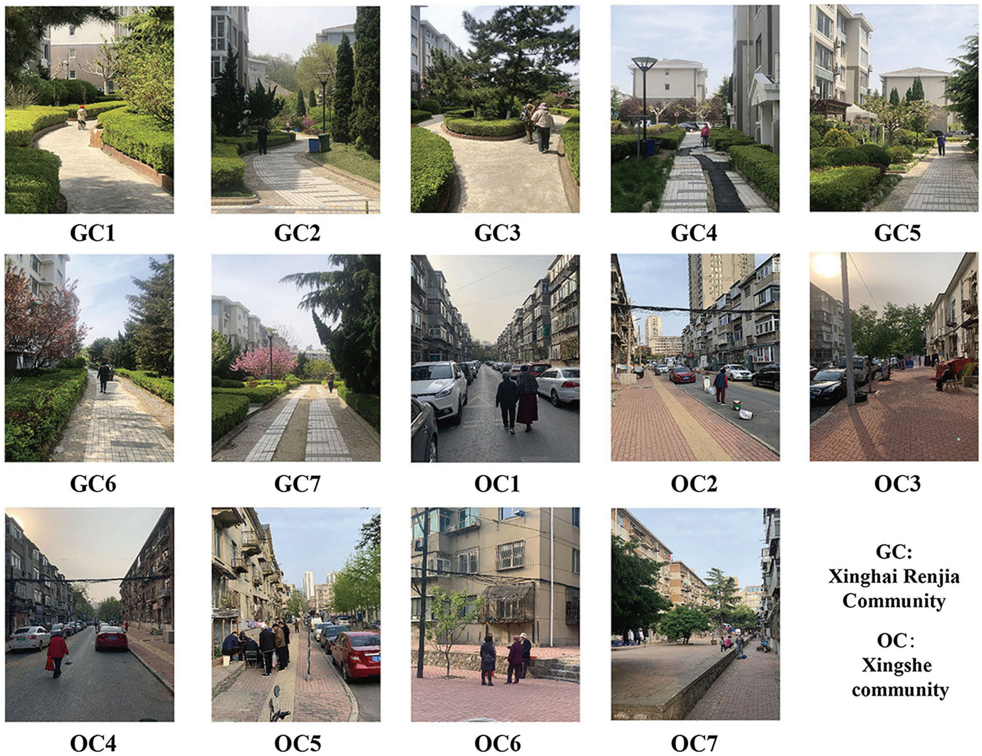

FIGURE 3 | Photos of the sites in Xinghai Renjia Community (GC) and Xingshe community (OC) where the surveys were conducted.

was about perceived dominance of sound sources including three questions. The identification of sound sources is important for understanding soundscape perceptions because the different categories of sound sources provide more information on perceived soundscape quality (Nilsson et al., 2007; Hong and Jeon, 2015; Lu et al., 2020). Based on widely used variables present in soundscape studies (Hong and Jeon, 2015, 2017), the current study classified sound sources into: traffic noise, human sounds (i.e., sounds from human activities), and natural sounds. For each perceived dominance of sound source, the evaluation was made with a five-point Likert type scale (−2 = Do not hear at all, −1 = Hear slightly, 0 = Hear moderately, 1 = Hear a lot, and 2 = Hear predominantly). The left extremity of the bipolar scale was coded as "−2," meaning that "Do not hear at all," and its right extremity was coded as "2," meaning that "Hear predominantly."

The second part of the questionnaire concerned noise annoyance including one question. Noise annoyance mainly covers immediate behavioral effects and evaluative aspects related to noise (Guski et al., 1999) and is easily caused by major sound sources in urban areas such as road traffic and sounds from people in resident areas (Gidlöf-Gunnarsson and Öhrström, 2010; Di et al., 2012; Hong and Jeon, 2015; Gozalo and Morillas, 2017). Procedures for assessing noise annoyance have been investigated thoroughly (Levine, 1981; Fields et al., 1997). According to these procedures, noise annoyance evaluation was carried out using a five-point Likert language scale (−2, Not at all; −1, Slightly; 0, Moderately; 1, Very; and 2, Extremely).

The third part of the questionnaire investigated soundscape perception dimensions including eight questions. Axelsson et al. (2010) proposed a two-dimensional model of soundscape perceptions, which were defined by two orthogonal factors, Pleasantness and Eventfulness. These two factors have been commonly assessed in several soundscape studies (Kang and Zhang, 2010; Hong and Jeon, 2017; Jeon et al., 2018). In this study, and according to the standard emotional vocabulary provided by the Swedish Soundscape-Quality Protocol (Axelsson et al., 2010; Hong and Jeon, 2015, 2017; Aletta et al., 2016), eight adjectives were used for evaluating soundscape perception dimensions; they were Pleasant, Unpleasant, Chaotic, Calm, Eventful, Uneventful, Exciting, and Monotonous. For each adjective, the evaluation was made with a five-point Likert type scale (−2 = Strongly disagree, −1 = Slightly disagree, 0 = Neither agree nor disagree, 1 = Slightly agree, and 2 = Strongly agree). The left extremity of the bipolar scale was coded as "−2," meaning that "Strongly disagree," and its right extremity was coded as "2," meaning that "2 = Strongly agree."

Procedure

In total, 30 participants (15 male and 15 female participants) were included in the listening experiments. They were all postgraduates, and their age distribution ranged from 22 to 29 years (mean = 26.0 years, SD = 2.0 years). Before participating in the experiment, aligned to prior research (Lu et al., 2020), all subjects were tested for air-conduction hearing threshold levels using a Madsen audiometer model ITERA. To ensure that the noise level meets the standard requirements (ISO/IEC IS 8253-1, 2010; International Organization for Standardization, 2010), the experiment was carried out in an audio-visual laboratory with certain sound insulation measures. According to the current standards (GBZ 49-2014; International Organization for Standardization, 2014), the results showed that all subjects had normal hearing.

It should be mentioned that actual dwellers in the same age group can be recruited for the laboratory experiments, which may have contributed to the reliability of the results. However, if the participants had not been of similar ages (Yang and Kang, 2005) or were, for example, older than 60 years, this may have caused large individual differences due to inconsistent hearing levels, thereby causing the conclusions to be unreliable. This study, therefore, recruited postgraduates, allowing for comparisons with other studies using young recruits.

The listening experiment was conducted using a Sennheiser HD-600 headphone, a Rane-HC4s corresponding power amplifier, and a B&K ZE-0948 audio interface. Given that the HD-600 headphone is a type of open-air headphone, it was easily affected by ambient noise; hence, based on prior research (Zhu et al., 2014; Jeon et al., 2018), the experiment was conducted in a semi-anechoic chamber. According to Zhu et al. (2014), to ensure that the noise level of the reproduced sound was exactly the same as that on the actual site, the binaural recording signals reproduced through a headphone that was placed on an artificial head and those recorded by the NTI XL2 sound level meter were compared.

Before the formal experiments, systematic training was provided to all participants to ensure that they understood the entire experiment process and could master the key points (Zhu et al., 2014). Based on a prior methodology (Jeon et al., 2018), the formal experiments were conducted as follows: each subject first listened to one audio excerpt (2 min) as a pre-exercise; then, 14 formal audio excerpts (2 min) were presented, in an irregular order, to every participant while they were concomitantly required to answer the questionnaires (see **Figure 4**). The final sample comprised 420 effectively responded questionnaires, 210 from each community.

The Wald-Wolfowitz runs test (Wald and Wolfowtiz, 1940; Bartels, 1982; Lu et al., 2019) conducted on 14 sets of data evaluations for each participant showed that the majority of the runs were insignificant, indicating that the datasets evaluated by each participant were independent. This inference can also be explained empirically. Each recording file is randomly recorded at different measuring points, and there are differences between each, which indicates that the soundscape evaluation is also independent to some extent. Thus, the sample size for both communities was 42, and for each community, the sample size was 210.

The sample size meets the requirements for statistical analyses. For a principal component analysis (PCA), the minimal adequate sample size should be five times the number of variables (O'Rourke and Hatcher, 2013). Regarding this study, the number of items is eight, which means that the sample size meets the requirements for each community (210 > 40). Additionally, the sample size for each community meets the requirements of SEM (210 > 200) (Kline and Little, 2011). Furthermore, a comparison between various sample sizes suggests that a sample size of 100–150 is generally acceptable for evaluating soundscapes in public spaces (Nilsson et al., 2007).

In addition, **Table 1** shows the noise level results of the survey sites. Based on prior research (Gozalo et al., 2018; Lu et al., 2020), two calculations were conducted as follows: $L_{Ceq}–L_{Aeq}$ and $L_{A10}–L_{A90}$. *T*-tests were then conducted for noise level parameters, which showed no statistical difference in noise level indicators between the two communities, suggesting that the discussion below is based on the premise that sound energy is broadly the same in both communities.

Data Analysis

First, to determine whether there was a significant difference in the sound environment between the gated and open community, the mean values for the soundscape evaluation parameters were compared. Shapiro–Wilk was used to determine whether data were normally distributed. If yes, an independent samples *t*-test or independent samples Mann–Whitney *U* test was used. For the soundscape perceptual dimensions, the principal component scores were calculated by the adjectives and then compared between the two planning modes.

Subsequently, SEM was carried out in AMOS 21.0 to test whether the community planning mode moderated the soundscape. In the first step, exploratory factor analysis (EFA) and confirmatory factor analysis (CFA) confirmed that the two models showed acceptable goodness of fit. Following this, multi-group SEM was used to examine the potential moderating role of community planning modes, and whether the proposed mediation model showed significant differences between the gated and open communities. The regression coefficients in each group model were constrained, and the changes were evaluated to test the moderating effect of community planning modes.

The recommended cut-off values for goodness-of-fit were as follows: χ^2/df < 5, root-mean-square error of approximation (RMSEA) < 0.1, comparative fit index (CFI) > 0.90, incremental fit index (IFI) > 0.90, and goodness-of-fit index (GFI) > 0.90 (Kline and Little, 2011).

RESULTS

Comparison of Soundscape Evaluation

Comparison of Perceived Dominance of Sound Sources

Table 2 shows the descriptive statistics of the soundscape evaluation parameters. **Figure 5** shows the evaluation results of perceived dominance for each sound source in the two communities. The dominance of traffic noise in the gated community (mean = 0.42, SD = 0.951) was lower than that in the open community (mean = 0.60, SD = 0.914). For traffic noise, the total response ratio for the options "Hear a lot" and "Hear predominantly" in the gated community (54.7%) was also larger than in the open community (64.8%). This was because, although the noise level of the two communities

TABLE 1 | Noise level indicator results of survey sites in dB.

Survey sites		L_{Aeq}	L_{Ceq}	L_{10}	L_{50}	L_{90}	L_{Ceq}-L_{Aeq}	L_{10}-L_{90}
Gated community	GC1	46.5	61.5	47.1	45.1	42.3	15	4.8
	GC2	47.6	63.9	50.1	45.6	42.1	16.3	8
	GC3	51.4	66.3	53	50.5	46.8	15	6.2
	GC4	50.4	67.9	52.8	49.8	44.4	17.6	8.4
	GC5	54	67	56.5	52.9	49.7	13	6.8
	GC6	53.2	66	55.3	52.3	49.5	12.8	5.8
	GC7	49.9	69.3	50.1	49	47.6	19.4	2.5
	Mean	50.4	66.0	52.1	49.3	46.1	15.6	6.1
	SD	2.5	2.4	3.0	2.8	2.9	2.2	1.9
Open community	OC1	49	65.8	50.4	47.8	46.4	16.8	4
	OC2	45.7	59.2	46.7	44.5	43.5	13.5	3.2
	OC3	53.6	70.5	56	52	48.7	16.9	7.3
	OC4	48.8	60.1	51.4	47.6	45	11.3	6.4
	OC5	53	66.7	56.2	51	44.3	13.6	11.9
	OC6	51.2	65.7	52.8	50.4	49	14.4	3.8
	OC7	49.5	61.6	49.3	47.6	46.8	13.1	2.5
	Mean	50.1	64.2	51.8	48.7	46.2	14.2	5.6
	SD	2.5	3.8	3.2	2.4	2.0	1.9	3.0

SD, standard deviation.

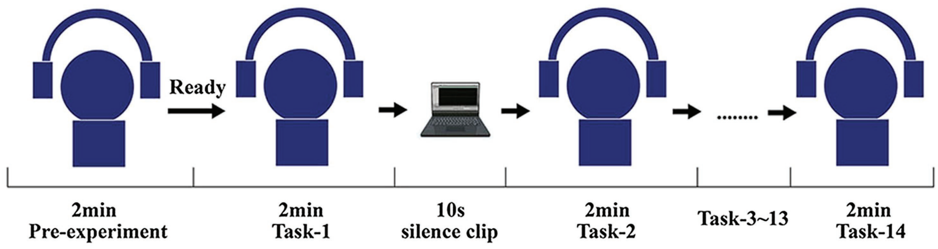

FIGURE 4 | The experimental procedure.

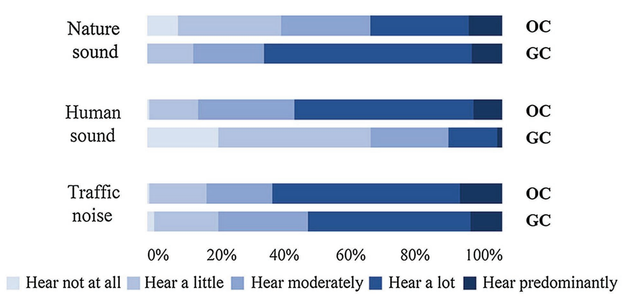

FIGURE 5 | Results of the sound source evaluation stratified by the gated community and the open community and the three sound sources. GC, the gated community and OC, the open community.

was basically the same, the traffic noise of the gated community comes from distant roads with reflected sounds accounting for a large proportion of the sound energy, and the overall fluctuation being small. In the open community, the traffic noise emanates from the nearby roads; therefore, the direct sound accounts for a large proportion of the sound energy, and the sound fluctuates greatly; these characteristics are obvious to our human perceptual capabilities.

The dominance of human sound in the gated community (mean = −0.66, SD = 0.995) was much lower than in the open community (mean = 0.52, SD = 0.848). For human sound, the total response ratio for "Hear a lot" and "Hear predominantly" was also diminished in the gated community (15.2%) compared with the open community (58.6%). This is because different planning modes bring forth different architectural functions and crowd activities. Compared with the gated community, the open community has more commercial facilities facing the street; therefore, there are more human activities that occur near or in the streets. Hence, there were more natural human sounds that could be heard at the open community test site.

The dominance of natural sound in the gated community (mean = 0.63, SD = 0.816) was much higher than in the open community (mean = 0.00, SD = 1.139). The total response ratio for "Hear a lot" and "Hear predominantly" was also higher in the gated community (67.2%) than in the open community (37.1%). This is because, compared with the open community, the ecology in the gated community tends to be better and, therefore, more conducive to birds settling there. Hence, more natural sounds were heard at the gated community test site.

The Mann–Whitney *U* test showed that there were significant differences in the perceived dominance of all three sound sources in the two communities.

Comparison for Noise Annoyance

As can be seen from **Table 2** and **Figure 6**, noise annoyance in the gated community (mean = −0.52, SD = 0.93) was significantly lower than in the open community (mean = −0.16, SD = 0.94). The total response ratio for "Very" and "Extremely" (15.2%) was also diminished in the gated community compared with that in the open community (25.7%). The Mann–Whitney *U* test showed that the noise annoyance in the two communities differed significantly.

Comparison of the Soundscape Perception Dimensions

To obtain the differences in soundscape perception by community planning mode, the data matrixes of the 420 individual responses to the third section of the questionnaire were created. To determine the optimized orthogonal components, varimax rotation was applied. Following the Kaiser criterion (Kaiser, 1960), two components with eigenvalues larger than one were obtained for the data, and they explained 68.91% of the total variance. Based on prior research, the minimum acceptable value is 60% (Reyment and Jvreskog, 1993).

Two main dimensions, labeled as Pleasantness and Eventfulness were extracted, concurring with prior research (Axelsson et al., 2010). The Pleasantness dimension contained the Pleasant, Unpleasant, Chaotic, and Calm adjectives and explained 35.07% of the total variance. The Eventfulness dimension contained the Eventful, Uneventful, Monotonous, and Exciting adjectives and explained 33.84% of the total variance. To analyze the data from each subject, component scores of Pleasantness and Eventfulness were calculated using the regression method – as described in prior research (Guski et al., 1999). The Mann–Whitney *U* test showed that there were significant differences in the soundscape perception dimension between the two communities as can be seen in **Table 2**.

An EFA using PCA was applied to extract the soundscape perception dimensions. By examining the reliability and validity of the evaluations in the PCA solution, the study reversed the direction of the evaluations of four adjectives: Unpleasant, Chaotic, Uneventful, and Monotonous, ensuring that they maintained a consistent score. Results showed that the respective Cronbach's alpha coefficient for the PCA was 0.849; hence, it was over 0.80, suggesting good reliability (Lance et al., 2006). The Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy was 0.787; hence, it was over 0.70, confirming the validity of the questionnaire. The Bartlett's spherical test results ($p = 0.000 < 0.01$) were also meaningful (Hair et al., 2010).

Reliability and Validity of Research Constructs Using SEM

The measurement model was tested using CFA (see **Figure 7**). The item loading was defined as the ratio between the item (question-statement) and the construct. The item loadings needed to be equal to or greater than 0.50 based on prior research (Kock, 2015). As the loading for the exciting item was 0.45–0.50, it was excluded from the study. All other item loadings were above 0.50, serving as validation parameters of the CFA (Kock, 2015).

Convergent validity and discriminant validity were then tested. To ensure scale reliability and internal consistency, Cronbach's alpha was applied and needed to be at least 0.70 (Peterson, 1994). The composite reliability analysis showed that the constructs were mutually interchangeable. As all the constructs exhibited an internal consistency, reliability was higher than the set target of >0.7 based on prior research (Hair et al., 2013). The average variance extracted (AVE) was defined as the proportion of variance in the items explained by the relevant construct. To ensure validity for the scale, the recommended AVE threshold was 0.50 (Kock, 2015), as an

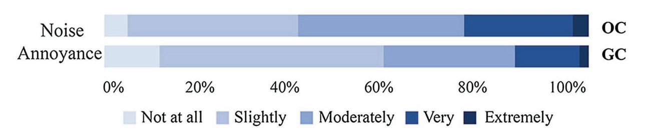

FIGURE 6 | Results of the evaluation of noise annoyance of the gated community and the open community. GC, the gated community and OC, the open community.

TABLE 2 | The descriptive statistics of the soundscape evaluation parameters.

Soundscape evaluation parameters	Observed variables	Total		Gated community		Open community		Skewness	Kurtosis
		M	*SD*	*M*	*SD*	*M*	*SD*		
Noise annoyance		−0.34	0.95	−0.52	0.93	−0.16	0.94	0.34	−0.45
Perceived dominance of sound sources	Traffic noise	0.51	0.94	0.42	0.95	0.60	0.91	−0.49	−0.48
	Human sound	−0.07	1.10	−0.66	1.00	0.52	0.85	−0.11	−0.96
	Natural sound	0.32	1.04	0.63	0.82	0.00	1.14	−0.41	−0.66
Soundscape perception dimensions	Pleasant	−0.04	0.85	0.12	0.86	−0.20	0.81	−0.06	−0.53
	Unpleasant	0.13	0.86	0.26	0.85	0.00	0.86	−0.21	−0.50
	Chaotic	−0.07	1.07	0.20	1.05	−0.33	1.03	0.20	−1.12
	Calm	−0.26	1.04	0.02	1.05	−0.54	0.96	0.26	−0.94
	Eventful	0.24	1.06	−0.14	1.04	0.62	0.94	−0.30	−1.02
	Uneventful	0.51	1.02	0.18	1.06	0.84	0.87	−0.60	−0.36
	Monotonous	0.44	0.94	0.18	0.95	0.71	0.85	−0.50	−0.42
	Exciting	−0.40	0.91	−0.60	0.87	−0.20	0.90	0.00	−0.56

Total (N = 420), gated community (n = 210), and open community (n = 210).

AVE of 0.50 represents that, on average, a construct can explain about 50% of the variance of its indicators. **Table 3** displays Cronbach's alpha, the AVE, and critical ratio, all of which being satisfactory.

Modification indices were applied though added error covariance between Pleasant and Unpleasant according to empirical rationales (Kline and Little, 2011). The results demonstrated acceptable model fit indices: χ^2/df = 3.93, CFI = 0.98, IFI = 0.98, GFI = 0.97, and RMSEA = 0.08. The skewness and kurtosis values, which were within the range of −1.12 and 0.26, indicated normally distributed variables – based on prior research (Smedema et al., 2010).

Multi-Group Analysis in the SEM

To test the moderating effect of community planning mode, group differences between gated and open communities were determined using multi-group analysis of SEM. The unconstrained structural model, which allowed for the structural paths to vary across community planning modes, was compared with the constrained structural model, which constrained the regression coefficients to be equal between the communities. The results showed that the unconstrained model (χ^2 = 254.42, df = 66) and constrained model (χ^2 = 66, df = 77) had significant differences ($p < 0.01$), suggesting that the community planning mode played a moderating role in the relationship among the different soundscape parameters.

The factor loadings of all items for two latent variables ranged from 0.43 to 0.95 in the two SEMs, suggesting good values for all variables (Kline and Little, 2011). **Table 4** shows the fitness indicators in the SEMs for the unconstrained and constrained model. The fitness index of the grouping model conformed to the recommended value, indicating that the theoretical model was valid.

As can be seen from **Figures 8, 9**, the two SEMs revealed that traffic noise and human sound had a significantly negative ($p < 0.05$) effect on Pleasantness and a positive effect ($p < 0.05$) on Eventfulness, in both gated and open communities. Moreover, traffic noise was positively associated with noise annoyance in both communities. Natural sound had non-significant ($p > 0.05$) effects on Pleasantness and Eventfulness. Further, noise annoyance was negatively associated with Pleasantness and positively associated with Eventfulness. Moreover, in the gated community, the dominance of the three sound sources was significantly related to noise annoyance; in the open community, only the dominance of traffic noise was significantly related to noise annoyance. Namely, to reduce noise annoyance, the gated community needs to have every type of sound source in it targeted and dealt with, while the open community requires only traffic noise to be diminished.

To clarify which relationships among the soundscape perception parameters have changed between the gated and open communities, path-by-path comparisons were conducted using critical ratios for differences (CRD); this method served to allow for examining the existing differences in each structural path across the two groups. If the CRD between the two groups is between ±1.96 using pairwise parameter comparison (Arbuckle, 2011; Byrne, 2013), then no difference existed between the two groups, otherwise, a significant difference existed.

As presented in **Table 5**, the CRD test showed that the paths from traffic noise to Eventfulness were statistically and significantly different between the two groups (CRD = 2.75, $p < 0.05$); specifically, traffic noise positively predicted Eventfulness in the open community ($\beta = 0.43$, $p > 0.05$), but showed no significant effect in the gated community ($\beta = 0.12$, $p > 0.05$). This means that greater emphasis should be placed on measures to reduce traffic noise fluctuations in the open community compared with the gated community. Also, it proved that the general research hypothesis, H1, was statistically significant.

Further, the paths from natural sound to noise annoyance were statistically and significantly different between the two groups (CRD = 2.12, $p < 0.05$), which proved that the general research hypothesis, H2, was statistically significant. In the gated community, natural sound showed a negative effect on noise annoyance ($\beta = -0.16$, $p < 0.001$), and the opposite effect occurred in the

TABLE 3 | Results of confirmatory factor analysis (CFA) for scale reliability and construct validity (N = 420).

Latent variable	Observed variable	Reliability (Cronbach's α)	Factor loadings	CR	AVE
Pleasantness	Pleasant	0.861	0.591	0.83	0.57
	Unpleasant		0.556		
	Chaotic		0.931		
	Calm		0.869		
Eventfulness	Monotonous	0.804	0.524	0.81	0.60
	Uneventful		0.804		
	Eventful		0.938		

AVE, average variance extracted; and CR, critical ratio.

TABLE 4 | Fitness indicators of structural equation models for the gated and open communities.

Fit indicators	χ^2/df	RMSEA	CFI	IFI	GFI
Unconstrained model	3.85	0.08	0.91	0.91	0.90
Constrained model	3.56	0.08	0.91	0.91	0.90

RMSEA, root-mean-square error of approximation; CFI, comparative fit index; IFI, incremental fit index; and GFI, goodness-of-fit index.

open community (β = 0.01, p > 0.05). Hence, to reduce noise annoyance, stakeholders should add natural sounds to a gated community, whereas this is not necessary in an open community.

The paths from noise annoyance to Eventfulness (CRD = −2.03, p < 0.05) also showed a significant difference, which proved that the general research hypothesis, H3, was statistically significant. In the gated community, noise annoyance showed a positive effect on Eventfulness (β = 0.32, p < 0.001), while there was no such significant relationship in the open community. Therefore, noise annoyance could not, as a unique evaluation index, explain the complex sound environment in communities.

These results demonstrated that the community planning mode moderated the relationships among the soundscape perception parameters differently between the gated and open community. No significant group differences were found in other structural paths.

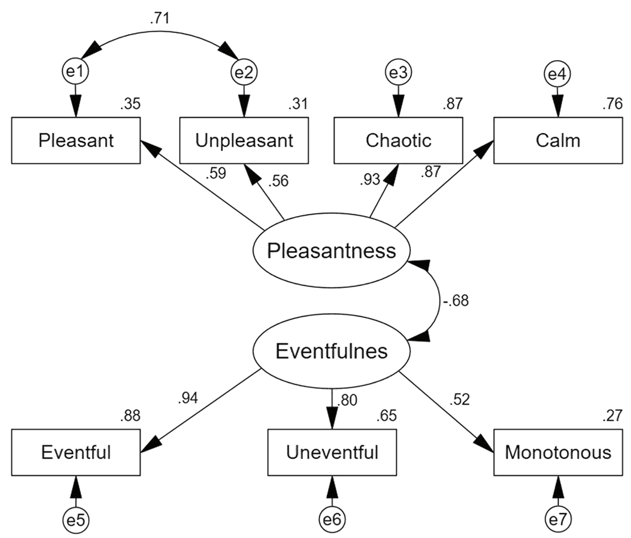

FIGURE 7 | Schematic description of the results for the CFA of the two first order factors (N = 420). All coefficients are significant at the p < 0.05 level.

DISCUSSION

Although there were no significant differences in noise level indicators, the three soundscape perception variables showed significant differences between the gated and open communities, which further proves that the contribution of sound sources to soundscape quality might be different in different scenarios (Hong and Jeon, 2015). The dominance of traffic noise and human sounds in the gated community were lower than their dominance in the open community. The dominance of natural sounds in the gated community was higher than in the open community, and noise annoyance in the gated community was much lower than in the open community. Furthermore, the scores for the Pleasantness and Eventfulness dimensions of

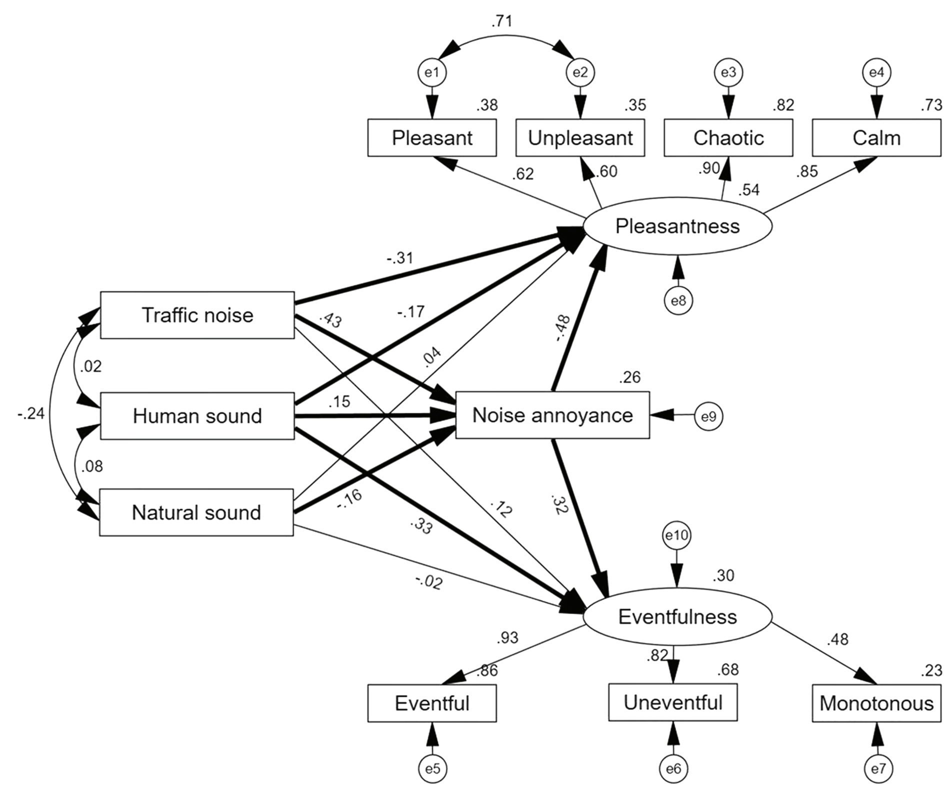

FIGURE 8 | Results of the multigroup analysis in the structural equation model (SEM) for the gated community (N = 210). The presented coefficients are standardized. e, error term, residue term; bold line, significant; and thin line, non-significant.

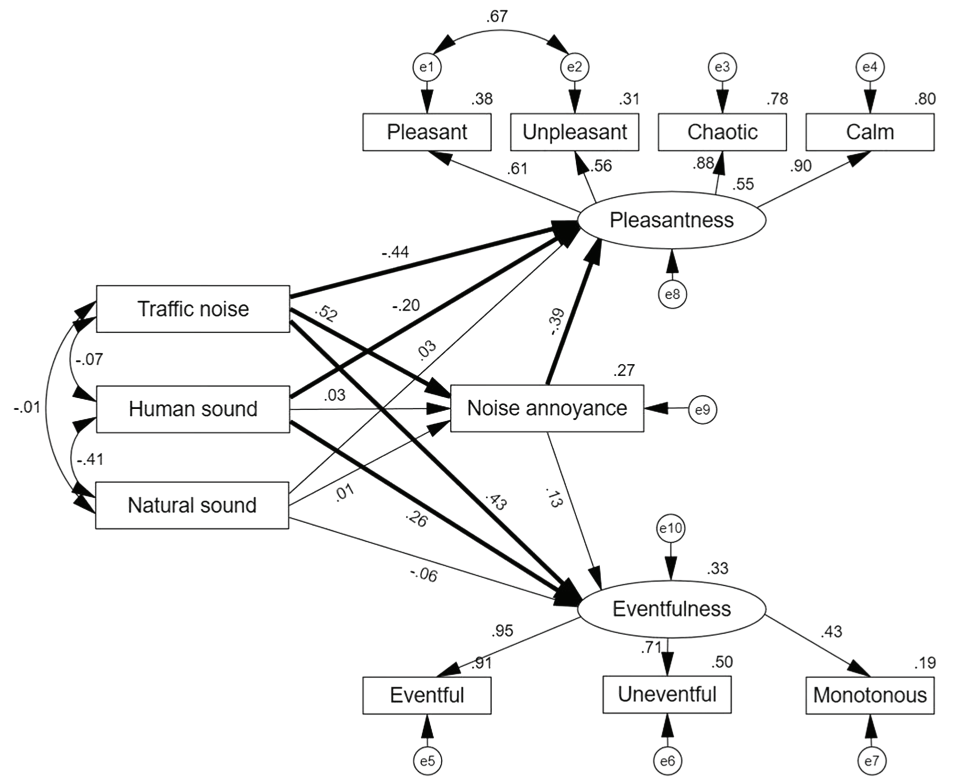

FIGURE 9 | Multigroup analysis in the SEM for the open community (*N* = 210). The presented coefficients are standardized. e, error term, residue term; bold line, significant; and thin line, non-significant.

TABLE 5 | Path coefficients for the relationships among the soundscape perception parameters and comparison between the gated and open community.

Path of regression	Gated community	Open community	CRD
Traffic noise → Pleasantness	−0.17***(−0.31)	−0.24***(−0.44)	−1.13
Human sound → Pleasantness	−0.09**(−0.17)	−0.11**(−0.2)	−0.48
Natural sound → Pleasantness	0.02(0.04)	0.01(0.03)	−0.22
Traffic noise → Eventfulness	**0.12(0.12)**	**0.42***(0.43)**	**2.75**
Human sound → Eventfulness	0.32***(0.33)	0.28***(0.26)	−0.39
Natural sound → Eventfulness	−0.02(−0.02)	−0.04(−0.06)	−0.26
Traffic noise → Noise annoyance	0.42***(0.43)	0.54***(0.52)	1.42
Human sound → Noise annoyance	0.14**(0.15)	0.03(0.03)	−1.26
Natural sound →Noise annoyance	**−0.18**(−0.16)**	**0.01(0.01)**	**2.12**
Noise annoyance → Pleasantness	−0.28***(−0.48)	−0.2***(−0.39)	1.27
Noise annoyance → Eventfulness	**0.34***(0.32)**	**0.12(0.13)**	**−2.03**

CRD, critical ratios for differences between parameters. The non-standardized path estimates are reported outside brackets, and the standardized path estimates are reported in brackets. Bold text represents the significantly different paths between the gated and open communities. $^{**}p < 0.01$; $^{***}p < 0.001$.

soundscape perception also significantly differed between the two communities' environments.

The study confirmed that the community planning mode moderated the relationships among the soundscape perception parameters between the gated and open community. This means that for different residential planning modes, the corresponding sound environment improvement strategies should be different. However, previous studies on residential areas often ignored the influence of the planning mode and only proposed the need to control traffic noise (Hong and Jeon, 2015). In gated communities, reducing noise annoyance may encompass the consideration of each sound source, be it either to increase or decrease their sounds; in open communities, only traffic noise may need to be considered for such aims. Specifically, a comparison of the path analysis of the two communities showed a significant difference in the relationship between natural sound and noise annoyance in both communities; namely, in gated communities, attempts can be made to reduce noise annoyance by adding natural sound. Meanwhile, in open communities, there may be no such requirement to increase natural sounds. This is different from the study of Hao et al. (2016), which found that annoyance and Pleasantness can be altered by increasing the volume of birdsong in the low noise area (<52.5 dB), regardless of the planning mode. This may be caused by the difference in experimental methods, that is, our research considered the influence of reflections from surrounding buildings, while the study by Hao et al. (2016) did not.

There were also significant differences between noise annoyance and Eventfulness in the two communities. Noise annoyance had a positive effect on Eventfulness in the gated community, but a non-significant correlation in the open community; this indicated that for a community with complex internal environments, only considering noise annoyance may be insufficient to improve the soundscape. We suggest that future research should analyze noise fluctuation indexes.

Although the findings of this study were derived from data collected from the activity spaces of older adults and children in two typical communities, ensuring that the findings are applicable to many communities in China, influencing factors such as urban traffic flow, building layout, and site facilities were not carefully analyzed. Further, the major conclusions of this study were derived from a laboratorial sound playback; in a real environment, vision also has an impact on hearing and may change the outcomes. In the future, related research should focus on practical soundscape design.

CONCLUSION

This study selected the main outdoor activity spaces (about 50 dBA) utilized by older adults and children in two typical communities in China as the measurement samples. The study was based on the premise that the noise level indicators are basically the same in both communities. Comparisons were then made for the soundscape perception between the gated and open communities. The conclusions were as follows:

1. The three soundscape perception variables showed significant differences between the gated and open communities, although the noise level was of no significance. It could be further explained that even if the objective characteristics of the sound environments are similar, there are still differences in soundscape perception, which is mainly due to the different modes of communities resulting in different content of the sound environment.
2. The community planning mode moderated the relationships among the soundscape perception parameters between the gated and open communities. To reduce noise annoyance in the gated communities, each sound source should be considered, particularly the addition of natural sounds; in open communities, only traffic noise should be considered.
3. There was no relationship between noise annoyance and Eventfulness in an open community, indicating that noise annoyance was insufficient to explain the complex sound environment of the community.

These findings will help urban designers and managers to adopt targeted strategies to improve the soundscape and quality of life of community dwellers. There are however limitations to this study. For example, the research conclusions (e.g., open communities do not need to increase natural sound), apply mainly to low-noise areas (50 dBA) in communities. In high-noise areas, the conclusions may be different. For example, Lu et al. (2020) believe that it is more effective to add natural sound in a high-noise area adjacent to a road than in a low-noise area, no matter what the planning mode. Therefore, in future studies, additional experiments should be conducted in high-noise areas to find possible differences between the two planning modes. Moreover, the communities selected for this study were all multi-story buildings. The sound environment perception of the communities with high-rise buildings may be different from those with multi-story buildings, considering that the sound environment perception will be affected by the building form (Echevarria et al., 2016). Therefore, in future studies by the present authors, experimental samples will be carried out on communities with various building forms.

DATA AVAILABILITY STATEMENT

The data used to support the findings of this study are available from the corresponding author upon request.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

XLu, PZ, and XLiu: research idea and study design. XLiu, WT,and XH: data collection. PZ, XLiu, XLu, and FG: data analysis and paper writing. PZ and XLu: supervision, project administration, and funding acquisition. All authors contributed to the article and approved the submitted version.

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Physical and Psychoacoustic Characteristics of Typical Noise on Construction Site: "How Does Noise Impact Construction Workers' Experience?"

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Construction noise is an integral part of urban social noise. Construction workers are more directly and significantly affected by construction noise. Therefore, the construction noise situation within construction sites, the acoustic environment experience of construction workers, and the impact of noise on them are highly worthy of attention. This research conducted a 7-month noise level (L_{Aeq}) measurement on a construction site of a reinforced concrete structure high-rise residential building in northern China. The noise conditions within the site in different spatial areas and temporal stages was analyzed. Binaural recording of 10 typical construction noises, including earthwork machinery, concrete machinery, and hand-held machinery, were performed. The physical acoustics and psychoacoustic characteristics were analyzed with the aid of a sound quality analysis software. A total of 133 construction workers performing 12 types of tasks were asked about their subjective evaluation of the typical noises and given a survey on their noise experience on the construction site. This was done to explore the acoustic environment on the construction site, the environmental experience of construction workers, the impact of noise on hearing and on-site communications, and the corresponding influencing factors. This research showed that the noise situation on construction sites is not optimistic, and the construction workers have been affected to varying degrees in terms of psychological experience, hearing ability, and on-site communications. Partial correlation analysis showed that the construction workers' perception of noise, their hearing, and their on-site communications were affected by the noise environment, which were correlated to varying degrees with the individual's post-specific noise, demand for on-site communications, and age, respectively. Correlation analysis and cluster analysis both showed that the annoyance caused by typical construction noise was correlated to its physical and psychoacoustic characteristics. To maintain the physical and mental health of construction workers, there is a need to improve on the fronts of site management, noise reduction, equipment and facility optimization, and occupational protection.

Keywords: construction workers, construction noise, noise level, physical and psychoacoustic characteristics, sound annoyance, impact on hearing, impact on on-site communication

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INTRODUCTION

In the process of urbanization, cities are often occupied by a large number of construction sites, which has caused the problem of construction noise. Although most construction noise is not continuous, its high sound pressure level and overall long exposure time have caused some problems to surrounding residents. In China, the number of complaints about construction noise ranked first among all types of noise in 2019, accounting for 45.4% of all complaints (China Ministry and Environment, 2020). The harm of noise to the human body cannot be ignored. As the most persistent physical contaminant in the human environment, a large number of empirical studies have focused on the adverse effects of noise on individual health. Such effects included hearing impairment (Clark and Paunovic, 2018), cardiovascular disease (Van Kempen et al., 2018), sleep disorders, etc. (Jung et al., 2020). In contrast, construction workers within construction sites are more directly and more significantly affected by construction noise, whose occupational noise exposure also deserves attention. As of 2019, there were 54.27 million workers in the construction industry in China (China National Bureau of Statistics, 2020). Most of the workers were disturbed by noise, which was caused by both the construction actions and the machinery. In the field of occupational noise, noise-induced hearing loss (NIHL) is the most direct consequence to workers, and has become the focus of extensive research (Basner et al., 2014). It was estimated that 16–24% of hearing impairment was related to works in the world (Nelson et al., 2005). Long term high-exposure noise could cause NIHL and even cause permanent hearing losses (ISO, 2013). Statistics had shown that more than 20 million Americans worked with high-exposure noise (Tak et al., 2010).

The academic community generally used equivalent continuous A-weighted sound pressure level (L_{Aeq}) as an evaluation index of noise exposure (Neitzel and Fligor, 2017). In the temporal dimension, 24 h has usually been used for environmental noise exposure and 8 h has generally been used for occupational noise exposure. At the same time, occupational noise exposure has been quantified by the exchange rate (ER), which was the change in average noise level (in dB). This corresponded to doubling or halving the allowed exposure time. Most countries and organizations used 3 dB as the basis for noise level changes, namely L_{EX}, also known as L_{A8hn} or L_{EX8h} (Neitzel and Fligor, 2017). Based on this, The National Institute for Occupational Safety and Health (NIOSH) proposed the Recommended Exposure Limit (REL). Among these parameters, L_{EX} is 85 dB(A) and ER is set to 3 dB (NIOSH, 1998). The American Conference of Governmental Industrial Hygienists (ACGIH) proposed the Threshold Limit Value (TLV) (ACGIH, 1999), which was essentially the same as NIOSH. Its purpose was to protect the relevant workers after 40 years of Occupational noise exposure. The median of their hearing loss was less than 2 dB. In addition, the European Union (European Union, 2003), Japan (Shaikh, 1999), and China (China National Standard, 2008) have also established occupational exposure restriction mechanisms. Its content was similar to the relevant regulations by the NIOSH and the ACGIH. However, the reality was not optimistic. According to the construction noise monitoring results in different countries and regions, the construction noise all exceeded the specification limit to varying degrees (Neitzel et al., 1999, 2011; Leensen et al., 2011; Haron et al., 2014). This poses potential threats to surrounding people and construction workers.

High-exposure noise will bring negative auditory feelings to construction workers. Related researches were devoted to exploring the relationship between construction noise and noise-induced annoyance. Noise-induced annoyance is defined as an individual's adverse reaction to noise (ISO, 2003), including dissatisfaction, bother, annoyance, and disturbance due to noise (Guski et al., 1999). Most of these studies conducted researches on urban residents through questionnaires (Chunk, 2000; Darus et al., 2015; Liu et al., 2017), and the results focused on the relationship between types of noise or noise level and noise-induced annoyance. However, not only the SPL, but also different construction noise types had different acoustic characteristics, and their subjective perceptions were also different (Lee et al., 2015). In addition to physical acoustics, psychoacoustics is equally important. Psychoacoustic indicators are mainly used in acoustic measurements, sound quality exploration, subjective prediction, etc. The areas involved include car sound quality (Lee, 2008; Volandri et al., 2018), traffic noise (Raggam et al., 2007), mechanical noise (Dragonetti et al., 2017), household appliance noise (Jin et al., 2007), soundscape (Aletta et al., 2020), etc. They were aimed at people's subjective feelings about sound. Zwicker proposed the psychoacoustic annoyance model, whose indicators included the percentile Loudness (N_5), Sharpness (S), Fluctuation strength (F), and Roughness (R). This model was proved to be suitable for different types of noise-induced annoyance estimation (Zwicker and Fastl, 1999). In the field of construction noise, the exploration of psychoacoustic indicators was gradually carried out (Carletti, 2013; Lee et al., 2015), which was also mainly used to explore the relationship between construction noise and noise-induced annoyance.

In order to reduce the risk of workers being exposed to harmful health factors at work, it is the goal of occupational health to put and maintain workers in an occupational environment that adapts to their physical and psychological abilities (Alli, 2008). As the direct contact of construction noise, the physical and psychological changes of construction workers affected by this are worthy of attention.

Based on this, this research carried out empirical studies through noise level measurement of the construction site, questionnaire of construction workers, collection of typical construction noise and acoustic analysis. This research aimed to explore the experience and impact of construction workers on the acoustic environment of the construction site and typical construction noise. Furthermore, this research also explored the factors governing the relevance between the experience of construction noise and the hearing ability and communication between construction workers. This was conducted using statistical methods such as correlation analysis and principal components analysis (PCA).

MATERIALS AND METHODS

Noise Level Measurement of the Construction Site

This study was based on a construction site of a residential complex in Shenyang, China. The site covers a total area of about 25,500 m^2 and includes two construction areas (area 1, area 2) and a living area for workers (area 3) (**Figure 1**). There are no facilities separating the three areas. The overall construction period for the 12 buildings with reinforced concrete shear wall structures on the site was 24 months. A 7-month delay was present between the start of the two construction areas. There were three construction stages measurement for the purpose of noise level monitoring: earthworks, concrete framing and block masonry, and indoor structuring.

The site was divided into 270 square grids of side length 10 m. The position occupied by the main building was removed, and so 184 grids were actually measured. Two surveyors performed L_{Aeq} measurement for 30 s at the center point of each grid from 10:00 to 11:00 for one working day per week. The measuring tool was a B&K 2250 sound level meter with a measuring height of 1.5 m. The overall measurement lasted for 30 weeks (2019.04.05–2019.10.17). There were no measurements in the week of 6, 22, 24, and 28, due to site and weather conditions, and thus a total of 26 measurements were taken. Except for the grid points that were restricted by on-site operating conditions, a total of 4539 valid data were obtained for the 26 weeks. **Figure 2** shows the construction information of each area in the measurement stages.

Typical Noise Collection and Analysis

As the main source of construction noise, the noise created by construction machineries in large dictate the overall noise level within the construction site. In order to explore the acoustic characteristics of mechanical noise, 10 typical noise sources (**Table 1**) including earthwork machinery, concrete machinery, and small hand-held machinery were selected for binaural acoustic measurement at the construction site (Brüel & Kjaer 4101A). The measurement height was 1.5 m and external noises were kept minimum during the measurements. The recording time of each type of noise was 2–3 min with normal operation of each machine, and the background noise during recording was also measured. Audio editing was carried out through B&K Connect sound quality analysis software. Based on the principle of intercepting the complete characteristic period, 10 s samples were intercepted from the material for physical and psychoacoustic analysis. Physical acoustic indicators include L_{Aeq}, L_5, L_{95}, and psychoacoustic indicators include Loudness (N) (ISO, 2017), Fluctuation strength (F), Roughness (R), Sharpness (S) (Zwicker and Fastl, 1999). The perceived overall Loudness of a time-variant sound is well represented by the percentile Loudness N_5 (ISO, 2018), which is the peak Loudness within a certain timeframe. In addition, other psychoacoustic percentile parameters should also be considered to characterize statistical eigenvalues of different psychoacoustic indicators in the temporal domain (ISO, 2019). In addition, the relevant indicators have been applied to the optimization of mechanical noise (Carletti and Pedrielli, 2011) and residents' perception of soundscape in urban public space (Rychtarikova et al., 2008; Rychtarikova and Vermeir, 2013). Thus, N_5, F_{10}, R_{10}, and S_5 should also be calculated. The arithmetic average of the data from both channels in the binaural acoustic measurement system was taken for all of the above parameters.

FIGURE 1 | Distribution of the three areas in the site.

Acoustic Environment Experience and Impact Survey of Construction Workers

Questionnaire Design and Data Collection

In order to understand the acoustic environment experience of the workers during the construction period and explore its influencing factors, a questionnaire was conducted for the workers. The questionnaire was divided into four parts: noisiness level of construction, self-evaluation on hearing ability (SEHA) and evaluation of the interference on on-site communications (EIOSC), evaluation of the annoyance by typical noises, and individual characteristics (**Table 2**). Among them, a five-level descriptive rating scale was employed for the noisiness level of construction and the evaluation of typical sound source annoyance, and the SEHA and EIOSC used a seven-level descriptive rating scale. All respondents signed an informed consent form before completing the questionnaire. They were informed of the purpose of the study and the use of the data. Ethical review and approval was not required for this study with the local legislation and institutional requirements. A total of 143 questionnaires including 12 types of tasks were distributed, and 133 valid questionnaires were returned, with a recovery rate of 93.0%.

Evaluation on the Post-specific Noise Level and Demand for Communication

In the form of a focus-group, four project managers who were familiar with the conditions of the construction site were invited to conduct a professional evaluation of the post-specific noise level and the demand for on-site communications level of the construction site for each type of workers. The evaluation index was a nine-level numerical level.

Statistical Analysis

To eliminate the effect of other variables, partial correlation analysis was employed to investigate the relationship between the results of the self-evaluation of the workers and the post-specific noise, the demand for on-site communications, age and working years. In addition, principal components analysis was used to cluster the ten typical noises according to the 133 respondents' evaluation of the annoyance by typical noises. The Jonckheere–Terpstra test was subsequently used to investigate common features within each cluster of noises.

RESULTS

The Noise Level in the Construction Site

The 4539 measured SPL data (L_{Aeq}) were in the range of 51.0–112.0 dB(A). These data were compared with the occupational noise exposure standards. The results showed that among the 4539 data points, the limit values set by various countries and institutions were exceeded to varying degrees (**Table 3**). 18.6% of the data points exceeded the limit of L_{EX} = 80 dB(A), and 4.3% exceeded the limit of L_{ex} = 85 dB(A).

To compare the noise levels of different construction stages in the construction site, five measurements from different construction stages were selected for comparison among 26 measurements. Through the Arc GIS platform, corresponding attributes were given to the spatial coordinate elements of the construction site, and the Kriging interpolation method was used to produce a noise map of the site.

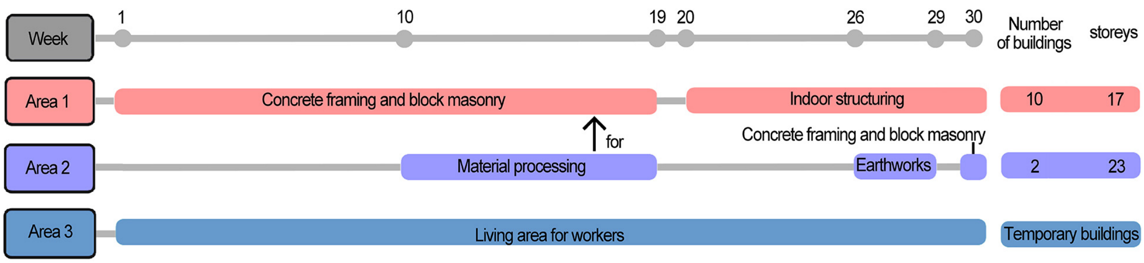

FIGURE 2 | During the 30-week measurement, the different construction stages in the three areas.

TABLE 1 | Ten types of typical noise sources, sound-producing machinery, annual presence time, operator types, and on-site measurement distance.

Machinery type	Construction noise type	Machinery sound	Duration on site (months/year)	Operating worker type	Measurement distance
Earthwork machinery	Earthwork transportation	Dump truck	6	Machinery operator	1–3 m
		Loader	3	Machinery operator	
	Earthwork crushing	Breaker	1	Machinery operator	
	Earthwork excavation	Excavator	3	Machinery operator	
Concrete machinery	Concrete pumping	Concrete pump	8	Machinery operator	1.5–2 m
	Concrete vibration	Concrete vibrator	8	Laborer	
Hand machinery	Material sanding	Angle grinder	12	Laborer/Plumber/Bricklayer	1.5–2 m
	Surface crushing	Jackhammer	12	Carpenter/Laborer	
	Material drilling	Electric drill	12	Laborer/Electric engineer/Plumber	
	Screw installation	Electric screwdriver	12	Electric engineer/Plumber	

TABLE 2 | Questionnaire composition.

Variable	Question description	Type of response
Self-evaluation on hearing ability (SEHA)	What do you think of the impact of construction noise on your own hearing since you participated in site work?	Descriptive rating scale: 1–7 (1-No impact at all to 7-Extremely high impact)
Evaluation of the Interference on On-Site Communications (EIOSC)	What do you think of the impact of construction noise on your communication with others?	
Noisiness level	How noisy do you think the overall acoustic environment of the construction site is?	Descriptive rating scale: 1–5 (1- NOT noisy at all to 5 Extremely noisy)
Typical construction noise annoyance	Please evaluate the annoyance level of the said machinery (The 10 machineries listed in table 1)	Descriptive rating scale: 1–5 (1- Not annoying at all to 5- Extremely annoying)
Individual characteristics	Age, Gender, Type of tasks, Working years	

The noise levels of different construction stages were not consistent (**Figure 3**). In terms of SPL: earthworks > concrete framing and block masonry > indoor structuring. Earthworks included many large-scale mechanical types of equipment, such as excavators, loaders, dump trucks, etc., which would produce a higher SPL during operation and the duration of the noise would be longer. The concrete framing and block masonry stage used more concrete machinery and hand-held machinery, and the SPL produced was smaller than that of the earthwork machinery. In the indoor structuring stage, most of the construction work was transferred to the building interior, which had a barrier effect on the sound transmission, resulting in the minimum contribution to the noise within the site. It is worth noting that area 2 (See **Figure 3B**) was the material processing area, and the rebar cutter and steel bar bender used would produce a relatively high SPL. In general, the distribution of construction noise within the site was not uniform. In addition, the sound pressure levels produced by different construction stages were different. Construction noise was mainly concentrated in the area where the construction work was carried out. Therefore, the occupational noise protection of related work types is worthy of attention.

Acoustic Environment Experience and Impact

Perceived Noisiness Level of the Environment and Self-Evaluated Impact on Workers

The basic characteristics for the composition of respondents included gender, age, working years, and types of tasks (**Table 4**). The reliability of the variables in the questionnaire was tested, and the results showed that Cronbach α was 0.716. This was good reliability that allowed the next step of data analysis to be carried out.

The result showed that only one respondent thought that the construction site was not noisy (**Figure 4**). The respondents who thought the site was "Very noisy" and "Extremely noisy" accounted for 33.1 and 44.6%, respectively. This meant that the respondents generally thought that the construction site was noisy (mean = 4.17), and the evaluation was consistent (SD = 0.97).

In the results of the SEHA and EIOSC, 29.3% (Mean = 4.52, SD = 1.68) and 34.6% (Mean = 3.90, SD = 1.98) of the respondents believed that the impact of noise on their hearing ability and on-site communications has been "Moderately high impact" or higher, respectively. The two self-evaluation results were highly discrete, which indicated that the subjective evaluation was also affected by other factors.

In order to explore the factors for noisiness level and self-evaluation results, the three variables were put to perform partial correlation analysis with post-specific noise, demand for on-site communications, age, and working years.

There was a significant positive correlation between the noisiness level of the construction and the post-specific noise [$r_{(133)} = 0.497$, $p = 0.000$] (**Table 5**). It can be seen that the respondents' results of noisiness level were affected by the post-specific noise.

The post-specific noise level [$r_{(133)} = 0.538$ $p = 0.000$] had different effects on the SEHA. In other words, workers believed that post-specific noise affected their hearing ability. It is worth mentioning that demand for on-site communications [$r_{(133)} = -0.357$ $p = 0.000$] was negatively correlated with impact on the hearing ability, and could also be related to the adaptability of workers on the construction site.

The EIOSC was significantly negatively correlated with the post-specific noise [$r_{(133)} = 0.604$, $p = 0.000$] and age [$r_{(133)} = 0.192$ $p = 0.028$]. It meant the post-specific noise and the hearing loss due to age had a significant impact on on-site communications. At the same time, it was found that EIOSC was negatively correlated with the demand for on-site communication [$r_{(133)} = -0.312$ $p = 0.000$], and could also be related to the adaptability of workers on the construction site.

TABLE 3 | Occupational noise exposure limit and the proportion of over-limit samples (*N* = 4539).

Exposure duration (h)	China		American						European UnionDirective 2003/10/EC					
	GB/T 12801-2008		ACGIH		NIOSH		OSHA		Lower exposure action value		Upper exposure action value		Exposure limit	
	L_{EX} dB(A)	Out of limit (%)	L_{EX} dB(A)	Out of limit (%)	L_{EX} dB(A)	Out of limit (%)	L_{EX} dB(A)	Out of limit (%)	L_{EX} dB(A)	Out of limit (%)	L_{EX} dB(A)	Out of limit (%)	L_{EX} dB(A)	Out of limit (%)
8	85	4.3	85	4.3	85	4.3	90	1.5	80	18.6	85	4.3	87	2.6
4	88	2.0												
2	91	1.3	88	2.0	88	2.0	95	0.4	83	10.2	88	2.0	88	2.0
1	94	0.4	91	1.3	91	1.3	100	0.2	86	3.5	91	1.3	91	1.3
1/2	97	0.2	94	0.4	94	0.4	105	0.1	89	1.6	94	0.4	94	0.4
1/4	100	0.2												
1/8	103	0.1												
0	115	0.1					115	0.1						

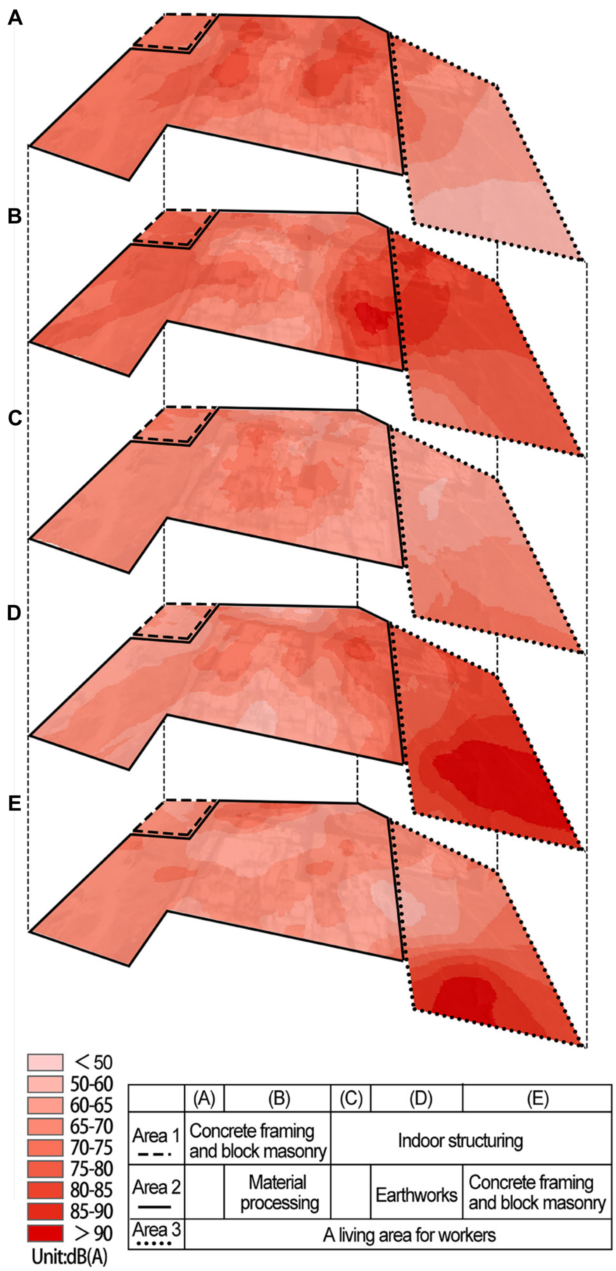

FIGURE 3 | Noise levels of different construction stages: **(A)** 26th Apr, 2019; **(B)** 19th Jun, 2019; **(C)** 22th Aug, 2019; **(D)** 20th Sep, 2019; **(E)** 19th Oct, 2019.

Acoustic Characteristics and Annoyance Analysis of Typical Construction Noise

Analysis of the Acoustic Characteristics

Figure 5 shows the frequency and energy distribution of the 10 typical construction noise over a 10 s period. As the interaural level difference was typically very small (Kang et al., 2018), data from the left channel was arbitrarily chosen to conduct the analysis. It can be seen from the frequency domain distribution characteristics of energy that the loader, the dump truck, and the excavator had higher energy in the low, medium, and high frequency (within 6 kHz) regions. The angle grinder, the jackhammer and the electric drill were distributed at even higher frequency region. The electric screwdriver had a more obvious energy concentration around 4 kHz. From the perspective of temporal-domain characteristics, the impact sound generated by the concrete pump and the breaker had strong periodic characteristics due to their operation mode. The time period of the former was about 1 s, and the latter was about 5 s. The remaining sounds showed a certain steady-state in 10 s.

The physical and psychoacoustic indices of the ten typical construction noises are shown in **Table 6**. The table also contains the maximum, minimum, mean, and standard deviation values. The L_{Aeq} of the ten kinds of construction noise was between 75.82 and 93.87 dB(A). Among them, that generated by the jackhammer and the breaker were above 90 dB(A), that generated by the electric screwdriver and the excavator were below 80 dB(A), and the generated by the other machinery was between 80 and 90 dB(A). Except for the dump truck, which was recorded on the move, the SPL fluctuations (L_5–L_{95}) were relatively small due to the stable sound of the intercepted audio samples. In terms of the psychoacoustic index, the breaker had the highest Loudness, reaching 98.65 sone. The electric screwdriver had the lowest Loudness at 29.86 sone. The Sharpness (S) of the electric drill, the electric screwdriver, the angle grinder, the breaker, and the jackhammer were all above 2 acum. The breaker (2.77 vacil) and the concrete pump (3.21 vacil) had more prominent Fluctuation strength peak values (F_{10}). The jackhammer (3.15 asper) and the breaker (3.81 asper) had higher Roughness(R).

Annoyance Evaluation

The results for the evaluation of typical construction noise annoyance are shown in **Table 7**. $ATCN_m$ represents the mean value of each noise annoyance rating of all respondents (95% confidence interval). Breaker, angle grinder and jackhammer had a mean annoyance greater than 4, which was a high level of annoyance. In particular, for the breaker, 82.7% of the responders thought it was "extremely annoying." The lowest annoyance score was achieved by the electric screwdriver. Its average value was 1.83, which was close to "slightly annoying," with 36.1% of the respondents thinking it was "not annoying at all." The sound of dump truck operations, with an average of 2.52, scored between "slightly annoying" and "moderately annoying." The mean annoyance of each of the other five noises was between 3 and 4, which was a medium annoyance level.

The relationship between $ATCN_m$ and the physical and psychoacoustic indices of typical construction noise was analyzed. The results showed that the $ATCN_m$ was significantly positively correlated with L_{Aeq}, L_5, L_{95}, N, N_5 (**Table 8**), from which it is clear that the noise intensity directly influenced the degree of annoyance. However, there was no correlation between the $ATCN_m$ with S, F, and R. It can be seen that other psychoacoustic indices alone apart from Loudness could not represent noise annoyance. Based on Zwicker's psychoacoustic annoyance (PA) model (Zwicker and Fastl, 1999), the PA of ten

TABLE 4 | The basic characteristics for the composition of respondents.

Gender (N%)		Age (N%)					Working years (N%)				
Male	Female	≤30	31–35	36–40	41–45	≥46	≤5	6–10	11–15	16–20	≥21
124 (93.2)	9 (6.8)	27 (20.3)	38 (28.6)	24 (18.0)	27 (20.3)	17 (12.8)	18 (13.5)	28 (21.1)	35 (26.3)	26 (19.5)	26 (19.5)
Types of tasks (N%)											
Project manager	Logistics and service staff	Rebar worker	Carpenter	Bricklayer	Machinery operator	Laborer	Scaffolder	Plumber	Electric engineer	Door and window installer	Welder
10 (7.5)	6 (4.5)	14 (10.5)	15 (11.3)	19 (14.3)	8 (6.0)	10 (7.5)	10 (7.5)	12 (9.0)	13 (9.8)	7 (5.3)	9 (6.8)

N = 133.

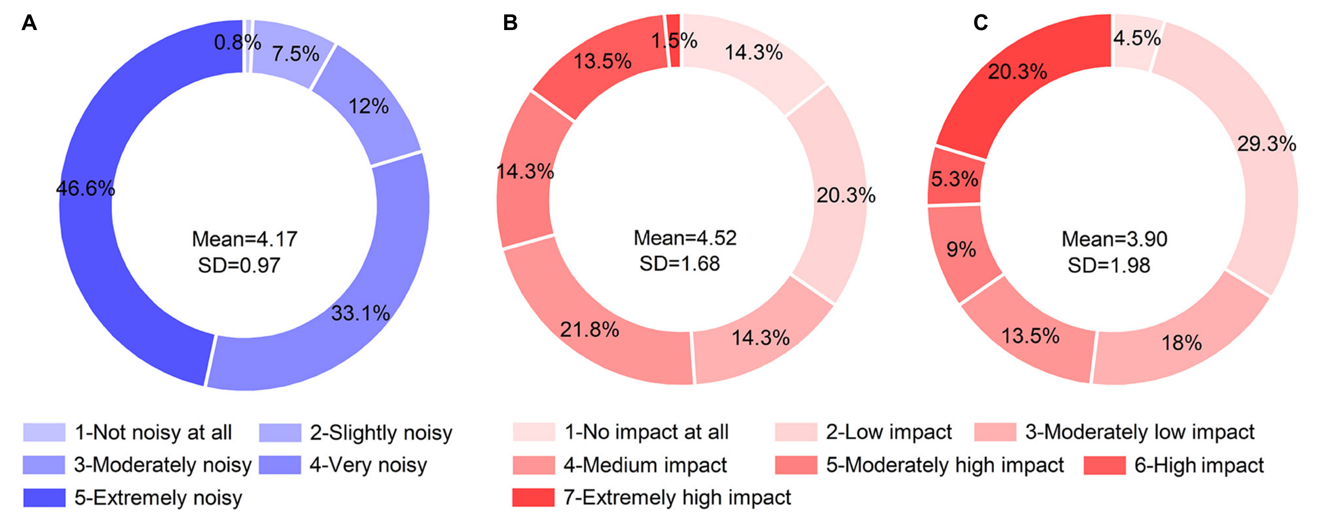

FIGURE 4 | Results of noisiness level and self-evaluation: **(A)** Noisiness; **(B)** SEHA; **(C)** EIOSC.

TABLE 5 | Results of partial correlation in evaluation results and related variables.

Variable		Post-specific noise	Demand for on-site communications	Age	Working years
Noisiness level	Partial correlation	0.497**	−0.013	0.062	−0.086
	Sig. (2-tailed)	0.000	0.879	0.480	0.332
SEHA	Partial correlation	0.538**	−0.357**	0.028	0.126
	Sig. (2-tailed)	0.000	0.000	0.752	0.154
EIOSC	Partial correlation	0.604**	−0.312**	0.192*	−0.116
	Sig. (2-tailed)	0.000	0.000	0.028	0.188

**Correlation is significant at the 0.05 level (2-tailed).*
****Correlation is significant at the 0.01 level (2-tailed).*

typical noise was calculated (See **Table 7**). The PA and $ATCN_m$ showed a high degree of correlation according to a correlation analysis [$r_{(10)} = 0.728$ $p = 0.017$] (See **Table 8**). In addition, the correlation analysis between PA and 10 typical noises shows that except for S (when $S < 1.75$ acum, S does not participate in prediction in the model), the PA was significantly positively correlated with the model's parameters N_5, F, R.

Kendall's W test ($W^a = 0.558$, $p = 0.000$) was used to evaluate the typical noise annoyance of 133 respondents, and principal components analysis was carried out on this basis. To identify the optimized components, varimax rotation was applied. Based on eigenvalues and scree plot analysis (eigenvalue = 0.972≈1, the scree plot showed an inflection point), three components (KMO = 0.735 > 0.7) were extracted, and they covered 57.9% of the total variance. Component 1 (C_1) explained 22.1% of the variance in the data set, including the dump truck, the loader, the excavator and the concrete vibrator. Component 2 (C_2) explained 20.2% of the variance in the data set, including the jackhammer,

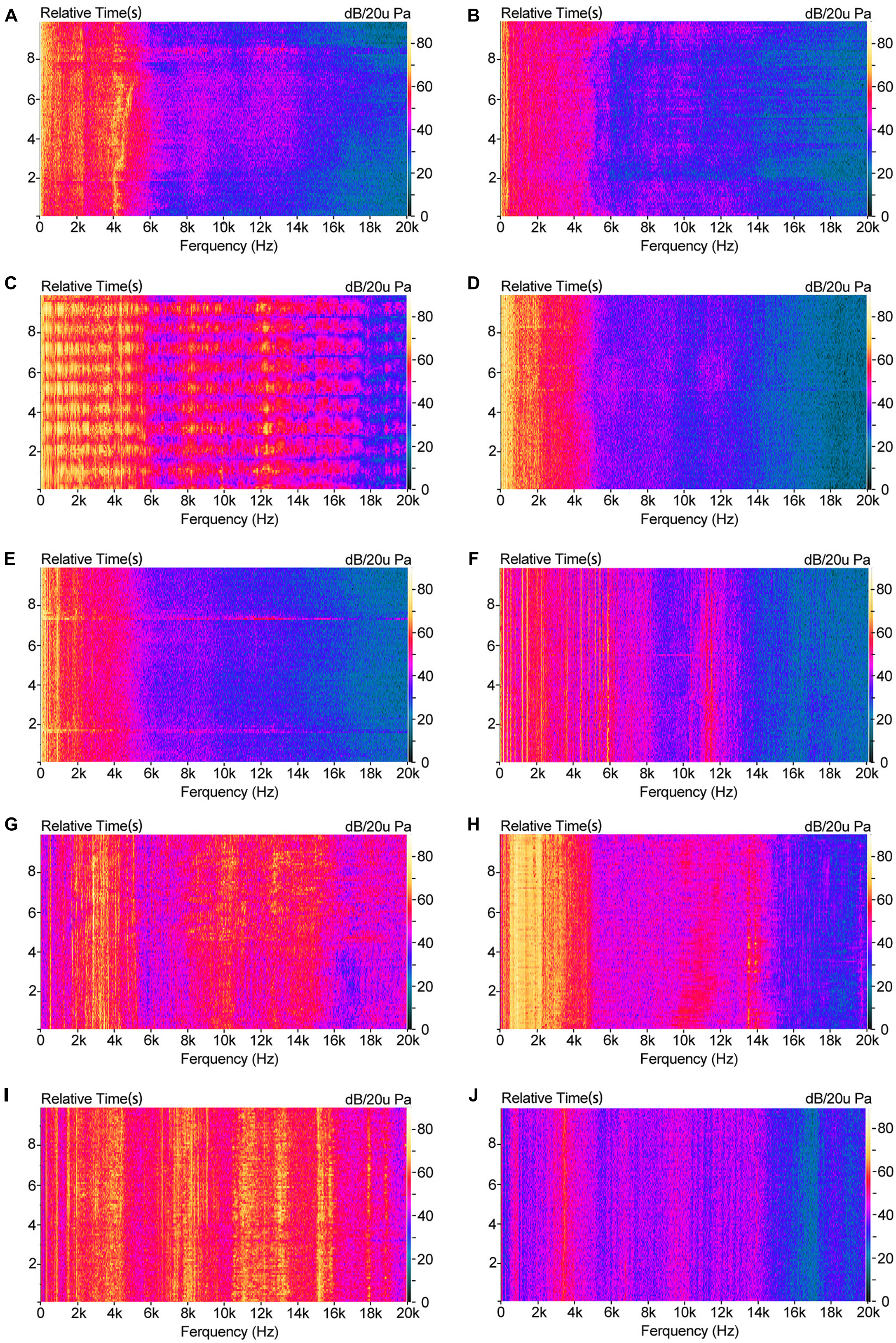

FIGURE 5 | FFT vs. Time: **(A)** Dump truck; **(B)** Excavator; **(C)** Breaker; **(D)** Loader; **(E)** Concrete pump; **(F)** Concrete vibrator; **(G)** Angle grinder; **(H)** Jackhammer; **(I)** Electric drill; **(J)** Electric screwdriver.

TABLE 6 | Results of physical and psychoacoustic indexes of ten typical noises.

Mechanical sound	L_{Aeq}/dB	L_5/dB(A)	L_{95}/dB(A)	L_5–L_{95}/dB(A)	N/sone	N_5/sone	S/acum	S_5/acum	F/vacil	F_{10}/vacil	R/asper	R_{10}/asper
Angle grinder	89.35	90.99	87.67	3.32	63.68	67.17	2.76	3.07	0.91	2.09	1.40	1.93
Jackhammer	93.87	94.70	92.95	1.74	93.97	93.12	2.08	2.53	0.54	1.51	3.15	3.06
Electric drill	88.67	89.73	87.41	2.31	71.42	75.73	3.26	3.61	0.55	1.84	2.55	2.50
Electric screwdriver	75.82	76.37	75.28	1.08	29.86	30.69	2.90	3.07	0.57	1.85	1.49	1.99
Concrete vibrator	83.23	84.21	82.18	2.04	64.03	68.25	1.85	1.99	0.60	1.92	1.77	1.89
Loader	88.46	89.85	87.36	2.49	84.51	90.10	1.53	1.65	0.60	1.69	1.27	1.86
Dump truck	84.54	86.89	80.73	6.17	67.28	75.54	1.69	1.87	1.03	1.96	1.41	1.88
Excavator	79.34	80.34	77.95	2.39	52.25	54.51	1.68	1.86	0.66	2.00	1.37	1.92
Breaker	92.30	93.63	90.06	3.57	98.65	105.62	2.15	2.56	2.82	2.77	3.81	3.55
Concrete pump	86.31	87.67	84.94	2.73	76.08	80.42	1.54	1.66	0.74	3.21	1.24	1.77
Max	93.87	94.70	92.95	6.17	98.65	105.62	3.26	3.61	2.82	3.21	3.81	3.55
Min	75.82	76.37	75.28	1.08	29.86	30.69	1.53	1.65	0.54	1.51	1.24	1.77
Mean	86.19	87.44	84.65	2.78	70.17	74.12	2.14	2.39	0.90	2.08	1.95	2.24
SD	5.61	5.76	5.54	1.39	20.15	21.10	0.61	0.68	0.69	0.51	0.91	0.61

TABLE 7 | Results of typical noise-induced annoyance.

Annoyance/Values (N%)	1-Not annoying at all	2-Slightly annoying	3-Moderately annoying	4-very annoying	5-Extremely annoying	ATCNm (SD)	Zwicker's PA
Breaker	0	1 (0.8%)	3 (2.3%)	19 (14.3%)	110 (82.7%)	4.79 (0.508)	178.2
Angle grinder	0	2 (1.5%)	18 (13.5%)	46 (34.6%)	65 (48.9%)	4.36 (0.772)	82.79
Jackhammer	0	2 (1.5%)	20 (15%)	46 (34.6%)	65 (48.9%)	4.31 (0.780)	121.42
Electric drill	0	9 (6.8%)	47 (35.3%)	26 (19.5%)	51 (38.3%)	3.89 (1.002)	113.19
Concrete vibrator	0	10 (7.5%)	35 (26.3%)	62 (46.6%)	26 (19.5%)	3.78 (0.847)	77.7
Excavator	0	17 (12.8%)	41 (30.8%)	47 (35.3%)	28 (21.1%)	3.65 (0.955)	60.75
Concrete pump	0	25 (18.8%)	39 (29.3%)	35 (26.3%)	34 (25.6%)	3.59 (1.067)	86.6
Loader	0	30 (22.6%)	48 (36.1%)	36 (27.1%)	19 (14.3%)	3.33 (0.983)	95.97
Dump truck	4 (3.0%)	85 (63.9%)	26 (19.5%)	7 (5.3%)	11 (8.3%)	2.52 (0.958)	84.47
Electric screwdriver	48 (36.1%)	65 (48.9)	15 (11.3%)	5 (3.8%)	0	1.83 (0.774)	39.91

N = 133.

TABLE 8 | Correlation between ATCNm and Zwicker's PA and typical noise acoustic indices.

		L_{Aeq}/dB	L_5/ dB(A)	L_{95}/ dB(A)	L_5-L_{95}/ dB(A)	N/sone	N_5/ sone	S/ acum	S_5/ acum	F/ vacil	F_{10}/ vacil	R/ asper	R_{10}/ asper	Zwicker's PA
$ATCN_m$	Correlation	0.775**	0.775*	0.790**	−0.023	0.718*	0.688*	0.000	0.117	0.436	0.233	0.605	0.588	0.728*
	Sig. (2-tailed)	0.008	0.012	0.007	0.950	0.019	0.028	0.999	0.747	0.208	0.517	0.064	0.074	0.017
Zwicker's PA	Correlation	0.837**	0.830**	0.805**	0.221	0.883**	0.887**	0.001	0.130	0.744*	0.272	0.856**	0.859**	
	Sig. (2-tailed)	0.003	0.003	0.005	0.593	0.001	0.001	0.998	0.721	0.014	0.447	0.002	0.001	

**Correlation is significant at the 0.05 level (2-tailed).*
***Correlation is significant at the 0.01 level (2-tailed).*

the angle grinder, the electric drill and the electric screwdriver. Component 3 (C_3) explained 15.6% of the variance in the data set, including the breakers and the concrete pump (**Table 9**).

In order to explore the characteristics of mechanical noise contained in the three components, Frequency spectrums analysis was conducted on the ten typical noises through Constant Percentage Bandwidth (CPB) filters (one-third octave band) (**Figure 6**). Relative to C_2, the mechanical noise in C_1 and C_3 was at a higher SPL in the low-frequency region below 500 Hz. The mechanical noise in C_2 accounted for a relatively high proportion of medium- and high-frequency sound pressure levels of 1 kHz and above.

To further explore the characteristics of components, Jonckheere–Terpstra test was used to explore the difference between the three components in typical mechanical noise psychoacoustic indicators. The results showed that a significant difference was found in the Fluctuation strength among the three components, and $F_{C3} > F_{C2} > F_{C1}$ ($z = 2.137$, $p = 0.033$), which indicated that the mechanical noise in C_3 had the characteristics of high Fluctuation strength. Significant differences were also found in the Sharpness values of the three components, and $S_{C2} > S_{C3} > S_{C1}$ ($z = 2.324$, $P = 0.020$), which indicated that the mechanical noise in C_2 had high Sharpness.

Sharpness is a measure of spectral shape and refers to the proportion of high-frequency energy relative to the total energy (Zwicker and Fastl, 1999). It can be inferred from the frequency distribution of ten typical noise (See **Figure 4**), the high-frequency components of each mechanical noise in C_2 accounted for a relatively high proportion, resulting in the sharp feeling of sound.

Temporal variations of sound resulted in two kinds of impressions: the Fluctuation strength and the Roughness (Rychtarikova and Vermeir, 2013). Fluctuation strength refers to the sound quality perceived when the individual Loudness fluctuations are audible (Hall et al., 2011). It gives people a sense of sound going up and down. The breakers and concrete pump in C_3 group could reflect this feature (**Figure 5**): the sound fluctuation of the breaker about once every 1 s and the sound intensity change of the concrete pump at the 2nd second and the 7th second caused the feeling of sound fluctuation. This was the main reason that groups C_3 and C_2 were two different kinds of noise.

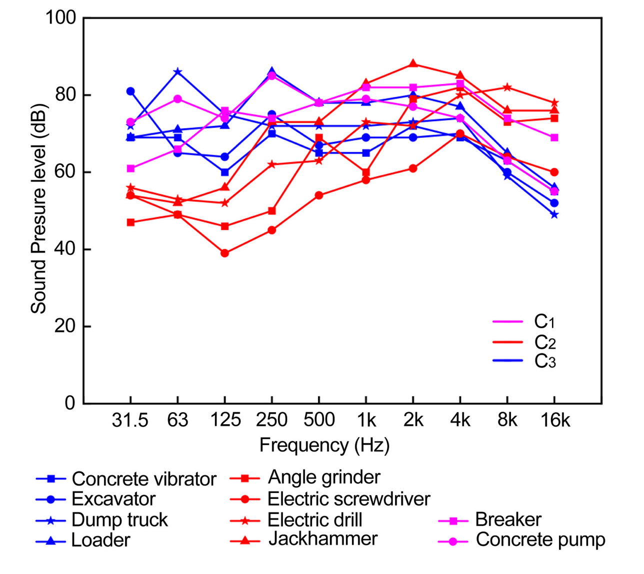

FIGURE 6 | Frequency spectrums of 10 typical noise.

DISCUSSION

"Cocktail Party Effect"

People can always grasp the information they want to know through hearing in a complex environment (Bronkhorst, 2015). This is the hearing selection ability of humans. It can allow them to recognize target sound information in a complex acoustic environment (Leech et al., 2009). Many factors will affect communications, such as the type of target sound, the spatial locality of the sound source, the level of interference sound, the level of background noise, and the person's hearing ability (Bronkhorst, 2000). Based on this, in a noisy environment, speakers often increase the intensity of their voice to ensure the smooth progress of the communication (Castellanos et al., 1996). In addition, related studies have shown that cognitive factors such as working memory (WM) can help the brain better capture target information (Bidelman and Yoo, 2020). According to the results that affect the on-site communications (See **Table 5**), construction workers with a high degree of communications demand believe that post-specific noise has little effect on their communications and hearing. Perhaps there is a reasonable explanation that the high volume of communications and the familiarization to the on-site environment have improved the construction workers' ability to capture the target sound, thereby making them believe that noise has a small impact on communications and hearing. Besides, for workers not equipped with radio communication devices, frequent communications needs force them to raise their voice when talking to each other. This consequently poses a potential threat to their voice. Other research has shown that for periodic noises like pulsed construction noises, there exist segmentations that lead to an audibly good separation of the speech signal and impulsive noise, and hence cause relatively little influence on the transmission of voice (Lee and Jeon, 2011). This is a likely explanation for why construction workers evaluate communications as a relatively small factor.

TABLE 9 | Results of principal components analysis showing the classification results of ten typical noises.

	Variance explained (%)	Mechanical sound	Components		
			1	2	3
C1	22.1	Dump truck	*0.836*	0.086	−0.141
		Loader	*0.715*	0.199	0.317
		Excavator	*0.610*	0.077	0.548
		Concrete vibrator	*0.476*	0.231	0.150
C2	20.2	Jackhammer	0.106	*0.767*	0.214
		Angle grinder	0.022	*0.754*	−0.091
		Electric drill	0.144	*0.631*	0.144
		Electric screwdriver	0.346	*0.591*	−0.083
C3	15.6	Breaker	0.019	0.045	*0.869*
		Concrete pump	0.498	0.073	*0.529*

Most important variables in each component are in Italic.

Workers' Unsafe Behavior

Most accidents are attributed to the unsafe behavior of the workers (Garavan and O'Brien, 2001). Excessive noise exposure is one of the factors that cause unsafe behavior (Kifle et al., 2014). According to the noise level measurement and typical noise collection, it is found that the noise exposure problems faced by construction workers cannot be ignored. Noise had a significant impact on the attention of construction workers, and a high-noise environment will accelerate their fatigue (Wang and Lv, 2015), thereby the probability of accidents is increased (Kirschenbaum et al., 2000).

According to the results of acoustic environment experience, almost all respondents believed that construction noise had an impact on communication. At the same time, they also believed that the on-site construction noise had an impact on their hearing. In other words, construction noise has a certain impact on the hearing and communications of construction workers. NIHL is mostly concentrated above 1000 Hz, which is also a critical range for workers to understand. This will result in reduced ability to perceive voice and warning signals (Suter, 2002). Due to the masking of noise, the workers cannot receive effective safety information (Deshaies et al., 2015), which leads to an increase in the probability of accidents. It is worth noting that the hearing protection device (HPD) will further reduce the workers' auditory perception of the signal (Suter, 1992). This may reveal the reason why construction workers rarely wear HPD on their own initiative. This suggests that the hearing protection for construction workers should start with the control of the noise source.

About Zwicker's PA Model

Related studies believed that Zwicker psychoacoustic annoyance model could not be well applied to compare the annoyance degrees of tonal noises and atonal noises (Guo et al., 2016), and it ignored noise under transient variation (Park et al., 2015). In this study, the respondents' self-evaluated degree of annoyance ATCNm for 10 typical construction noises had a significant correlation with Zwicker's PA [$r_{(10)}$ = 0.728 p = 0.017], which showed that Zwicker's PA model was useful for evaluating the annoyance degree of construction noise and had a certain applicability. However, the correlation between the two and various psychoacoustic indicators was not consistent (See **Table 8**). This may be due to the small amount of typical noise samples collected and evaluated in this study, which did not reflect good statistical results. It may also be due to the high level of on-site construction noise intensity (L_{Aeq}, as well as N) (See **Table 6**), which weakened the influence of psychoacoustic indicators. In future research, the noise sample size can be increased, and in-depth research can be carried out to determine the practicality of Zwicker's PA model in evaluating the mechanical noise annoyance of construction sites, or to optimize the model in a targeted manner.

Research Limitations

As part of the research, this article explored the subjective annoyance of construction workers to typical construction noise and its factor of acoustic characteristics. According to the results of on-site construction noise (See **Figure 3**), there were differences in the situation of on-site mechanical operations in different temporal stages, and the noise was not independently experienced by construction workers due to the combined operation of many machines in time and space. Research on the annoyance of construction workers caused by combined construction noise should be increased Related studies have shown that annoyance caused by combined noise is significantly higher than the annoyance caused by individual noise when L_{Aeq} increases over 65 dB(A) (Lee et al., 2015). In this study, respondents' subjective evaluation of typical noise annoyance was based on their long-term experience of the noise in their work experience, while the audio representative of typical construction noise was the standard audio collected on site. Compared with the laboratory listening evaluation, the correspondence between the evaluation results and the evaluation objects was weakened, but the results were more practical. In addition, unfortunately, due to the environmental conditions and safety management, the standardization of sound acquisition is limited, which is the limitation of this research.

CONCLUSION

This research conducted a 30-week construction site noise monitoring to summarize the noise level, collected 10 typical construction noises, analyzed their physical and psychoacoustic characteristics, and obtained objective data on the occupational environmental noise of construction workers. A questionnaire survey of 133 construction workers of different types of work was conducted to determine the impact of construction noise. The results showed that the noise situation on construction sites is not optimistic, and the construction workers have been affected to varying degrees in terms of psychological experience, hearing ability, and on-site communications. The respondent's post-specific noise level was significantly positively correlated with the evaluation of the noisiness. The self-evaluated impact on hearing ability was significantly positively correlated with the post-specific noise level and was significantly negatively correlated with the demand for communications. The impact on on-site communications was significantly positively correlated with the respondent's post-specific noise level and their age, and significantly negatively correlated with the demand for communications. In addition, correlation analysis and cluster analysis both showed that the annoyance caused by typical construction noise was correlated to its physical and psychoacoustic characteristics. These subjective and objective data and their correlation provided a basis for strengthening on-site management, implementing site noise reduction, optimizing construction machinery, and providing hearing protection for construction workers.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

Ethical review and approval was not required for this study in accordance with the local legislation and institutional requirements. The participants provided written informed consent to participate in the study.

AUTHOR CONTRIBUTIONS

XY: noise collection and acoustic analysis, questionnaire design, and manuscript writing. YW: site noise measurement and questionnaire survey. RZ: statistical analysis of the data. YZ: overall supervision, research design, and the structuring of the manuscript. All authors contributed to the article and approved the submitted version.

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The Effectiveness of Facial Expression Recognition in Detecting Emotional Responses to Sound Interventions in Older Adults With Dementia

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This research uses facial expression recognition software (FaceReader) to explore the influence of different sound interventions on the emotions of older people with dementia. The field experiment was carried out in the public activity space of an older adult care facility. Three intervention sound sources were used, namely, music, stream, and birdsong. Data collected through the Self-Assessment Manikin Scale (SAM) were compared with facial expression recognition (FER) data. FaceReader identified differences in the emotional responses of older people with dementia to different sound interventions and revealed changes in facial expressions over time. The facial expression of the participants had significantly higher valence for all three sound interventions than in the intervention without sound ($p < 0.01$). The indices of sadness, fear, and disgust differed significantly between the different sound interventions. For example, before the start of the birdsong intervention, the disgust index initially increased by 0.06 from 0 s to about 20 s, followed by a linear downward trend, with an average reduction of 0.03 per 20 s. In addition, valence and arousal were significantly lower when the sound intervention began before, rather than concurrently with, the start of the activity ($p < 0.01$). Moreover, in the birdsong and stream interventions, there were significant differences between intervention days ($p < 0.05$ or $p < 0.01$). Furthermore, facial expression valence significantly differed by age and gender. Finally, a comparison of the SAM and FER results showed that, in the music intervention, the valence in the first 80 s helps to predict dominance ($r = 0.600$) and acoustic comfort ($r = 0.545$); in the stream sound intervention, the first 40 s helps to predict pleasure ($r = 0.770$) and acoustic comfort ($r = 0.766$); for the birdsong intervention, the first 20 s helps to predict dominance ($r = 0.824$) and arousal ($r = 0.891$).

Keywords: facial expression recognition, sound intervention, emotion, type of sound source, elderly with dementia

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INTRODUCTION

Dementia is a set of syndromes characterized by memory and cognitive impairment caused by brain diseases. China currently has the largest population of older people with dementiain the world, ~14 million (Jia et al., 2020). The decline in cognitive function causes older adults with dementia to gradually lose the ability and opportunities to engage in various activities, and scarce activity can easily induce depression and agitation behavior (Mohler et al., 2018). Lack of external stimuli is a prominent cause of negative emotions in older people with dementia. Studies have found that sensory stimulation through acoustic intervention can reduce the agitation behavior of older people with dementia (Riley-Doucet and Dunn, 2013; Nishiura et al., 2018; Syed et al., 2020). Therefore, how to create a healthy acoustic environment for the older with dementia has become an urgent problem for countries worldwide to be solved.

Emotions can be perceived and evaluated as their status changes with change in the person–environment relationship (Rolls, 2019). Despite their cognitive impairment, older adults with dementia continue to display emotions, and their internal emotional processing may be intact or partially retained (Satler et al., 2010); specifically, they retain the feeling and acquisition of emotions (Blessing et al., 2006). In addition, the emotions reflected by facial expressions are similar between older adults with mild dementia and typical older adults (Smith, 1995). Along with the decline in cognitive function, older adults with dementia can experience various emotional problems, such as anxiety, depression, and excitement. At present, there are no effective treatment methods and drugs for dementia. Therefore, effective emotional intervention is especially important to suppress negative emotions and generate positive emotions (Marquardt et al., 2014). Common methods include environmental intervention, behavioral intervention, psychological intervention, social therapy, and entertainment therapy (Howe, 2014).

Some previous studies have shown that environmental interventions can play a therapeutic role for older adults with dementia (Satariano, 2006). In this regard, the acoustic environment is important, and appropriate sound interventions can help delay the onset of dementia (Wong et al., 2014). Music has been widely used in treating dementia during the past decade, and remarkable results have been achieved with respect to memory and mood disorders (Ailun and Zhemin, 2018; Fraile et al., 2019). Music can reduce depression (Li et al., 2019) and improve behavioral disorders, anxiety, and restlessness in older people with dementia (Gomez-Romero et al., 2017). In addition, some studies have investigated how best to design the acoustic environment for older adults with dementia based on the phenomenon of auditory masking (Hong et al., 2020). For example, adding white noise to the environment may mitigate some auditory hallucinations, helping older adults with dementia to temporarily relax. White noise can also reduce the mental and behavioral symptoms of older adults with dementia (Kaneko et al., 2013). Conversely, some studies have revealed a negative impact of noise on the quality of life of older people with dementia. For example, some studies showed that high noise can lower the social mood of elderly with dementia and induce falling behaviors (Garre-Olmo et al., 2012; Jensen and Padilla, 2017). When the daytime noise level is continuously higher than 55 dBA, it can induce emotional and behavioral agitation in older adults with dementia (Harding et al., 2013). The current development trend of the acoustic environment is changing from noise control to soundscape creation, that is, from reducing negative health effects to promoting positive health trends (Kang et al., 2020). However, research on how the acoustic environment can promote the health of older adults with dementia has so far only focused on music and noise. Whether other types of sound interventions, such as birdsong and stream sound, improve mood and health in older people with dementia have not been examined. In addition, some studies have proved that the playing time of a sound source is also an important factor affecting the perception of sound in people (Staats and Hartig, 2004; Korpela et al., 2008). However, there is no relevant research on whether the time of intervention of the sound source will affect emotions.

Prior research on emotions has mainly been conducted at the three levels, namely, physiology, cognition, and behavior. Different research levels correspond to different research contents and methods (Zhaolan, 2005). However, wearing physiological measuring devices may induce negative emotions in older people with dementia, who are more prone to mood swings.

Most common in emotion research is the study of cognitive theory, which posits that a stimulus can only produce a specific emotion after the cognitive response of the subject (Danling, 2001). The main method adopted is a subjective questionnaire. For example, Meng et al. (2020b) studied the influence of music on communication emotions through a field questionnaire, which asked participants to evaluate their emotional state. Zhihui (2015) and Xie et al. (2020) conducted field experiments in train stations and hospital nursing units, asking participants how various types of sound sources affect their emotions. However, surveys have several limitations. First, the questionnaire is subjective, and an "experimenter effect" might occur if the questionnaire is not well-designed (Brown et al., 2011). Second, a single-wave survey cannot show trends over time in how participants react to a sound intervention, which precludes calculating the role of time in the intervention process.

The third main research avenue is the study of behavioral emotions. Behaviorists believe that external behaviors caused by emotions can reflect the true inner feeling of a person (Yanna, 2014). The main method is to measure emotional changes in people through facial, verbal, and bodily expressions. Psychologists generally believe that expressions are a quantitative form of changes in emotions. As a tool for evaluating emotions, the software FaceReader, based on facial expression recognition (FER), has been applied in psychological evaluation (Bartlett et al., 2005; Amor et al., 2014; Zarbakhsh and Demirel, 2018). The effectiveness of FER has been proven in many previous studies, and it can measure emotions with more than 87% efficacy (Terzis et al., 2010). The validity of FaceReader for East Asian people, in particular, has been shown to be 71% (Axelsson et al., 2010; Yang and Hongding, 2015). The efficiency of this method has been tested in many research fields. For example, Hadinejad et al. (2019) proved that, when participants watched travel advertisements, arousal and positive emotions diminished. Leitch et al. (2015) found that the length of time after tasting sweeteners affected the potency and arousal of facial expressions. In addition, Meng et al. (2020a) conducted laboratory experiments to test the effectiveness of facial expressions for detecting sound perception and reported that the type of sound source had a significant impact on the valence and indicators of facial expressions. FER has also been used in research on the health of older adults with dementia. Re (2003) used a facial expression system to analyze the facial expression patterns and facial movement patterns of older people with severe dementia. Lints-Martindale et al. (2007) measured the degree of pain of older adults with dementia through a facial expression system. However, no study has tested whether FER can be used to investigate the effect of the acoustic environment on the emotions of elderly with dementia. In addition, the characteristics of the normal population, such as their gender, age, and so on, are related to their emotions (Ma et al., 2017; Yi and Kang, 2019). However, in older adults with dementia, it is not clear whether these characteristics affect the results of facial expression.

To address this gap in the literature, this study explored the effectiveness of FER in measuring how sound interventions affect the emotions of elderly with dementia. Specifically, this study is focused on the following research questions: (1) Can facial expression analysis systems be used to study sound interventions on the emotions of older people with dementia?; (2) How do different types of sound interventions affect the valence and other indicators of facial expressions of elderly with dementia?; (3) Do demographic and time factors, such as age, gender, Mini-Mental State Examination (MMSE) scores, intervention duration, and intervention days, cause different degrees of impact? A field experiment was conducted to collect facial expression data of 35 elderly with dementia in an older adult care facility in Changchun, China. The experiment included three sound sources typically preferred by elderly with dementia: music, stream, and birdsong.

MATERIALS AND METHODS

Participants

The participants in this study are older people with dementia residing at seven institutes in Changchun, China. A total of 35 older people with mild dementia was selected, comprising 16 men and 19 women aged 60–90 years (mean = 81, *SD* = 7). The number of participants was determined based on similar related experiments (El Haj et al., 2015; Cuddy et al., 2017).

The following selection criteria were applied. First, participants had to be at least 60 years old. Second, participants had to score 21–27 on the MMSE, indicating mild cognitive impairment or dementia. Third, participants had to be able to communicate through normal conversation and have normal hearing. Fourth, participants were required to have <5 years of music training to ensure that the music intervention induced cognitive emotions rather than memory emotions (Cuddy et al., 2015). Fifth, any individuals with obvious symptoms of anxiety or depression were excluded. Sixth, participants were required to refrain from smoking or drinking alcohol, coffee, or other beverages that stimulate the sympathetic nervous system during the 6 h before the test (Li and Kang, 2019). Finally, written informed consent was obtained from all participants before the test began.

Activity

To select the type of activity that would best facilitate the sound intervention experiment, we visited seven elderly care facilities in northern China to select older people with dementia. Through observation, we identified that older peoplewith dementia participated in painting, origami, singing, gardening, finger exercises, Tai Chi, ball sports, card games, watching TV, and walking. Finger exercises were selected as the activity for the experiment in this study for four reasons: First, of the abovementioned activities, finger exercises were the most actively participated activity by older people with dementia in the seven elderly care facilities. Second, they are convenient for capturing facial expressions because participants are seated during the exercise, facing forward, and body movements are relatively less. Third, for the collective activity of finger exercises, the error caused by the number of experiments can be reduced. Finally, the finger exercise itself does not produce noise, so it will not interfere with the sound intervention activity.

Experiment Site

Emotion experiments are usually carried out in the field or a laboratory. Field experiments are conducted in a naturally occurring environment, with high reliability and authenticity (Harrison, 2016). A key consideration in this study is that elderly with dementia are particularly sensitive to unfamiliar environments. Thus, to ensure that the participants were as comfortable as possible and thereby to improve the reliability and validity of the results, it was necessary to implement the intervention in a place familiar to them (El Haj et al., 2015). After considering the sensitivity of participants and the collective nature of the finger exercise activity, we decided to conduct a field experiment and hence selected the public activity space of an institute in Changchun, China, as the experiment site.

Sound Source

Some previous studies have proved that the following six types of sound sources may help to improve mood, namely, music, birdsong, fountain, stream, wind/rain, and wind/leaves (Zhongzhe, 2016; Hong et al., 2020). Birdsong was mainly concentrated in the high-frequency region and other sound sources are mainly concentrated in low frequencies, while the sound of the music had an obvious rhythm. An external speaker was used for the output of the sound source for the experiment, as prolonged use of a headset would cause the participants to become uncomfortable and would interfere with the experimental results. As it is difficult to distinguish between the emotions induced by the music and the lyrics of songs, instrumental music is more suitable for use in such an experiment (Cuddy et al., 2015). Therefore, we selected a piano performance of "Red River Valley" as the music intervention stimulus: the song was included in the Chinese Academy Award film with the same name, released in 1996. The film *Red River Valley* shows the heroic and unyielding national spirit of the Chinese people and is well-known among older adult participants. A previous study on music therapy showed that this song has the effect of regulating emotions (Shuping et al., 2019).

To deepen the understanding of sound source preferences by participants while also considering the impact of sound interventions on the work of care staff, a survey was conducted. Across the seven elderly care facilities, a total of 73 older people with dementia (35 men, 38 women; mean age = 79, SD =

9) were surveyed on their sound source preferences. The 1-min equivalent sound pressure level (SPL) was adjusted to 55 dB(A) for each audio frequency by AuditionCS6 to remove differences in volume during the stimulation of the four sounds and to ensure that the participants listened to the four auditory stimulus sounds under similar playback SPL conditions. The background noise was below 45 dB(A) during the survey (Zhou et al., 2020). The selected retirement facilities met the following two criteria: (1) providing sufficient daily activities and being fully equipped to ensure that the conditions in which older adults reside would not affect their evaluation of the sound sources and (2) having 10 or more residents, allowing efficient distribution of the questionnaire and increasing the statistical reliability of collected data. Each sound source was played in a loop for 1 min. At the end of one sound source, participants had 10 s to conduct a sound preference questionnaire for the sound source. We used a Likert scale in the sound preference questionnaire, as its structural simplicity and relative clarity make it particularly suitable for completion by elderly with dementia. The questionnaire design is outlined in **Table 1**. We also surveyed 23 care partners (mean age = 36, $SD = 12$; 6 males, 17 females) of older people with dementia to collect their insights on the extent to which each sound source affects their work. The statistics are shown in **Figure 1**.

A one-sample t-test with 3 (meaning do not care in the questionnaire) as the test value was performed on the preference scores for different types of sound sources. As shown in **Table 2**, elderly with dementia liked music ($p = 0.001$, $t = 7.56$), birdsong ($p = 0.018$, $t = 2.42$), and the sound of a stream ($p = 0.001$, $t = 3.34$) but disliked the sound of wind and rain ($p = 0.001$, $t = -5.36$) and of wind blowing leaves ($p = 0.03$, $t = -2.21$); their evaluation of the fountain sound was neutral ($p = 0.724$, t = 0.35). We also performed a one-sample t-test on the degree to which each sound source affected the work of care partners. The results show that care partners believed music ($p = 0.001$, $t = 4.04$) and the sound of a stream ($p = 0.043$, $t = 2.15$) would promote their work; the sound of wind and rain ($p = 0.009$, $t = -2.86$) would disturb the work; but birdsong ($p = 0.788$, $t = 0.27$), the sound of a fountain ($p = 0.497$, $t = 0.72$), and the sound of wind blowing leaves ($p = 0.418$, $t = -0.83$) would have no effect. Based on these findings, we selected music, birdsong, and the sound of a stream to be the sound sources for the interventions in our field experiment as sounds preferred by older adults and that will not disturb the work of care partners.

TABLE 1 | Contents of the sound preference questionnaire for older adults with dementia.

Sound preference questionnaire		Description
Demographic information		Gender, age
Sound source type	Music	1 = Extremely dislike
	Birdsong	2 = Slightly dislike
	Fountain	3 = Don't care
	Stream	4 = Slightly like
	Wind and rain	5 = Extremely like
	Wind blowing leaves	

To avoid any change in sound during the activity that could shape the activity effect of participants, the sound intervention time was set to match the finger exercise time (4 min 20 s), and the SPL was set to 60 dBA (El Haj et al., 2015). We recognized that, if the experiment time was too long, participants would be distracted, thus harming the accuracy of collected data. To determine a suitable analysis time, a pilot study was conducted, setting the FER sampling rate at 15/s and measuring arousal, which ranges between 0 (inactive) and 1 (active). **Figure 2** shows changes of arousal in the first 120 s, with the absolute value of arousal determined every 20 s for each of the three sound sources. The trends are similar: during 0–20 s and 20–40 s, the arousal was the largest; the subsequent arousal decreased significantly, and then remained relatively stable until the end of the recording. However, in the trials with the sound of a stream and with birdsong, arousal rose again after 80 s, which may be due to distraction among the participants. The result is consistent with previous research findings (Meng et al., 2020a). Accordingly, we chose the first 80 s as the duration for analysis in our experiment.

Emotional Evaluation Scale Design

To enable comparison with the data collected using FaceReader, we divided the subjective evaluation scale into three parts. The first part is the emotion scale, for which we selected the SAM—a nonverbal tool for self-assessment of emotions devised by Bradley and Lang (1994). The SAM can be used for people with different cognitive levels and with different cultural backgrounds, including children and adults (Ying et al., 2008; Peixia et al., 2010), and is simple and easy to operate. It includes three dimensions: arousal, pleasure, and dominance. Each dimension has five images depicting different levels, each with an associated point between the two pictures. The SAM can quickly quantify the emotional state of the subject on the three dimensions without the need for them to verbalize emotions. Backs et al. (2005) confirmed that the three dimensions of the SAM have high internal consistency. The SAM has been successfully applied in studies of people with dementia, especially those with mild-to-moderate dementia, including memory impairment. It can be used to objectively express the subjective emotional experience of dementia (Blessing et al., 2010; Lixiu and Hong, 2016). In the second part of the subjective evaluation scale, we included a question asking participants to indicate their acoustic comfort with the sound source (see **Table 3**). The third part of the survey collects demographics, including the age of the participant, gender, MMSE score, and other information. These data were obtained by asking the care partners or checking the medical records of the participants.

Facial Expression Recognition

FaceReader recognizes facial expressions through a three-step process. The first step is detecting the face (Viola and Jones, 2001). The second step is accurate 3D modeling of the face using an algorithmic approach based on the Active Appearance Method (AAM) (Cootes and Taylor, 2000). In the last step, facial expressions are classified by training an artificial neural

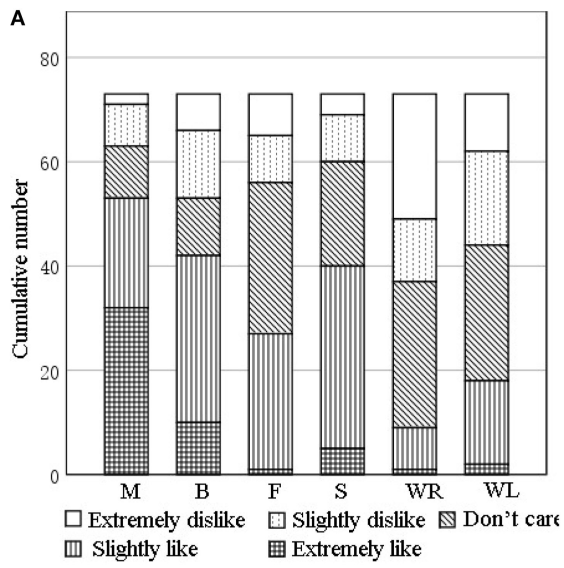

FIGURE 1 | (A) Sound type preferences of older adults with dementia. **(B)** Evaluation of the effect of each sound type on care partners on activity engagement; M, Music; B, Birdsong; F, Fountain; S, Stream; WR, wind and rain; and WL, wind blowing leaves.

TABLE 2 | Comparison of the degree of preference of older adults with dementia on different types of sound sources.

	M	B	F	S	WR	WL
Score	4.00 ± 1.13	3.34 ± 1.20	3.04 ± 0.99	3.38 ± 0.98	2.32 ± 1.09	2.73 ± 1.06
t-value	7.56**	2.42*	0.35	3.34**	–5.36**	–2.21*
p-value	0.001	0.018	0.724	0.001	0.001	0.030

***p < 0.01, *p < 0.05; M, music; B, birdsong; F, fountain; S, stream; WR, wind and rain; and WL, wind blowing leaves.*

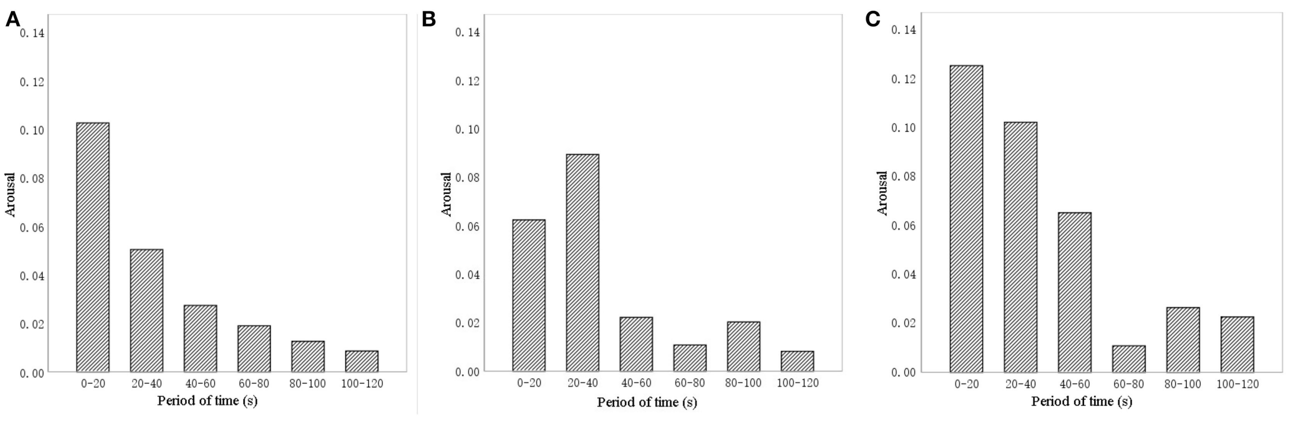

FIGURE 2 | Pilot study results for arousal by the different sound interventions. **(A)** Music, **(B)** stream, and **(C)** birdsong.

network: the AAM is used to compute scores of the probability and intensity of six facial expressions (happiness, surprise, fear, sadness, anger, and disgust) on a continuous scale from 0 (absent) to 1 (fully present) (Lewinski et al., 2014). FaceReader also calculates the valence and arousal of facial expressions. Valence refers to the emotional state of the participant, whether positive (from 0 to 1) or negative (from −1 to 0), while arousal indicates whether the test subject is active or not (from 0 to 1) (Frijda, 1986).

FaceReader inputs can be pictures or videos of a human face, and the software supports offline video input. In comparison with the pictures, videos enable more data to be generated, and

TABLE 3 | Contents of the emotional evaluation scale.

Subjective evaluation		Range
Acoustic comfort		Very uncomfortable (1) to very comfortable (5)
Emotion dimension	Pleasure	Very unpleasant (1) to very pleasant (9)
	Arousal	Very sleepy (1) to very excited (9)
	Dominance	Very passive (1) to very proactive (9)

the output data can be connected to reveal changes in trends over time. Therefore, we selected videos as the input in our experiment. In the video-recording process, the subject must always face the camera, and only a small angle of rotation is allowed. Older people with dementia can fully meet these requirements when performing finger exercises. The number of FaceReader online recording devices is limited. Therefore, we recorded offline videos of the facial expression of the subject.

The experiment site selected was the indoor public activity space of an elderly care facility in Changchun (15.5 × 16.5 × 2.8 m). **Figure 3** shows the layout of the room, delineating the main experiment site within the dotted frame, where participants performed the finger exercises. The site was equipped with seven chairs, three tables, video equipment, and a sound source. The video equipment was an iPhone, placed 0.5 m from each elderly person and 0.5 −1.5 m from the sound source. Because the mobile phone can meet the video pixel requirements of FER software and its size is small, it is convenient to use it with a bracket fixed to the table, which will not make older adults fearful. The care partner was positioned at 2 m from the participant to offer guidance. Throughout the experiment, the doors and windows of the room were closed. To ensure that neither the indoor temperature nor the level of illumination affected the mood and performance of the participant (Altomonte et al., 2017; Petersen and Knudsen, 2017), we ran the experiment from 10:00 to 11:00 in the morning and maintained the temperature at 23 to 25°C (Nematchoua et al., 2019).

In the pilot study, it was found that the intervention effect disappeared 1 week after stopping the intervention (section Data Analysis). Therefore, the sequencing effect of the stimuli can be ignored. Thirty-five participants were arranged to repeat each set of experiments. To avoid distraction by including too many people during exercise, a total of 35 participants were randomly allocated into groups of 7 for an exercise before each experiment. After the first group was seated, the designated sound source was played and the care partner guided participants in performing finger exercises for 4 min and 20 s. It is worth noting that, in no sound group experiment, the speaker was turned off. Subsequently, the emotional evaluation scale was issued for completion by the participants, with assistance from care partners where necessary, within a 5 min window. In turn, other groups undertook the same process to complete one experiment. The experiment was repeated for 5 days under the same sound source. The experiment interval of different groups was 1 week (Meilan Garcia et al., 2012). The flow of the experiment is shown in **Figure 4**.

Data Analysis

Statistical Product and Service Solutions (SPSS 23.0) was used to analyze the survey data. Data with a large degree of dispersion were removed. In the pilot study, we performed an independent-samples t-test between valence data before and 1 week after the first intervention (before the second intervention). The pre-intervention valence (-0.173 ± 0.086) and the 1-week-post-intervention valence (-0.141 ± 0.096) did not significantly differ ($p = 0.297$). This indicates that, although the experiments were performed by the same groups of participants, the intervention effect disappeared within a week, meaning that the groups can be considered independent in each experiment. Therefore, a one-way ANOVA was used to record the differences in valence from the results of interventions with different sound sources. Linear, quadratic, and cubic regression analyses were used to analyze the changes in valence and facial-expression indicators over time. Then, the repeated measurement method was used to test the changes in potency on different days of the experiment. We also used Pearson's correlations to calculate the relationship between the results from FaceReader and the results from the emotional evaluation scale and to identify individual differences. Effect sizes were also reported using an effect size calculator, represented by the sign r (Lipsey and Wilson, 2000). TheA point-biserial correlation was used to determine the relationship between gender and test results.

RESULTS

The Effects of Sound Interventions on the Facial Expressions of Older Adults With Dementia

FaceReader calculates the valence for the facial expression in each frame. Each individual has different initial values for facial expressions in their natural state. Therefore, experiments with no sound intervention were performed to provide initial data. The average valence after 20, 40, 60, and 80 s with no sound intervention and with the three types of sound interventions was compared. **Figure 5** shows how average valence changed from 20 to 80 s (error bars represent the 95% confidence interval). Valence was higher for the sound interventions than for the no-sound intervention. The valence of birdsong had the greatest drop (from −0.085 to −0.147), followed by music (from −0.047 to −0.083). The valence of music was always the highest at 20 s (−0.047) and 60 s (−0.081); the valence of the sound of a stream dropped from 20 s (−0.068) to 60 s (−0.083) but has the highest valence at 80 s (−0.068). The valence for the no-sound intervention increased from 20 s (−0.161) to 60 s (−0.158), then decreased again at 80 s (−0.174). To determine the difference between sound interventions, ANOVA was carried out. Significance at 20, 40, 60, and 80 s was 0.001, 0.001, 0.003, and 0.001, respectively; this indicates that, after intervention for 20, 40, 60, and 80 s, the type of sound source had a significant effect on the facial expressions of elderly with dementia.

To test the difference between various sound source types, a multiple comparison analysis was also carried out. As **Table 4** shows, the biggest difference in valence was between no sound

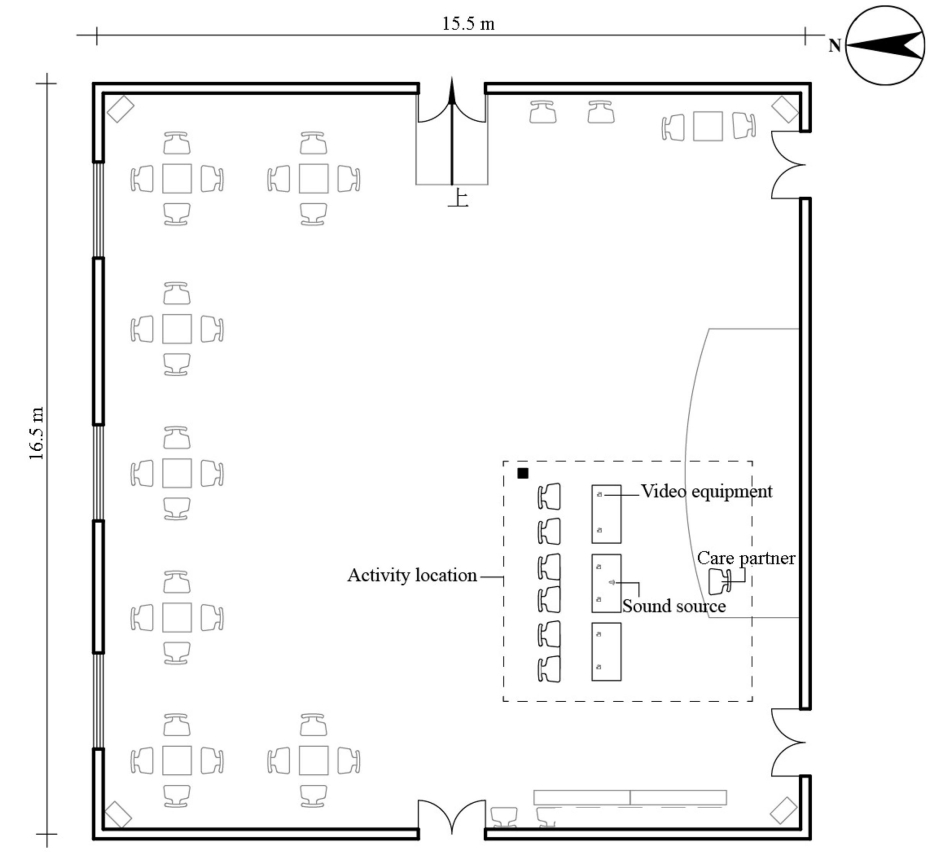

FIGURE 3 | Layout of the experimental site.

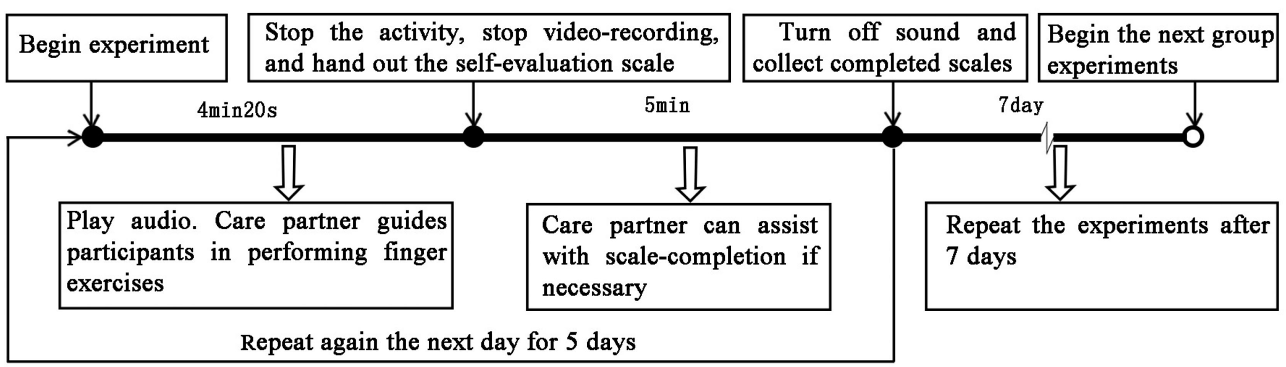

FIGURE 4 | Experimental procedure steps.

and music sound, with an average difference of 0.769 at 60 s ($p = 0.001$), followed by the difference between no sound and stream, with an average difference of 0.746 at 60 s ($p = 0.008$). The average difference in valence between birdsong and no sound was significant at 20 s ($p = 0.049$) and 40 s ($p = 0.038$), but non-significant at 60 s and 80 s. In addition, valence was mostly similar between music and stream. However, valence differed significantly between music and birdsong at 60 s (average difference = 0.059, $p = 0.025$) and between stream and birdsong at 80 s (average difference = 0.794, $p = 0.029$). The valence results in **Figure 5** and **Table 4** show that the interventions with sound sources have a positive effect on the valence of facial expressions of older adults with dementia compared with the no-sound source interventions. In addition, there are differences in valence between the sound source types at different time points in the intervention, which indicates that FaceReader can

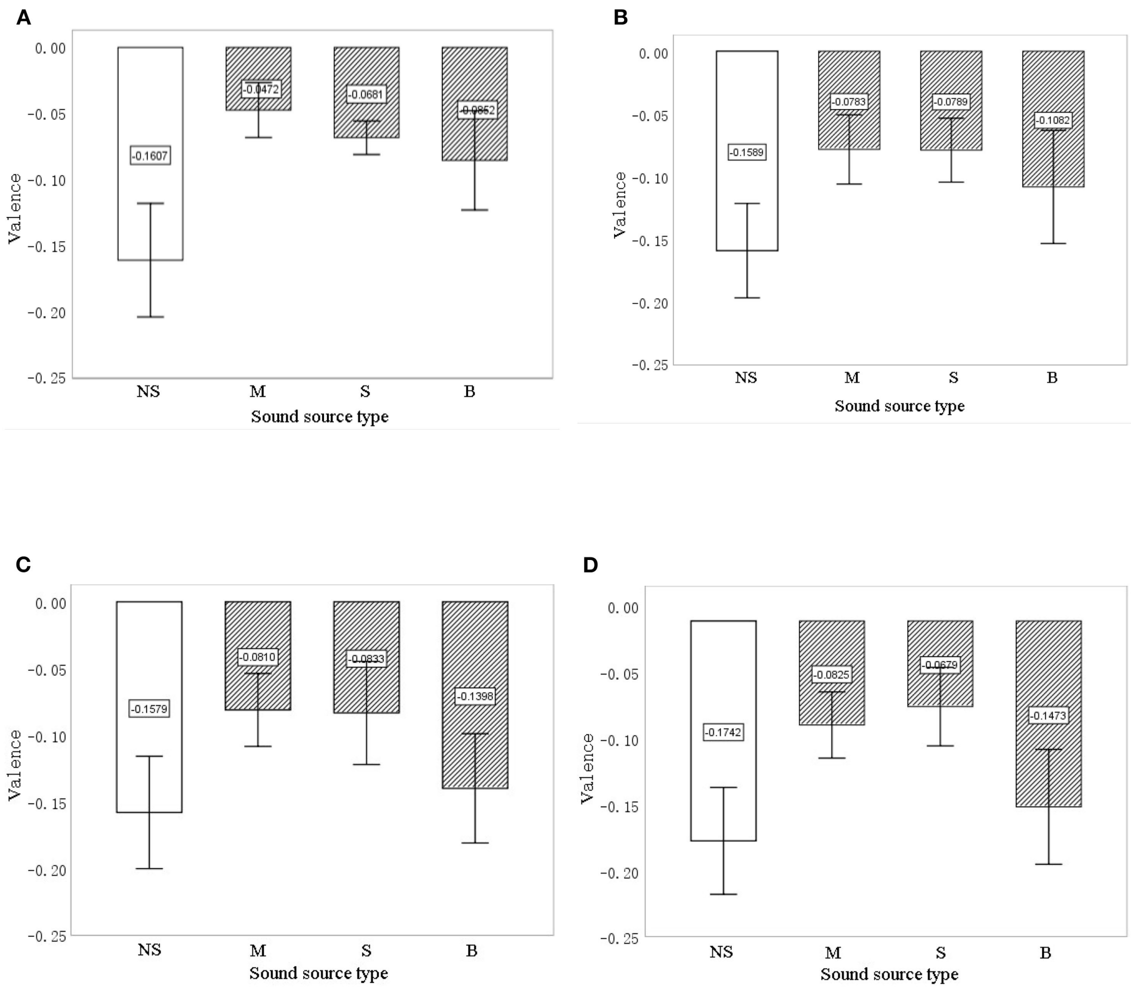

FIGURE 5 | The valence for the different intervention sound types and the no-sound intervention at 20 s **(A)**, 40 s **(B)**, 60 s **(C)**, and 80 s **(D)**. The error bars show 95% CIs. NS, no sound; M, music; S, stream; and B, birdsong.

TABLE 4 | The average difference in valence between different sound source types at 20, 40, 60, and 80 s during the intervention.

Intervention time point	NS&M	NS&S	NS&B	M&S	M&B	S&B
20 s	–0.113**	–0.096**	–0.075*	0.021	0.017	0.170
40 s	–0.081**	–0.080**	–0.051*	0.001	0.038	0.029
60 s	–0.769**	–0.746**	–0.018	0.022	0.059*	0.057
80 s	–0.092**	–0.106**	–0.289	-0.145	0.648	0.794*

***p < 0.01, *p < 0.05; NS, no sound; M, music; S, stream; and B, birdsong.*

identify differences in the emotional responses of older people with dementia to different intervention sound sources.

By performing linear, quadratic, or tertiary regression analysis on each intervention, **Figure 6** shows the trend of valence over time for each of the three sound interventions. Valence changed significantly over time for music ($p = 0.001$) and birdsong ($p = 0.016$) sound interventions but the valence for the sound of a stream intervention did not change. In the music intervention, valence decreased at around 60 s by 0.058 and then recovered slightly. In the birdsong intervention, valence dropped by 0.091 from 0 to 40 s, then rose by 0.138 until 100 s, before subsequently declining again. These results demonstrate that FaceReader can reflect how the facial expressions of elderly with dementia change over time.

The Influence of Sound Interventions on Facial Expression Indices

Figure 7 shows the differences in facial expression indices of the participants between the three types of sound sources.

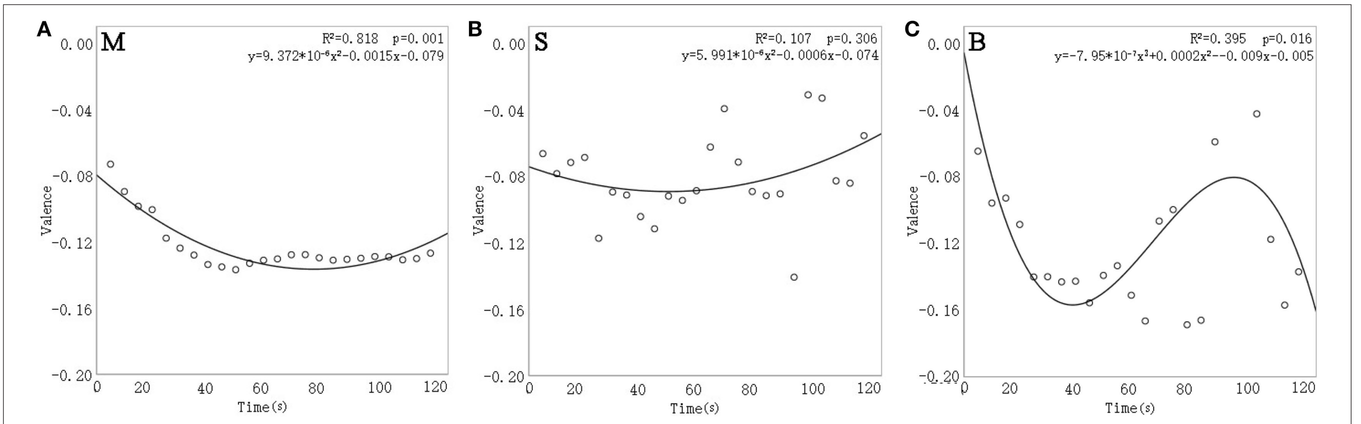

FIGURE 6 | The relationship between valence and time for the sound interventions of music **(A)**, stream **(B)**, and birdsong **(C)**.

Sadness (mean = 0.036, *SD* = 0.015), fear (mean = 0.049, *SD* = 0.022), and disgust (mean = 0.042, *SD* = 0.021) all differed significantly between interventions ($p < 0.01$), whereas happiness ($p = 0.081$), surprise ($p = 0.503$), and anger ($p = 0.071$) did not. Therefore, facial expression indices of sadness, fear, and disgust were selected to analyze the impacts of different sound interventions.

Figure 8 shows the results of linear, quadratic, and cubic regression analyses for the facial expression indices of sadness, fear, and disgust. All three expression indices were significantly affected by time except for disgust with the sound of a stream ($p = 0.920$) and for fear with the birdsong intervention ($p = 0.682$).

Focusing first on sadness, **Figure 8A** shows that, for the music intervention, sadness expression increased by 0.015 from 0 to 40 s before gradually decreasing. For the stream sound, sadness dropped by 0.003 from 0 to 20 s and then gradually rose by 0.014 until 80 s, before subsequently decreasing again. For birdsong, sadness gradually increased over time (by ∼0.01 every 20 s).

Turning to fear, **Figure 8B** shows a gradual rise from 0 to 50 s (0.009 every 20 s) for the music intervention and then a decrease of 0.007 from 50 to 80 s, followed by a linear rise (of 0.002 every 20 s). For the stream sound, fear expression increased by 0.021 in the first 60 s and then decreased by 0.035 from 60 to 120 s. For birdsong, the fear expression did not change significantly over time ($p = 0.682$).

Regarding disgust, **Figure 8C** shows a rapid rise of 0.028 from 0 to 40 s for the music intervention and then a slow drop of 0.008 from 40 to 100 s. For birdsong, disgust increased by 0.06 from 0 s to about 20 s and then showed a linear downward trend, with an average decrease of 0.03 every 20 s. For the stream sound, disgust expression did not change significantly over time ($p = 0.920$).

The above results show that, under different sound interventions, sadness, fear, and disgust are all significantly affected by time. Therefore, in the study of emotions in older adults with dementia, these facial expression indices can be used to evaluate the effects of emotional intervention.

The Influence of Time on Facial Expressions of Elderly With Dementia

To explore the influence of intervention duration on facial expressions, we conducted a further set of experiments in which the intervention sound (music) began to be played 2 min before the exercise started (advance group) and at the beginning of the exercise (normal group). The other experimental steps were unchanged.

Figure 9A shows that valence significantly differed between the advance group and the normal group at 20 s ($p = 0.003$), 40 s ($p = 0.021$), 60 s ($p = 0.019$), and 80 s ($p = 0.019$). In addition, valence in the advance group (mean = −0.156, −0.156, −0.119, −0.120) was significantly lower than that in the normal group (mean = −0.047, −0.07, −0.081, −0.082) at the four respective time points.

In terms of arousal, **Figure 9B** shows significant differences between the advance group and the normal group at 20 s ($p = 0.001$), 40 s ($p = 0.003$), 60 s ($p = 0.001$), and 80 s ($p = 0.001$). Moreover, arousal in the advance group (mean = 0.315, 0.304, 0.308, 0.298) was significantly lower than in the normal group (mean = 0.444, 0.401, 0.378, 0.361) at the four respective time points.

The Influence of Intervention Duration on Facial Expression Indices

Figure 10 shows the relationship between the intervention duration (advance group and normal group) and the six facial expression indices. There are significant differences between the advance and normal groups in happiness ($p = 0.002$), fear ($p = 0.018$), and surprise ($p = 0.001$).

Figure 10A shows that happiness expression was significantly lower in the advance group (mean = 0.022, SD = 0.024) than in the normal group (mean = 0.035, *SD* = 0.026), with the largest difference at 80 s. **Figure 10D** shows that surprise expression was also significantly lower in the advance group (mean = 0.021, *SD* = 0.026) than in the normal group (mean = 0.039, *SD* = 0.032), with the largest difference at 60 s. **Figure 10E** shows that fear expression in the advance group (mean = 0.038, *SD* = 0.036) was

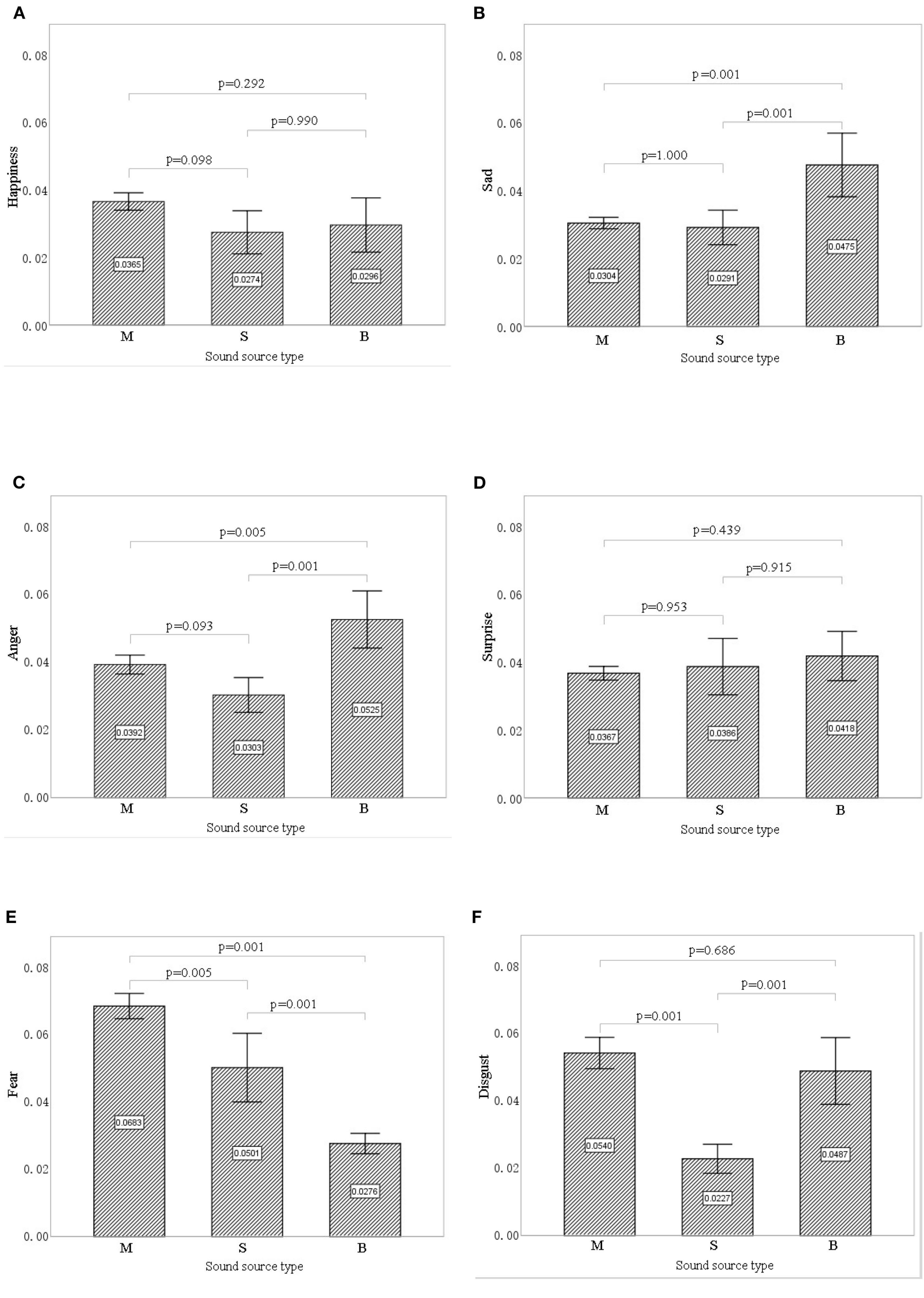

FIGURE 7 | The effect of each sound source type on different facial expression indices: **(A)** happiness, **(B)** sadness, **(C)** anger, **(D)** surprise, **(E)** fear, **(F)** disgust. Error bars show 95% CIs. M, music; S, stream; B, birdsong.

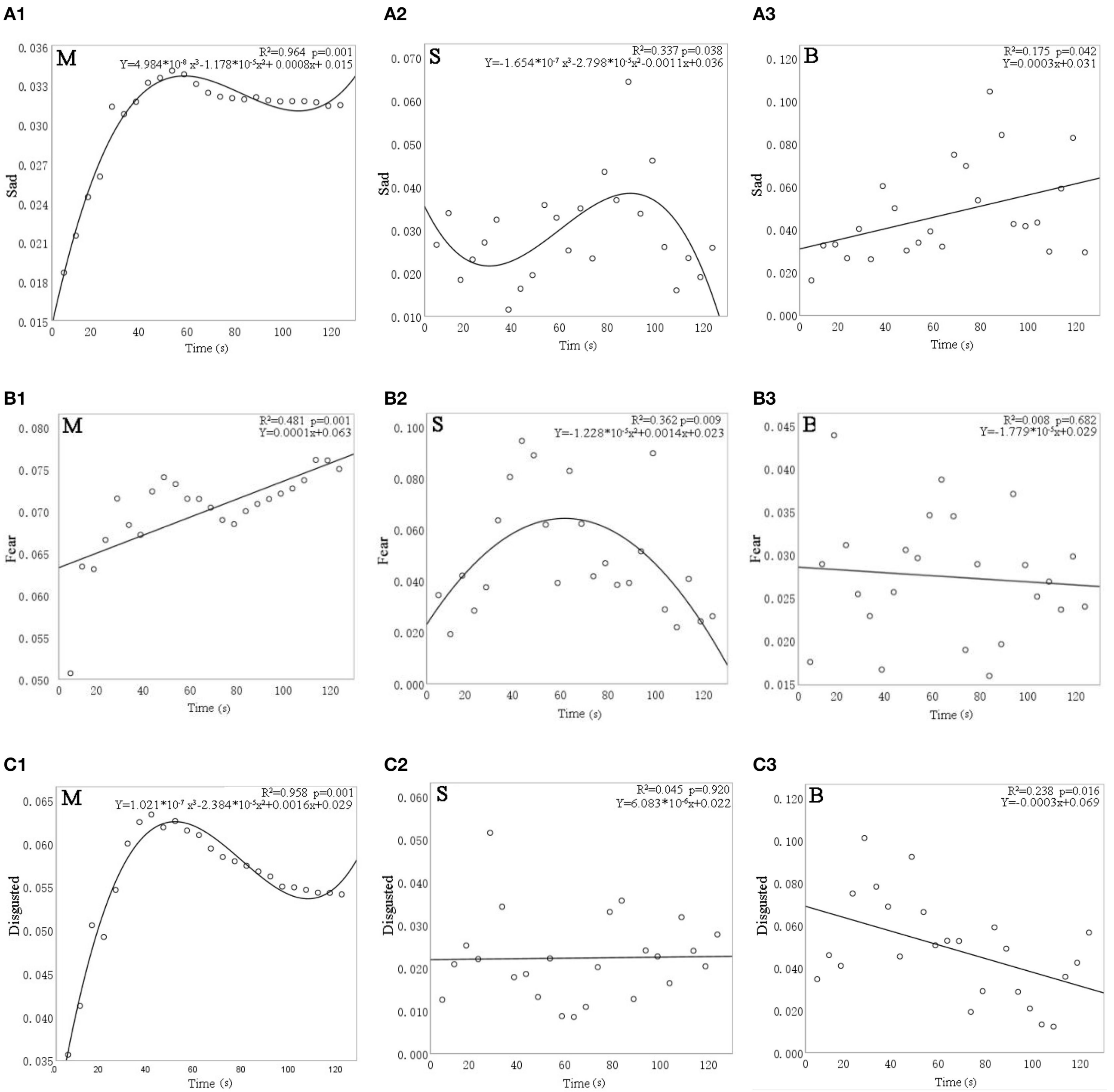

FIGURE 8 | The relationship between facial expression indices—**(A)** sadness, **(B)** fear, and **(C)** disgust—and time for different sound interventions. M, music; S, stream; and B, birdsong.

significantly lower than that in the normal group (mean = 0.060, *SD* = 0.071), most substantially at 80 s.

DISCUSSION

To decide whether and how FaceReader can take the place of questionnaires as a tool in sound perception research, the results of these two methods should be discussed. As mentioned earlier, FaceReader can recognize the facial expressions of older people with dementia. Whether FaceReader can replace the subjective evaluation scale as a tool for emotional research in older people with dementia is discussed. Bivariate Pearson correlations were used to analyze the relationship between the subjective emotional evaluation of the participant and facial expression valence, reporting the effect size of Cohen'*d* (**Table 5**). Based on the sign of r, the valence of facial expressions is positively correlated with the subjective evaluation of pleasure, arousal, superiority, and acoustic comfort. In the music intervention, pleasure (r ranging

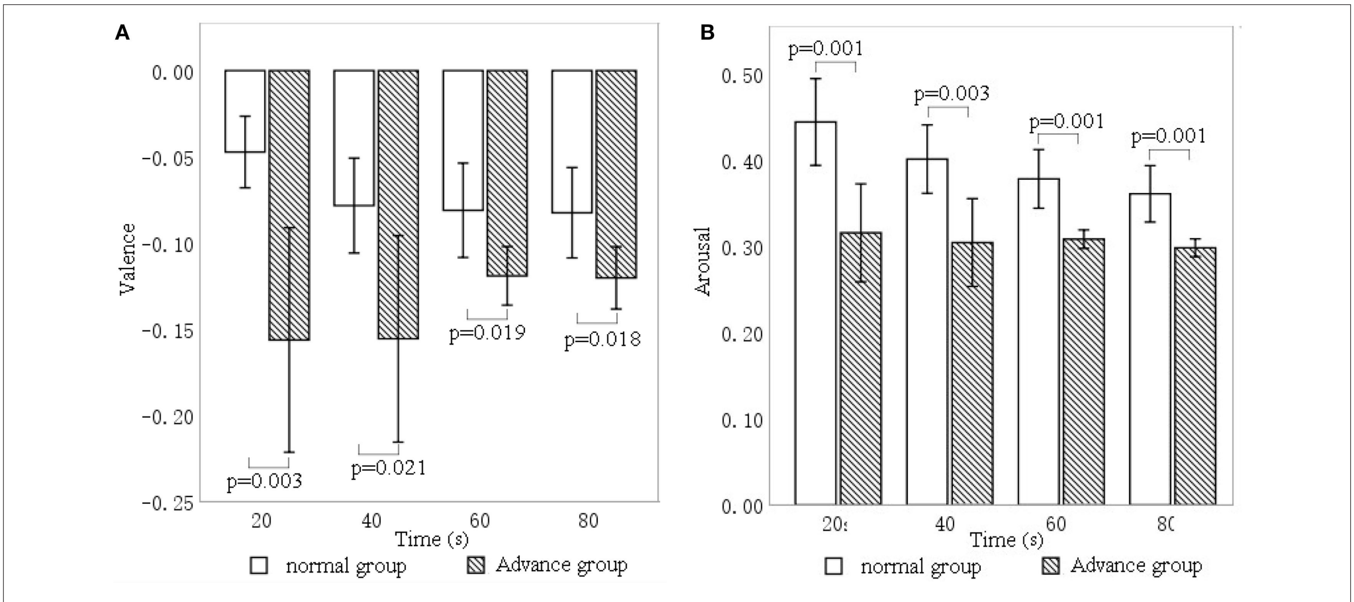

FIGURE 9 | Differences in **(A)** valence and **(B)** arousal for music intervention of different durations.

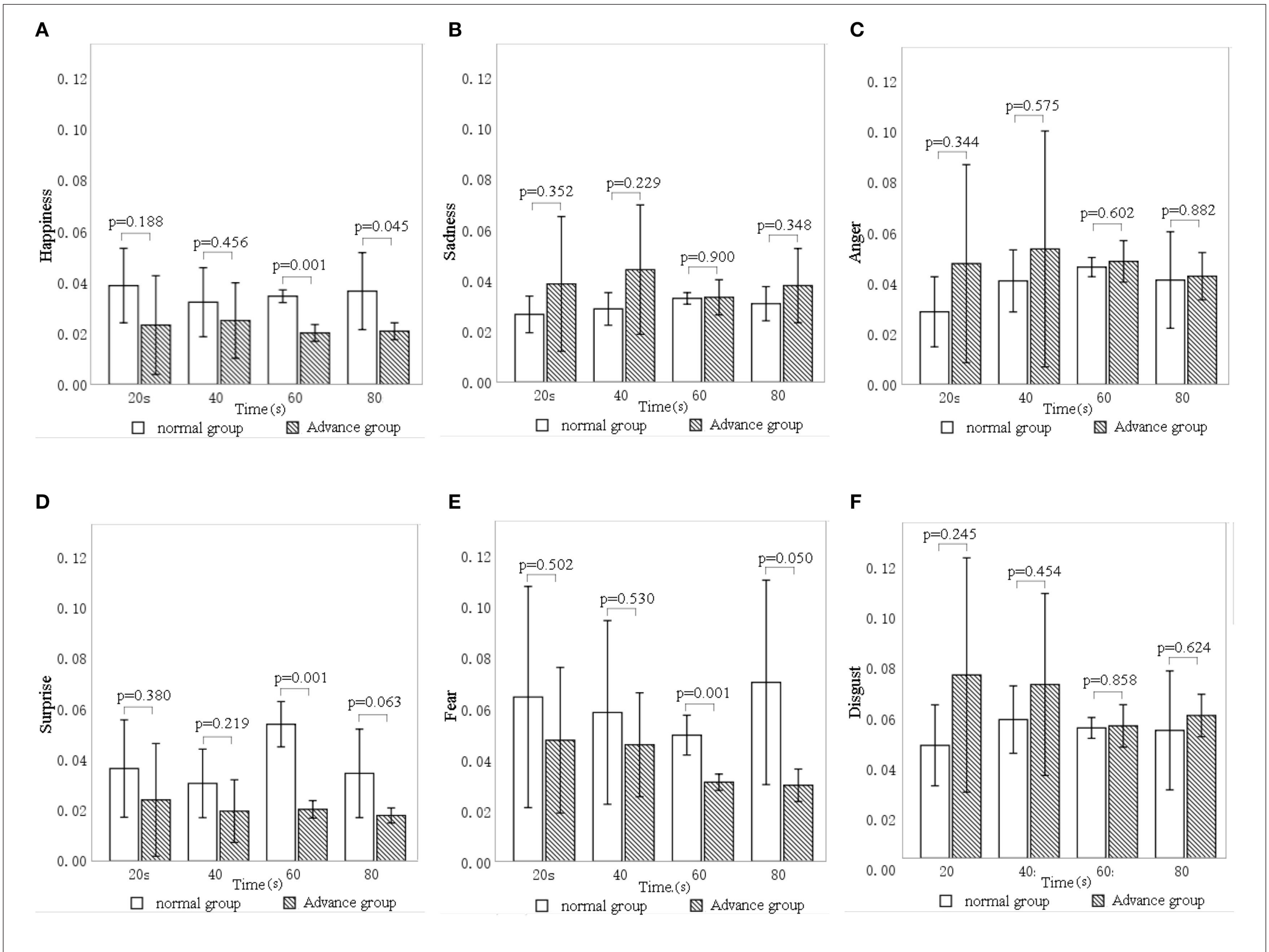

FIGURE 10 | Differences in facial expression indices—**(A)** happiness, **(B)** sadness, **(C)** anger, **(D)** surprise, **(E)** fear, **(F)** disgust—for different intervention durations.

TABLE 5 | The relationship between subjective emotional evaluation and facial expression valence in three sound interventions at 20, 40, 60, and 80.

Sound source type		Subjective emotional evaluation			
	Time	Pleasure	Arousal	Dominance	Acoustic comfort
Music	20 s	0.601**	0.468*	0.282	0.202
	40 s	0.679**	0.406	0.431	0.374
	60 s	0.565*	0.354	0.535*	0.475*
	80 s	0.460*	0.343	0.600**	0.545*
Stream sound	20 s	0.021	0.061	0.790*	0.102
	40 s	0.770*	0.749	0.236	0.766*
	60 s	0.762*	0.772*	0.192	0.760*
	80 s	0.692	0.866*	0.064	0.697
Birdsong	20 s	0.727	0.891*	0.824*	0.769
	40 s	0.768	0.760	0.588	0.862*
	60 s	0.830*	0.844*	0.651	0.860*
	80 s	0.796	0.514	0.400	0.907*

***p < 0.01, *p < 0.01.*

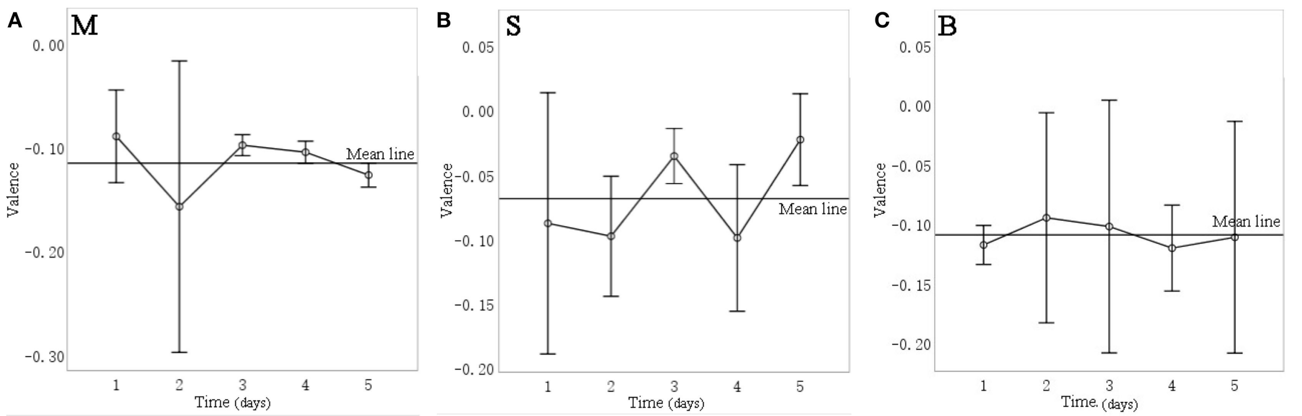

FIGURE 11 | Changes in valence over 5 days of experiment for different sound interventions. **(A)** music, **(B)** stream, **(C)** birdsong.

from 0460 to 0.679) is significantly correlated with valence at all four-time points. Dominance (r ranging from 0.282 to 0.600) and acoustic comfort (r ranging from 0.202 to 0.545) were significantly correlated with valence at 60 s and 80 s, while arousal ($r = 0.468$) was significantly correlated with valence at 20 s. For the sound of a stream, valence change in the first 60 s can be used to predict arousal (r ranging from 0.061 to 0.866), pleasure (r ranging from 0.021 to 0.0762), and acoustic comfort (r ranging from 0.102 to 0.760), while dominance can be reflected by valence change at 20 s ($r = 0.790$). In the birdsong intervention, valence change in the first 60 s can be used to predict pleasure ($r = 0.830$), arousal ($r = 0.891$), and acoustic comfort (r ranging from 0.769 to 0.907), while dominance ($r = 0.824$) can be represented by valence at 20 s.

In terms of individual differences, first, the point-biserial correlation analysis revealed that gender and facial expression are not significantly correlated in the music and birdsong interventions. This is consistent with previous research conclusions reached from evaluating acoustic environment using questionnaires (Meng et al., 2020a). However, a significant correlation was found between facial expressions and gender at 20 s in the stream sound intervention, with valence significantly higher among women than men ($r = 0.869$, $p = 0.011$). This suggests that the sound of a stream can more easily elevate the emotions of women. Regarding age, the results of the bivariate Pearson correlation analysis show a negative correlation between age and facial expression valence ($r = -0.467$, $p = 0.044$) at 80 s for the music intervention but a positive correlation at 20 s for the stream sound ($r = -0.756$, $p = 0.049$). However, there was no correlation between age and valence for the birdsong intervention. Finally, we found no correlation between the MMES score and facial expression valence for any of the three sound types.

In terms of intervention days, **Figure 11** shows the mean valence of each day for different sound sources for over 5 days of intervention. Repeated measurement variance analysis reveals that the valence for music intervention on the third day (mean $= -0.098$, $SD = 0.014$) and fourth day (mean $= -0.104$, $SD =$

0.015) was significantly higher ($p = 0.007$) than that on the fifth day (mean = −0.126, $SD = 0.016$). For the stream sound, valence on the fourth day (mean = −0.099, $SD = 0.046$) was significantly lower ($p = 0.041$) than that on the third day (mean = −0.356, $SD = 0.017$) and the fifth day (mean = −0.023, $SD = 0.029$). For birdsong, however, there were no significant differences in valence between the days ($p = 0.094$). The above results indicate that the facial expressions of elderly with dementia are affected by the number of intervention days for two of the three sound sources. Therefore, in studying how sound interventions affect the mood of older people with dementia, the number of days of the intervention should be considered.

In a field experiment studying the emotions of elderly with dementia, various factors may affect the facial expressions of the participant, such as vision, smell, and the mood of the care partner. This makes it somewhat difficult to recognize emotions through only facial expressions. Acknowledging this limitation, the aim of this research was to verify the effectiveness of FER in emotion recognition for older people with dementia.

CONCLUSIONS

This study proposes FaceReader as a potential method for evaluating the impact of sound interventions on emotions in older people with dementia. Through field experiments with 35 participants, the following conclusions were drawn.

First, FaceReader can identify differences in the emotional responses of older people with dementia using different types of sound interventions. Among the three sound sources, music showed the most positive effects on the mood of older adults with dementia. The effects of music, birdsong, and the sound of a stream were higher than that with no sound source. The facial expression indices of sadness, fear, and disgust also differed significantly between sound sources, while happiness, surprise, and anger did not.

Second, the sound and activity started simultaneously had a more positive influence on the mood of older adults with dementia than when playing the sound before the activity started, especially under the intervention of music and streams. Regarding intervention days, only music and stream sound showed significant differences in the effect between different dates. Birdsong also had differences in effect, but those differences were not significant. This shows that, when using FaceReader to measure the impact of sound interventions on emotions in elderly with dementia, more than one intervention must be performed to obtain accurate and reliable results.

The comparison of results from FaceReader and the subjective evaluation scale shows that facial expression valence can predict pleasure, arousal, dominance, and acoustic comfort.

In terms of gender, the sound of a stream more easily elevated the emotions in women than in men. In terms of age, only under the intervention of music and stream sound was age related to the emotions of older adults with dementia. Regardless of the sound source, no correlations were found between facial expression valence and MMSE scores.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

YL: conceptualization, validation, writing—review and editing, supervision, and funding acquisition. GY: methodology and formal analysis. ZW: investigation, data curation, and writing—original draft preparation. All authors have read and agreed to the published version of the manuscript.

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Perceptions of Wind Turbine Noise and Self-Reported Health in Suburban Residential Areas

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Wind turbines play an important role in the worldwide mission of producing renewable energy. The development toward integrating large-scale wind turbines in the urban environment has raised concerns over the noise impacts on urban residents. While most of the existing studies on wind turbine noise (WTN) have focused on rural settings, this paper investigates the relationship between WTN, noise perception and self-reported health of people, and controlling for background characteristics of the residents in urbanized areas. Questionnaire surveys were carried out around three suburban wind farms in the UK with 359 respondents. A-weighted sound pressure levels of WTN were predicted using noise mapping, for the most exposed façade of each dwelling of the respondent. The dose-response relationship was found between WTN and annoyance, moderated by age and degree of education. WTN was associated with some aspects of self-reported health, including raised health concerns, having headaches, nausea, and ear discomfort, but was not related to sleep disturbance directly. Noise sensitivity, attitudes to wind energy, and visibility of the wind turbines were found to significantly influence self-reported health. By employing a second variant of the questionnaire with the research aim masked, this study also addressed the focusing effects induced by the questionnaire design. The significant differences in the reported adverse health between questionnaire variants implied focusing bias among the sample who knew the research purpose. This elicited a methodological finding that should be noted in future research.

Keywords: annoyance, health impact, focusing effect, wind turbine noise, questionnaire survey

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INTRODUCTION

Wind turbines (WTs) play an important role in producing renewable energy and mitigating greenhouse gas emissions. In recent years, there has been a development toward integrating large-scale WTs within the urban environment (Ishugah et al., 2014), which can reduce electricity loss and network costs due to its proximity to users (Archer and Jacobson, 2007; Hoppock and Patiño-Echeverri, 2010). However, noise pollution to the surrounding premises can be obstacle to wind energy exploitation. Noise emission from a WT is larger than the typical urban noise sources and consists of dominant components at low frequencies (below 200 Hz), which is attenuated less by buildings than mid- to high-frequency sound (Bolin et al., 2011).

The potential noise impacts of WTs have attracted substantial public, policy, and scientific attention. A limited number of cross-sectional studies have conducted questionnaire surveys to investigate the impact of wind turbine noise (WTN) on self-reported noise evaluations. Dose-response relationships between the exposure to WTN and annoyance have been found in five studies conducted in Sweden, the Netherlands, Poland, and Canada (Pedersen and Waye, 2004, 2007; Pedersen et al., 2009; Pawlaczyk-Łuszczyńska et al., 2014; Michaud et al., 2016). In addition, a dose-response relationship between self-reported sleep disturbance and noise exposure was found (Pedersen, 2011; Bakker et al., 2012; Pawlaczyk-Łuszczyńska et al., 2014). Other health-related effects such as psychological distress were found to be associated with WTN, with noise annoyance as a mediator (Pedersen, 2011; Shepherd et al., 2011). However, much of the existing research has focused on rural settings, with suburban respondents being a minority. Results from previous studies on the WTN evaluation in urbanized areas have been in a state of flux. One study found that living in an urbanized area (as opposed to a rural area) reduced the risk of annoyance with WTN (Pedersen and Waye, 2007), and another study found that living in a built-up area increased the probability of being annoyed (Pedersen et al., 2009), while another article of people living in noisy areas reported that noise exposure did not lead to noise annoyance among those who noticed the sound (Bakker et al., 2012). It has been inconclusive that urban residents were more vulnerable or adaptive to WTN than rural residents. One reason might be the existence of a complex set of socioeconomic parameters in urban areas that had not been fully controlled for in previous studies. Perceptions of noise could also be moderated by the visual aspects (Bangjun et al., 2003; Maffei et al., 2013; Aletta et al., 2016), vegetation (Van Renterghem, 2019), and the existing background noise (Qu and Kang, 2019). Given the increase in the WT size and the number of built-up areas, there is a need to investigate the perception and health impact of WTN in urbanized environments, controlling for respondent demographical and attitudinal factors.

Furthermore, previous surveys have asked respondents living near WTs to assess the impact of WTN directly (Pedersen and Waye, 2004, 2007; Pedersen et al., 2009; Pawlaczyk-Łuszczyńska et al., 2014). Therefore, it would have been obvious to the respondents that the purpose of the questionnaire was to investigate potential adverse health effects of WTs (Nissenbaum et al., 2012), and if so, such questionnaires may be susceptible to a focusing bias (Wilson et al., 2000; Ubel et al., 2011), where the questions lead the respondents to pay more attention than they usually do to the noise and thus answer differently. Therefore, there is a need for a questionnaire survey designed to avoid possible focusing bias.

This study aims to model the distribution of WTN in the suburban–urban residential areas and to investigate the relationships between the modeled exposure to WTN and noise perceptions, self-reported sleep disturbance, and health of the respondents. Noise annoyance of this study in the suburban–urban areas is compared to that in previous studies in rural areas. The work also explores if demographical and attitudinal factors affect reporting of noise impacts by the respondents. In addition, the study is designed to minimize the potential bias caused by focusing effects by using two variants of the questionnaire: one with and another without specific questions on WTs. These two variants of the questionnaire allowed an investigation on whether the knowledge of the motivation of the survey affects the reporting of health impacts by respondents.

MATERIALS AND METHODS

Questionnaires

The study used a questionnaire survey of those living near WTs to investigate the relationship between the exposure to WTN, noise perceptions, and the self-reported health of the respondents. The questionnaire asked about the responses to WTN, sleep disturbance, the prevalence of health-related problems, and general health. It also measured the socioeconomic status of a respondent, architectural factors, attitudes to environmental issues, as well as visibility of the WT (full questionnaires are shown in **Supplementary Material Sections 1, 2**). In general, the questionnaire had three sections in the following order: (i) well-being and health, (ii) evaluation of the neighboring environment (including WTN), and (iii) sociodemography and dwelling. Most of the questions were drawn from the established national surveys of health and well-being such as the British Household Panel Survey (BHPS), with several modifications to fit this survey.

Questionnaire Variants

To minimize the potential focusing bias caused by the knowledge of the motivation of the survey, two variants of the questionnaire were used: "Questionnaire Variant 1" included questions on noise perceptions, personal attitudes, and health problems related to WTs, while "Questionnaire Variant 2," allocated to a control group, which had no reference to WTs except in one question where WTs were referred to as one of several environmental nuisances. Other questions that did not refer to WTs were kept identical across the variants.

Outcome Variables

The main outcome variables included the perception of WTN, self-reported sleep disturbance, perceived health impact, the prevalence of specific health symptoms, and general health status. Perceptions of residents on WTN were assessed in a set of contingency questions adapted from a previous survey (Pedersen and Waye, 2004). Respondents were first asked to indicate whether they noticed any of the seven environmental nuisances including WTN, and if yes, they were asked to rate their degree of annoyance on a 5-point scale from "not at all" to "extremely." In Variant 1, the annoyance with WTN was further examined in three questions: addressing annoyance overall, outdoors, and indoors. Sleep disturbance in this survey was measured without referring to noise and was kept identical in Variants 1 and 2. Unlike the previous studies that investigated the occurrence of disturbed sleep by noise using a single question (Pedersen and Waye, 2004, 2007; Bakker et al., 2012), the present study assessed the occurrence of various types of sleep disturbances such as difficulty in falling asleep, sleeping less deeply, and awakening. Further, the participants were asked to indicate whether they experienced the listed 10 physiological and psychological health problems during the past week, including headache, dizziness, ear discomfort, cardiovascular disease, tension and edginess, and lack of concentration. In Variant 1, the respondents were then allowed to indicate whether they felt WTN might be the cause. The response scale was configured as "yes," "possibly," "no," and "I don't know." In addition, all respondents were asked to self-assess their general health on a five-point scale from poor to excellent.

Moderating Variables

As for moderating variables, the survey included questions on sociodemographic, personal/attitudinal, and architectural factors. First, sociodemographical factors such as age, sex, longstanding illness, and household income that were found to influence noise annoyance and health in previous studies were assessed (Fields, 1993; Bluhm et al., 2004; Dolan et al., 2008; Frijters and Beatton, 2012). Second, personal/attitudinal questions addressing personal noise sensitivity, environmentally sustainable lifestyle, and attitude to the noise source were added in line with the previous studies (Weinstein, 1980; Guski, 1999; Job, 1999). Noise sensitivity was measured in one question with two items: (a) "I find it hard to relax in a place that's noisy" and (b) "I get used to most noises without much difficulty," assessed on a 6-point scale from agree strongly to disagree strongly. The question was drawn from an established 21-item noise sensitivity questionnaire (Weinstein, 1978), shortened in this following questionnaire (Benfield et al., 2014). The attitude of respondents to WTs was also assessed using eight antonym adjectives to describe WTs, drawn from a previous study (Pedersen and Waye, 2004). A question identified the financial stakes of respondents in the wind farm. Furthermore, three questions were on architectural factors, such as the number of bedrooms in the dwelling, the housing type, and the orientation of the dwelling, which were found to have effects on resisting the WTN in previous studies (Qu and Kang, 2017). Furthermore, dwelling-related questions measured the visibility of the WT, length of residency, and ownership of the dwelling.

A detailed report on the questionnaire design can be found in Qu and Tsuchiya (2018).

Study Sites and Sample

The target population of the survey was defined as the residents who lived within 2 km of modern WT(s) in suburban areas in the UK. The selection of each sample is explained below.

Study Area

Three typical suburban sites with modern WTs were selected, based on the UK wind energy online database (UKWED, 2014) and a map of each wind farm site on Google Earth. The photos of the three sites are shown in **Figure 1**. Site A is in the suburban area near Nottingham in East Midlands, site B is in the suburb of a Dundee city in Scotland, and site C is in the town of Lowestoft on the eastern coast of England. The WTs were large and modern, with tower heights between 80 and 85 m. The distances between the sampled residences and the closest WT were within 500–2,000 m. All sites could be classified as suburban with high population densities (2,000–4,000/km^2). Site selection criteria and detailed site maps are shown in **Supplementary Material Section 3**.

Study Sample

To ensure that residents exposed to different levels of noise were represented in the sample, disproportionate stratified sampling was applied with modeled WTN levels as the strata. Preliminary noise modeling was carried out to predict the distributions of WTN across the residential areas of each site, considering different WT models and terrain conditions. The sample was sorted according to 5 dB noise intervals calculated from the noise maps (shown in **Supplementary Material Section 3**). The sample size in each stratum was calculated based on the power analysis (sample size calculation in **Supplementary Material Section 4**). Addresses were randomly selected from the edited version of the electoral register, by stratum, for each of the two questionnaire variants. All addresses in the highest noise-exposed group were included to reach the proportionate sample. Where there were several adults at the same address, one individual was selected at random. To save on the labor and cost of a survey, fewer samples were selected for the control group of Variant 2. As there were insufficient or unreachable addresses in some strata, a total of 2,971 individuals were sampled (2,238 for Variant 1 and 733 for Variant 2). Questionnaires were mailed or door-dropped to the sampled individuals.

Noise Exposure Modeling Using the Noise Map Technique

In this article, WTN exposure was represented by the modeled maximum sound pressure level (SPL) at each dwelling of the respondents. To examine the spatial distribution of WTN levels in each study site, noise maps were calculated using the software package CadnaA (DataKustik GmbH, 2006). The map and topographical information of the study sites were obtained from the EDINA Ordnance Survey Digimaps in the UK (Ordnance Survey, 2013). A-weighted SPLs on the most exposed façade (maximum façade exposures) of target buildings were predicted. The calculation in the software was based on the ISO 9613-2 (ISO 9613-2, 1996) sound propagation standard. Noise emission from the WT was calculated under downwind conditions representing the worst case. In line with the IEC 61400-11 standard (IEC 61400-11, 2012), the WT was simulated as a point source at hub height. The sound power level and the spectrum of the point source were set based on that given by the manufacturer, where the sound powers are relatively high at low frequencies and attenuate with octave. The ground absorption was set to 0.5 in accordance with the Good Practice Guidelines in the UK (Cand et al., 2013). The temperature in software calculation was set to 10°C and the relative humidity was set to 70% for atmospheric absorption, which was consistent with common practices (Keith et al., 2016). The reflection order by buildings was set to 3, based on a previous study (Kang, 2006). The receiver was set at a 4 m height, with a 0.05 m façade-receiver distance, to take into account reflections at the exposed façade. After setting all the parameters, the

FIGURE 1 | Photos of three study sites (left: Site A with wind turbine (WT) in the field; middle: Site B with WTs on the industrial site; right: Site C with WT at the seaside; photos were taken by the author).

building evaluation in the software generated the maximum SPL at each dwelling. The noise exposure for respondents was obtained based on their location on the noise maps. The calculations using the above method have been verified by field measurements. Results of validation showed that the software model provided an accurate estimate of the relative difference between locations around a building, especially at the middle-higher frequencies.

Statistical Analysis

Statistical analyses were performed using the SPSS version 22 (Statistics, 2009). Descriptive statistics was provided for the characteristics of the participants, their attitudes to WT projects, their perceptions of WTN, and their self-reported health. Differences in the distribution of respondent characteristics and perceptions across four sound intervals and between two variants were examined using Pearson's chi-square (χ^2) for categorical variables or ANOVA (*F*, in one-way ANOVA) for continuous variables. A nonparametric approach was also applied as an alternative to one-way ANOVA, using the Kruskal–Wallis test. Pearson's correlation coefficient (r) was used to test the bivariate correlation between noise exposure and subjective factors.

Binary logistic regression was applied to analyze the effects of noise exposure on annoyance with the noise, sleep disturbance, and perceived health impact. As very few respondents were highly annoyed in this study, annoyance measured on verbal scales was dichotomized with slightly annoyed to extremely annoyed classified as "annoyed." The main explanatory variable, noise exposure, was represented by the A-weighted SPL, calculated for the most exposed façade of a dwelling from the noise map outlined above. Preliminary regression analyses were carried out to explore the influence of demographical, architectural, and attitudinal factors on noise perception and select the variables for the final regression models. Odds ratios (ORs) are reported for variables in each regression model with 95% CIs, with a *p*-value of below 0.05 considered to be statistically significant. The Nagelkerke pseudo-R^2 was applied as a measure of the explained variance. The Hosmer–Lemesow goodness-of-fit [*p* (H-L)] was presented for each logistic regression model, with a *p*-value of >0.05 indicating no statistically significant difference between the modeled and the observed data.

RESULTS

Descriptive Statistics

Respondents

The numbers of respondents of the two questionnaire variants were 262 and 97, respectively, with a total of 359. The overall response rate was 12.0%. The response rates of Variants 1 and 2 were similar, of 11.7 and 13.2%, respectively. Based on a chi-squared test of goodness-of-fit, the distribution of the respondents according to 5-dB(A) noise intervals was not statistically different across questionnaire variants, $\chi^2(7) = 3.34$, $p = 0.343$.

Across the two variants, the mean age in the study population was 56 ($SD = 17.7$), and 49% were male. Most of the respondents were employed (43%) or retired (41%). Overall, 49% of the respondents lived in detached or semidetached houses, and 68% of the respondents privately owned their accommodation. No respondents in this study had a financial stake or were employees of the local wind farm. The characteristics of respondents were similar across the two variants.

Respondents were not evenly distributed across the four noise groups. In general, respondents exposed to high levels of noise pollution were more vulnerable than those living in lower sound residences, shown to be older ($F_{(3,352)} = 9.87$, $p < 0.001$), retired ($\chi^2(7) = 13.23$, $p = 0.004$), widowed ($\chi^2(7) = 15.38$, $p = 0.002$), living in a rented flat ($\chi^2(7) = 30.61$, $p = 0.002$), and had lower household income ($r = -0.19$, $p = 0.050$). This might be due to the planning of wind farm areas where residences in proximity to the turbines were more often rented by people from a low social class, while lower sound residences were detached or semidetached with more bedrooms and were more likely to be owned by mid-to-high class people. These demographical factors were controlled for in the relationship between WTN exposure and potential health effects.

Perception of WTN

Overall, 16% of the respondents ($n = 59$) noticed the WTN and 11% of the respondents ($n = 39$) were being annoyed by it when asked alongside a set of environmental nuisances. Of those who noticed WTN, 41% were not annoyed by the noise.

It was found that 80% of the annoyed respondents were living within 850 m, and 90% were living within 900 m from the

WT. When the WT was over 900 m away from the residence, the percentage of respondents who noticed and were annoyed decreased to 8.1 and 2.7%, respectively.

When respondents in Variant 1 were asked further about their annoyance with WTN in a separate question, 12% ($n = 32$) indicated that they were annoyed by the noise overall, 16% ($n = 45$) were annoyed outdoors, and 9% ($n = 25$) were annoyed indoors. In terms of sound characters, more than half of the respondents of Variant 1 (55%) described the WT as noiseless/quiet. Swishing (29%) and whooshing (20%) were the most common sound characteristics chosen, which are verbal descriptors of low-frequency components of the sound from WTs.

Across the two variants, there were no differences in the proportions of respondents who noticed noise from WTs ($\chi^2(3) = 0.09$, $p = 0.763$) or those who indicated to be annoyed ($\chi^2(3) = 0.04$, $p = 0.837$).

Attitudinal and Visual Factors (Variant 1 Only)

Participants in Variant 1 were asked for their judgments on WTs using 14 adjectives (Question No. 15 in the questionnaire of Variant 1 shown in **Supplementary Material 1**). The adjectives that most of the respondents agreed with were "environmentally friendly," (71%) "efficient," (41%) "necessary," (38%) and "harmless" (37%). "Ugly" was the most frequently selected among the negative adjectives (23%).

Factoring analysis was employed to extract the oblique factors underlying the 14 inter-related adjectives. Five factors were identified; three of them were significantly related to noise annoyance. One factor was a positive attitude to the utility of WTs ($r = -0.14$, $p = 0.023$), described as environmentally friendly, efficient, harmless, and natural. Another factor was a negative attitude to the necessity of exploiting wind energy ($r = 0.22$, $p < 0.001$), which was expressed as unnecessary and threatening. The last factor was a negative attitude to environmental impacts ($r = 0.34$, $p < 0.001$), including not environmentally friendly, dangerous, ugly, and unnatural.

Respondents to Variant 1 were asked to indicate the visibility of WT(s) from their residence; 31% ($n = 80$) responded that they could not see any from their home; 31% ($n = 80$) could only see WT(s) from a window; 12% ($n = 30$) could only see it/them from the garden or front yard; and 25% ($n = 66$) could see WT(s) from both a window and the garden/yard. Respondents who could not see any WT from home were associated with a lower proportion of annoyance than those who could see the turbine (3.8 vs. 14.8%, $\chi^2(3) = 6.65$, $p = 0.010$), while those who could see the turbine from both a window and the garden significantly increased the proportion of annoyance (from 6.6 to 24.2%, $\chi^2(3) = 15.55$, $p < 0.001$).

Self-Reported Health

Respondents in both Variants 1 and 2 indicated sleep disturbances without referring to noise. Overall, 13.4% of the respondents did not have their sleep disturbed. The most often chosen problems were "sleeping less deeply" (33.1%) and "lie awake for a while" (32.6%). The proportion of disturbed sleep was not associated with noise exposure from the WTs.

Levels of general health were self-reported based on an established question using 5-scales from excellent to poor. A majority of the respondents reported their health as good ($M = 2.92$, $SD = 0.98$). No statistically significant differences were found related to the general health between the questionnaire variants or noise exposure groups.

The perceived health impacts of respondents in Variant 1 showed different distributions across four noise groups. The proportion of respondents who indicated that noise from the WT(s) had no effect on their health varied from 93.8 to 92.1% at low SPLs but decreased to 77.3% at SPLs >40 dBA; such a difference between sound categories was statistically significant ($\chi^2(7) = 10.50$, $p = 0.015$).

Respondents in both Variants 1 and 2 indicated whether they experienced any of the listed health symptoms during the past week, such as headache, nausea, dizziness, and stress. The percentage of respondents in each variant who experienced each health symptom is shown in **Figure 2**. The prevalence of the reported health symptoms was higher in Variant 2, which might be due to a significantly higher proportion of respondents having a long-standing illness or disability in Variant 2. Another reason might be that some respondents in Variant 1, knowing that the motivation of the survey was to link their reported health symptoms to WTN, under-reported their health problems unless they thought that WTN might be the cause.

Dose-Response Relationships Between Noise Exposure and Perception

Table 1 shows the percentage of respondents noticed and annoyed by WTN in each group of 5 dB sound intervals. The proportion of "noticed" respondents increased from 5 ($n = 5$) at a sound interval below 30 dBA to 47% ($n = 25$) at a sound interval above 40 dBA. The proportion of annoyed respondents also increased with sound interval, from 3% ($n = 3$) in the lowest to 30% ($n = 16$) in the highest. Chi-squared tests show that the differences between sound intervals were statistically significant.

Effects of WTN on the Perception and Health Controlling for Personal Factors

Annoyance With WTN

Binary logistic regression was used to examine the association between noise exposure, personal factors, and annoyance. In preliminary regression analyses, the modeled maximum SPL at the dwelling was kept in each regression model as the main explanatory variable; personal factors that were hypothesized to have an effect were then added to the regression model one by one. Eighteen preliminary regression models were run to select the independent variables to be used in the main multivariate model (results of these preliminary regression analyses are shown in **Supplementary Table 1**). It is worth noting that annoyance with WTN was not associated with sex or income and was not different statistically among vulnerable respondents who had a long-standing illness, who were being retired or on maternity leave, or whether they owned their dwellings. Self-reported noise sensitivity, which significantly influenced noise annoyance in previous studies, was not found to have a significant impact on

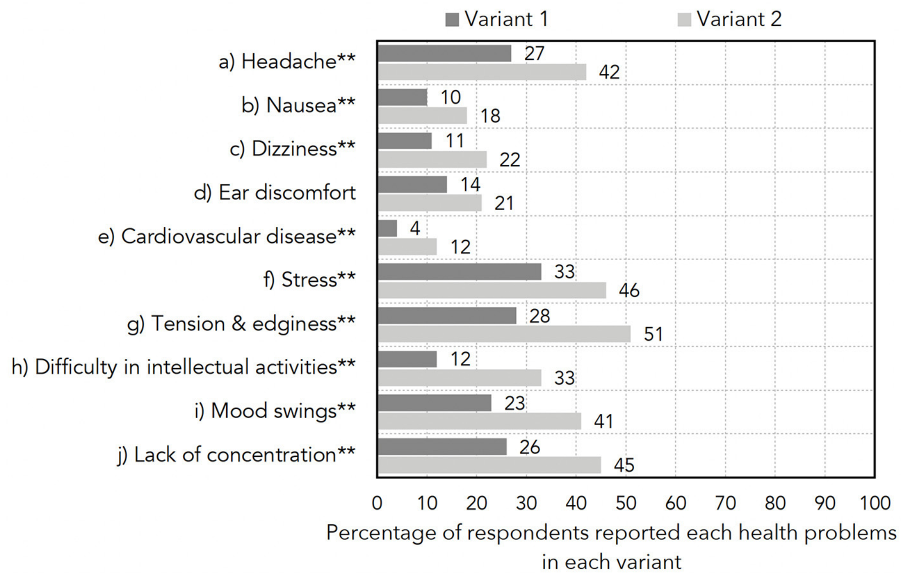

FIGURE 2 | Clustered bar chart showing the percentage of respondents reporting health problems in Variants 1 and 2 (**significant differences across variants with $p < 0.05$ for chi-squared tests).

TABLE 1 | Annoyance with wind turbine noise (WTN) related to sound exposures is shown as the percentage within each sound interval with 95% CI.

	Overall	Maximum sound pressure levels at dwelling [dB(A)]				Chi-squared test
		<30	30–35	35–40	>40	
Variants 1+2	**Percentage (95% CI)**	**Percentage within each sound interval (95% CI)**				
Noticed (among other nuisances)	16 (13–20)	5 (1–11)	12 (6–19)	20 (12–29)	47 (33–61)	$\chi^2 = 45.056$; $p = 0.000$
Annoyed overall (among other nuisances)	11 (8–15)	3 (0–6)	8 (3–14)	13 (7–21)	30 (17–43)	$\chi^2 = 24.598$, $p = 0.000$

noise perceptions in this study. Architectural factors, including the number of bedrooms, housing type, and orientation, were not associated with annoyance.

The multivariate regression models predicted annoyance using the moderating variables that had a significant influence in the bivariate models, shown in **Table 2**. The OR of being annoyed by WTN increased with each dB increase in SPLs at the most exposure façade. Age was positively associated with annoyance at a diminishing rate. Having higher educational qualifications than A-level or O-level decreased the probability of being annoyed. Visibility of the WT from both window and garden increased the odds of being annoyed than not visible from home ($p < 0.10$). Holding a negative attitude to the environmental impact of WTs was positively associated with annoyance.

Sleep Disturbance

Sleep was not related to WTN but annoyance with the noise. The annoyance of a respondent was positively associated with sleeping less deeply both for the whole data and for the main sample of Variant 1 (**Table 3**). Fixing the degree of annoyance overall, higher age, and having a long-standing illness increased the odds of sleeping less deeply. Being female and sensitive to noise did not make a significant difference. Of the models on the sample of Variant 1, the visibility of the WT from both a window and garden significantly increased the odds of a less deep sleep by 2.78 times than those who only saw it from a window.

General Health and Perceived Health Impact

Wind turbine SPL was not significantly associated with the self-reported general health levels but might affect the perceived health impact of a respondent among the sample of Variant 1. To explore the influence of subjective factors on the perceived health impact, binary multiple logistic regression was used (**Table 4**). Two models were created: one containing WT SPL at the dwelling as the prime variable and the other containing both SPL and annoyance. As shown in **Table 4**, WTN exposure increased the level of health concerns. When adding annoyance of WTN into the model, the effect of SPL was still significant, though not at the 0.05 level. Respondents who were annoyed by WTN were much less likely to report no health concerns than those not annoyed. Age and having positive attitudes to the utility of WTs increased the odds of reporting no health impact. Holding negative attitudes to the necessity or environmental impact of the WT did not significantly increase health concerns. Being female significantly decreased the odds of reporting no health impacts.

TABLE 2 | Association among annoyed by WTN, sound pressure levels (SPLs), and covariates.

Model	Variables	*p*-value	Odds Ratio (OR)	95% CI for OR
	Annoyed by WTN *[n = 356, R^2 = 0.264, $p_{(H-L)}$ = 0.308]*			
1	SPL	0.000	**1.18**	(1.08–1.28)
(Variants 1+2)	Age	0.011	**1.24**	(1.05–1.47)
	Age squared	0.006	**0.81**	(0.69–0.94)
	Highest qualification (ref: A-level or O-level)			
	- No qualification	0.153	0.49	(0.18–1.31)
	- Higher education below degree	0.077	**0.31**	(0.08–1.14)
	- Degree level	0.047	**0.25**	(0.06–0.98)
	- Other (professional certificate)	0.602	1.51	(0.32–7.22)
	Variant 2	0.799	0.89	(0.38–2.11)
	Annoyed by WTN *[n = 254, R^2 = 0.339, $p_{(H-L)}$ = 0.331]*			
2	SPL	0.050	**1.12**	(1.00–1.26)
(Variant 1)	Age	0.025	**1.24**	(1.03–1.48)
	Age squared	0.016	**0.80**	(0.67–0.96)
	Highest qualification (ref: A-level or O-level)			
	- No qualification	0.167	0.40	(0.11–1.48)
	- Higher education below degree	0.039	**0.22**	(0.05–0.93)
	- Degree level	0.073	**0.25**	(0.06–1.14)
	- Other (professional certificate)	0.634	1.69	(0.20–14.41)
	Variables only in Variant 1 below:			
	Visibility of the WT (ref: cannot see any from home)			
	- See WT from the window	0.249	2.43	(0.54–10.98)
	- See WT from the garden	0.851	0.82	(0.10–6.80)
	- See WT from both the window and the garden	0.062	**4.81**	(0.93–24.95)
	Negative attitude to the environmental impact of WT (no/yes)	0.001	**4.84**	(1.84–12.73)

Statistically significant associations with $p < 0.10$ in boldface.

TABLE 3 | Association among sleep, WTN annoyance, and covariates.

Model	Variables	*p*-value	Odds Ratio (OR)	95% CI
1	***Sleep less deeply (no/yes)*** *[n = 335, R^2 = 0.110, $p_{(H-L)}$ = 0.827]*			
(Variants 1+2)	SPL	0.317	0.98	(0.94–1.02)
	Annoyance overall (scale 1–5)	0.024	**1.54**	(1.06–2.25)
	Age	0.057	**1.02**	(1.01–1.04)
	Female	0.599	0.88	(0.54–1.42)
	Longstanding illness (no/yes)	0.035	**1.69**	(1.02–2.78)
	Sensitivity to noise (scale 1–6)	0.369	1.08	(0.92–1.27)
	Variant 2	0.148	0.66	(0.38–1.16)
2	***Sleep less deeply (no/yes)*** *[n = 242, R^2 = 0.209, $p_{(H-L)}$ = 0.949]*			
(Variant 1)	SPL	0.234	0.97	(0.91–1.02)
	Annoyance overall (scale 1–5)	0.021	**1.83**	(1.11–3.03)
	Age	0.058	**1.03**	(1.01–1.05)
	Female	0.973	0.99	(0.54–1.80)
	Longstanding illness (no/yes)	0.013	**1.86**	(1.00–3.44)
	Sensitivity to noise (scale 1–6)	0.930	0.99	(0.81–1.22)
	Negative attitude to the environmental impact of WT (no/yes)	0.781	1.10	(0.58–2.09)
	Visibility of the WT (ref: see WT from window)			
	- Cannot see WT	0.198	1.67	(0.77–3.62)
	- See WT from the garden	0.755	0.85	(0.29–2.44)
	- See WT from both the window and the garden	0.011	**2.78**	(1.20–6.42)

Statistically significant associations with $p < 0.10$ in boldface.

TABLE 4 | Association among no health concerns, sound pressure levels (SPLs), and covariates.

Model	Variables	*p*-value	Odds Ratio	95% CI
	Perceived no health impact *[n = 255, R^2 = 0.203, $p_{(H-L)}$ = 0.672]*			
1	SPL (maximum)	0.012	**0.89**	(0.81–0.97)
(Variant 1)	Age	0.034	**1.03**	(1.00–1.06)
	Female	0.038	**0.34**	(0.12–0.94)
	Positive attitude to the utility of WT (no/yes)	0.018	**4.36**	(1.29–14.69)
	Negative attitude to the necessity of WT (no/yes)	0.169	0.38	(0.10–1.51)
	Negative attitude to the environmental impact of WT (no/yes)	0.951	0.97	(0.32–2.89)
	Perceived no health impact *[n = 255, R^2 = 0.252, $p_{(H-L)}$ = 0.833]*			
2	SPL (maximum)	0.053	**0.91**	(0.83–1.00)
(Variant 1)	Age	0.053	**1.03**	(1.00–1.06)
	Female	0.022	**0.28**	(0.10–0.84)
	Positive attitude to the utility of WT (no/yes)	0.016	**4.91**	(1.35–17.93)
	Negative attitude to the necessity of WT (no/yes)	0.244	0.42	(0.10–1.82)
	Negative attitude to the environmental impact of WT (no/yes)	0.695	1.26	(0.40–4.01)
	Annoyed by WTN overall (no/yes)	0.008	**0.22**	(0.07–0.67)

Statistically significant associations with $p < 0.10$ in boldface.

TABLE 5 | Association among health problems, WTN (SPLs), and covariates in Variant 2.

Model	Variables	*p*-value	Odds Ratio (OR)	95% CI for OR
1	***Headache*** *[n = 97, R^2 = 0.385, $p_{(H-L)}$ = 0.791]*			
	SPL	0.071	**1.100**	(0.99–1.22
	Age	0.087	**0.970**	(0.93–1.01)
	Female	0.077	**2.752**	(0.89–8.45)
	Household income	0.833	0.941	(0.54–1.65)
	Sensitivity to noise (scale 1–6)	0.001	**2.126**	(1.35–3.35)
2	***Nausea*** *[n = 97, R^2 = 0.519, $p_{(H-L)}$ = 0.012]*			
	SPL	0.038	**1.250**	(1.01–1.54)
	Age	0.004	**0.907**	(0.85–0.97)
	Female	0.140	3.969	(0.63–24.81
	Household income	0.193	0.530	(0.20–1.38)
	Sensitivity to noise (scale 1–6)	0.056	**2.712**	(0.98–7.54)
3	***Ear discomfort*** *[n = 97, R^2 = 0.280, $p_{(H-L)}$ = 0.509]*			
	SPL	0.059	**1.118**	(0.99–1.25)
	Age	0.030	**1.068**	(1.01–1.13)
	Female	0.597	1.413	(0.39–5.09
	Household income	0.830	1.083	(0.52–2.25)
	Sensitivity to noise (scale 1–6)	0.021	**1.883**	(1.10–3.21)

Statistically significant associations with $p < 0.10$ in boldface.

Self-Reported Health Symptoms

Noise exposure from WTs was positively related to the prevalence of headache, nausea, and ear discomfort, but only within the respondents of Variant 2. **Table 5** shows the binary logistic regression models with a significant association between SPL and a health symptom among the sample of Variant 2. As the socioeconomic status of a respondent was related to WTN exposure, the regression controlled for age, sex, household income, and self-reported noise sensitivity. The results suggested that age slightly decreased the odds of headache and nausea but increased the probability of having ear discomfort. Other things being equal, the female was 2.7 times more likely to report headaches than the male, while the self-evaluated noise sensitivity level was positively associated with reporting health symptoms. All models had relatively high levels of R^2, indicating that more than 38% of the variance in headache and 51% of the variance in nausea could be explained by SPLs and the personal variables in the regression model.

DISCUSSION

Comparison With Previous Studies in Rural Areas

This study has found that the risk of annoyance with WTN increased with the modeled noise levels at a dwelling, which confirms the dose-response relationship found in previous studies (Pedersen and Waye, 2004, 2007; Pedersen et al., 2009; Pawlaczyk-Łuszczyńska et al., 2014; Michaud et al., 2016). Comparing the results of this study to those in rural areas, WTN in urbanized areas of this study is less noticeable than those in rural areas. Higher levels of WTN could annoy more rural residents than those of suburban inhabitants. The findings correspond well with Bakker et al. (2012) that further analyzed the data of Pedersen et al. (2009), covering both rural and built-up areas and indicated that the risk of being disturbed and distressed by WTN is pronounced in quiet areas compared to noisy areas.

The reason for the above differences between the current study and previous ones could be explained from both acoustical and contextual aspects. From the acoustical aspect, the study sites of the current study were more urbanized than those of the previous studies. In urbanized areas, higher levels of road traffic and neighborhood noise can have a masking effect on WTN (Qu and Kang, 2019). It is also possible that WTN is less prominent than other nuisances and stressors in a suburban area; the most frequently reported being the barking of dogs, racing cars, and motorcycles in this study. To explain the difference from the contextual aspects, respondents in suburban areas of this study seemed to be optimistic about new clean energy devices, which is supported by the free comments left at the end of the questionnaire, where many of them gave positive comments on wind energy and referred to various sustainable lifestyles such as fitting solar panels. The beliefs of people about the importance of the source of the noise could decrease annoyance, as stated in the literature (Fields, 1993).

Effects of Moderating Factors

The degree of noise annoyance can considerably vary between individuals of different characteristics, as identified in the literature (Weinstein, 1980; Fields, 1993; Guski, 1999). In this study, it is important to note that the background characteristics of respondents were significantly different across noise categories, where respondents in the higher exposure group were also lower in the sociodemographic status. This increased the probability of multicollinearity. Efforts had been made to assess the effects of WTN controlling for a series of demographic, attitudinal, architectural, and visual factors. The results suggest that the characteristics of residents such as age, gender, education, and noise sensitivity significantly affect the degree of individual noise perception or self-reported health, most of which were not reported as significant in previous WTN studies.

Negative attitudes to the environmental impact of WTs, described as not environmentally friendly, dangerous, and ugly, were positively associated with the risk of annoyance. It is consistent in previous studies that the negative attitudes to WTs especially to their visual impacts increase the possibility of annoyance (Pedersen and Waye, 2004, 2007; Pawlaczyk-Łuszczyńska et al., 2014).

Having at least one WT visible from the dwelling has been found to increase noise annoyance in a previous study (Pedersen and Waye, 2007). Among the respondents of this study, visibility of the WT did increase annoyance compared to not being able to see any but was not statistically significant. This may be interpreted along with the previous finding that the visual impact was more pronounced in rural areas when compared to that in the more densely populated areas (Pedersen and Larsman, 2008). However, a significantly higher annoyance was found among those suburban respondents who can see the WT from both a window and the garden, where the WT might be perceived as more obvious and contrasting with the landscape, which may lead to more annoyance, as stated by previous investigations (Pedersen and Larsman, 2008; Maffei et al., 2013).

Effects of WTN on Self-Reported Health

It has been found that noise levels were not associated with sleep but the degree of noise annoyance significantly increased the possibility of sleeping less deeply. The results agree well with the previous findings that WTN does not directly influence sleep, but annoyance acts as a mediator (Bakker et al., 2012). However, it should be noted that a reverse causality from sleep to annoyance might exist. The absence of a significant association between noise levels and sleep in this study might also be because urban respondents were more adaptive to noise. According to the findings of a meta-analysis study, a dose-response relationship between self-reported sleep disturbance and A-weighted noise exposure was not found in more densely populated suburban areas with various sound sources (Pedersen, 2011).

It was found that both the WTN level and annoyance increased perceived health impacts within the studied sample, controlling for sociodemographic variables. Being male, age growth and a positive attitude to wind energy project significantly moderated the health concerns, which has not been addressed in previous studies.

Self-reported general health was not found to be related to the WTN level nor the annoyance with the noise but was related to socioeconomic factors such as household income and the presence of illness within the studied sample. One possible reason is that the noise effect on subjective health and well-being might take more time to appear than the effects on annoyance. It is also possible that the level of general health might be related to other contextual factors that were not included, such as urbanization (Hudson, 2006), trust (Helliwell, 2006), and individual adaptation (Luhmann et al., 2012).

The association between SPL and the self-reported headache, nausea, and ear discomfort is in line with the literature that environmental noise with low-frequency components such as aircraft noise was more likely to increase the risk of headache and irritability (Stansfeld et al., 2000). The effects of WTN on dizziness and ear discomfort have been pointed out in several reports based on the complaints of local residents (Harry, 2007; Thorne and Leader, 2012), but have not been found in the previous field studies.

Effect of Questionnaire Variants

An important finding of the study lies in the difference between the two groups. Adverse health problems were more frequent in Variant 2 for whom the research purpose was masked. No significant associations were found between the noise level and the prevalence of health problems among respondents in the main group of Variant 1. A reversed focusing effect might exist in some participants of Variant 1, showing under-reported health problems. The reason could be related to the effect of the questionnaire design that has informed the participants in Variant 1 that their health data would be analyzed in relation to WTN. This might have led to fewer health problems being reported by the respondents of Variant 1, as 89% of them had indicated that WTN did not influence health. Another possible reason might be that the respondents of Variant 1 living in the low exposure zones over-reported their health symptoms, as the survey asked them to attribute the cause of any health symptom to WTN, which made them focus on the adverse impact of WTN on health and introduced bias. This behavior has been reported in a previous study on aircraft noise, that the wording of specific questions aimed at eliciting symptoms had a marked effect on the answers (Barker and Tarnopolsky, 1978). However, the differences in adverse health impacts between Variants 1 and 2 implied that results in Variant 1 with symptoms attributed to noise might represent focusing effects based on the knowledge of a respondent rather than on real noise effects.

In previous studies, the substantial questions on attitudinal and visual aspects of the WT in the same questionnaire implied the research topic to respondents. In this situation, the questions get the respondents to focus on WTN, and respondents might choose the item they thought was most relevant to the study. The usefulness of the two variants is a methodological finding, which is important to be noted.

Practical Implications of the Finding

The findings of this article can be utilized to guide the planning authorities to define suitable areas for the placement of WTs within the existing suburban contexts. From the perspective of noise management, urbanized landscapes are considered more suitable for one or two stand-alone modern WTs than rural landscapes with natural values. The separation distance for one or two WTs in urbanized areas is suggested to be at least 900 m. As in this study, 80% of the annoyed respondents were living within 850 m, and 90% were living within 900 m from the WT. From an architectural perspective, it is suggested to develop apartment buildings to attract younger and highly educated residents. Garden areas and bedroom windows are best to be at the quiet side of the building, opposite the WT. This can reduce the visibility of the turbine from both a window and the garden, which was found to be more annoying in this study. In addition, as negative attitudes were found to significantly influence subjective evaluations of WTN, public participation in an early stage of the planning might be useful, such as consultations and site visits that could change the adverse impression of a resident and build public trust.

Limitations and Future Works

The study had several limitations, which could be worthwhile for future work. One limitation related to the noise mapping was that the study only considered the WTN exposure in the worst case, such as in downwind conditions and with an 8 m/s wind velocity for the near-maximum noise output. Using one calculated SPL value to represent a certain situation might introduce inaccuracy, as the SPL could vary during the day and night due to atmospheric conditions. Future work can estimate an average level of SPL using the yearly statistics of wind speed, which might be more appropriate to predict the long-term noise annoyance.

Another limitation of this survey was, as with the previous cross-sectional studies, that establishing causality was difficult. It is worth noting that for this study, it was difficult to isolate the effect of the noise itself due to the high positive correlation between the increased noise and the decreased socioeconomic status. Although many socioeconomic characteristics were controlled for, the inter collinearity between factors might change the impact coefficient of noise. Future works could conduct longitudinal studies over some time to investigate the long-term noise effects on subjective well-being. Future studies could investigate the effects of more moderating factors including the possibility of accessing to quiet side and the visibility of green areas in an urban context.

CONCLUSION

Wind turbine noise exposure was positively associated with the self-reported noticeability and annoyance due to the noise. However, a higher level of noise seemed to generate less annoyance in urbanized areas of this study than that in rural areas, and the effects of personal factors could not be ignored. Annoyance due to WTN was found to be higher among older people and lower among those having higher education qualifications. Negative attitudes to the environmental impact of wind projects, judging them as dangerous, unnatural, and ugly, were positively associated with annoyance. Being able to see WT(s) from both a window and the garden/yard significantly increased the probability of being annoyed than those who could not see any from home.

This article found that WTN was associated with variations in some aspects of self-reported health, including raising health concerns, having headaches, nausea, and ear discomfort. It confirmed the findings of previous studies that sleep disturbance was not associated with noise levels directly but was related to noise annoyance and was moderated by age and long-standing illness.

This study established a method of employing a second variant of the questionnaire with the research aim masked to investigate the self-reported health symptoms and to reduce focusing bias. The main sample (Variant 1), who knew the research purpose, reported fewer health problems than the control group (Variant 2). A possible reason was that the questionnaire made these respondents focus on WTN and consider it as a source of ill health, which might induce the respondents to report symptoms based on their knowledge or assumptions of impacts and introduced focusing bias with over- or under-reported symptoms. It is suggested that future research could minimize the focusing bias by involving a control group with the research purposefully masked to differentiate the statistically modeled noise impact from the focusing impact of a respondent.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by School of Architecture at the University of Sheffield. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

FQ carried out the noise mapping, resident survey, data analysis, and writing of the manuscript. AT participated in the supervision of the questionnaire design and statistical analyses, and reviewed and corrected the manuscript. Both authors approved the final version of the manuscript.

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SUPPLEMENTARY MATERIAL

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ORIGINAL RESEARCH
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Combining Music and Indoor Spatial Factors Helps to Improve College Students' Emotion During Communication

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Against the background of weakening face-to-face social interaction, the mental health of college students deserves attention. There are few existing studies on the impact of audiovisual interaction on interactive behavior, especially emotional perception in specific spaces. This study aims to indicate whether the perception of one's music environment has influence on college students' emotion during communication in different indoor conditions including spatial function, visual and sound atmospheres, and interior furnishings. The three-dimensional pleasure–arousal–dominance (PAD) emotional model was used to evaluate the changes of emotions before and after communication. An acoustic environmental measurement was performed and the evaluations of emotion during communication was investigated by a questionnaire survey with 331 participants at six experimental sites [including a classroom (CR), a learning corridor (LC), a coffee shop (CS), a fast food restaurant (FFR), a dormitory (DT), and a living room(LR)], the following results were found: Firstly, the results in different functional spaces showed no significant effect of music on communication or emotional states during communication. Secondly, the average score of the musical evaluation was 1.09 higher in the warm-toned space compared to the cold-toned space. Thirdly, the differences in the effects of music on emotion during communication in different sound environments were significant and pleasure, arousal, and dominance could be efficiently enhanced by music in the quiet space. Fourthly, dominance was 0.63 higher in the minimally furnished space. Finally, we also investigated influence of social characteristics on the effect of music on communication in different indoor spaces, in terms of the intimacy level, the gender combination, and the group size. For instance, when there are more than two communicators in the dining space, pleasure and arousal can be efficiently enhanced by music. This study shows that combining the sound environment with spatial factors (for example, the visual and sound atmosphere) and the interior furnishings can be an effective design strategy for promoting social interaction in indoor spaces.

Keywords: social interaction, college students, audiovisual interaction, music, emotion during communication, pleasure-arousal-dominance emotional state model, spatial factors, social characteristics

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INTRODUCTION

There has been a weakening of social interaction among contemporary college students, many of whom prefer chatting online as opposed to face-to-face communication. According to The 47th China statistical report on Internet Development (2021), by December 2020, netizens aged 20–29 accounted for 17.8% of total users, and students accounted for the highest proportion in the occupational structure. College is a period characterized by dynamic development of the brain and strong interactions within the social environment. Students are vulnerable to a range of psychological problems; three-quarters of cases of four common mental disorders begin between the ages of 20 and 30 (Patel et al., 2007; Mirón et al., 2019). Research has shown that social anxiety is a significant and common issue for college students, given the growing range of academic and social stressors (Evans et al., 2018; Yang et al., 2019). Addiction to online networks can impair social activities, work/study, interpersonal relationships, and/or psychological health and well-being (Andreassen and Pallesen, 2014), and significant amounts of screen time correlate with both depression and anxiety (Lin et al., 2016; Rosenthal et al., 2021). As good interpersonal communication ability is one of the most important qualities of college students, the use of architectural design to improve communication spaces and promote interaction is of great significance. However, architectural methods of promoting communicative behavior have so far remained at the level of spatial design and have neglected the architectural sound environment.

Human actions, particularly in face-to-face encounters, invite responsive behaviors that include variations in wording, stress, volume, tone of voice, gesture, gaze, head movements, and even breathing patterns (Jensen and Pedersen, 2016). The social interaction model indicates that senders' displays of emotion provide powerful signals to receivers during interpersonal interactions, which people are hard-wired to pick up on and then rely on to guide their own behavior (Côté, 2005). Furthermore, interpersonal relationships can be fulfilled by emotions (Wubben et al., 2009). Authentic displays of some emotions – for instance, happiness – communicate an intention to affiliate and indicate that the individual is friendly and agreeable (Côté, 2005). The concept of emotional contagion (Hatfield et al., 1993) entails a ripple effect (also known as an imitation effect) of human interaction through conscious or unconscious induction of emotional states and behavioral attitudes (Hess and Blairy, 2001). For instance, negative emotions, especially anger, can often lead to violence (Umberson et al., 2003); conversely, regarding positive emotions, positive correlations have been found between the total amount of face-to-face interaction and the interlocutors' resulting mood (Ono et al., 2012). Communication is a fundamental part of social face-to-face interaction that can produce cooperation or coordination (Olguin et al., 2009). However, there is insufficient research focusing on how to balance emotions during communication in combination with the sound environment.

Previous studies have shown that emotion can be affected by environmental contexts (Li et al., 2012; Lazarus, 2014), including luminous, thermal, and acoustic factors. In terms of acoustic perception, the soundscape is defined as a sonic environment, with an emphasis on the way it is perceived and understood by individuals or by society (Brown et al., 2011). Evaluations of stimuli indicate that human emotions track changes in environmental sounds, especially in speech and music (Ma and Thompson, 2016). As a specific sound source, music has been found to be beneficial for rewards, motivation, pleasure, stress, arousal, immunity, and social affiliations (Juslin and Västfjäll, 2008; Chanda and Levitin, 2013). Evidence against a strict cognitivist position suggests that music can induce some sort of emotional response (Hunter and Schellenberg, 2010), which can be categorized as one of the nine common emotions of wonder, transcendence, tenderness, sadness, nostalgia, peacefulness, power, joy, and tension (Huron, 2011). Previous studies have found a modulation of the activities of the brain's core structures ascribed to emotion processing by music, involving the amygdala and the hippocampus, which are central elements in the network that process emotions such as happiness, anxiety, anger, and annoyance, as well as for assessing facial expressions and thereby contributing to communication, social behavior, and memory (Koelsch and Skouras, 2014; Hans-Eckhardt, 2017). For instance, music can lead to emotional contagion; happy music triggers the zygomatic muscle for smiling, together with an increase in skin conductance and breathing rate, whereas sad music activates the corrugator muscle (Koelsch, 2014). Despite these valuable findings, most research on music-evoked emotion has been conducted under laboratory conditions without taking into account the broader context, including spatial conditions and the physical environment. In addition, most studies have focused on the individual emotional state to the neglect of social interactions in specific patterns of behavior.

Being physically, emotionally, and psychologically aware of the space, we occupy is a feeling that can be described as being present. Jürgen Joedicke noted the need to take into consideration, the experience of space as well as spatial perception (Vasilski, 2016). Indoor space is the main site for human activities. Interaction between people and their located environment, like social interaction, is spontaneous and unavoidable, and the specific psychological emotions evoked by the physical and environmental attributes of personal interior space offer a highly interesting topic for research (Reddy et al., 2012). Interrelated elements of interior design, including spatial form, structure, light, texture, and color, as well as environmental factors such as lighting, sound, temperature, and humidity, affect spatial atmosphere and emotion (Reddy et al., 2012).

Taking spatial form as an example, a study of the impact of office design on absence rates has shown that stress levels and sick leave rates are higher in traditional open-plan offices than in cell-offices or combi-offices (Danielsson et al., 2014). Numerous studies have also examined the effects of light on emotion. For instance, the use in accent lighting of saturated blue and cyan colors with a color temperature of 5,000–5,500 K has been found to lead to the emotion of liveliness (Kim and Mansfield, 2021). In terms of color, red is likely to be stimulating because it increases blood pressure and heart rate (Manav, 2017).

Natural communication is dynamic in nature, hence the importance of investigating the audiovisual effects of space on social interaction (Boer et al., 2018). However, most studies of emotional perception have relied on the visual factors of spaces and ignored the combined sound environment.

Previous work in a classroom context analyzing the effects of music on conversational interaction has shown that, to a certain degree, musical sound has a masking effect on other noises and promotes communication in general (Jiang et al., 2019). Here, emotion during communication refers to changes in emotion following communication compared to the original emotional state before communication. The study utilizes the three-dimensional pleasure–arousal–dominance (PAD) emotional model to assess the emotions of participants through three dimensions of pleasure, arousal, and dominance before and after communication. The difference values (*d*-values) of pleasure, arousal, and dominance are used to reflect the changes in emotion during communication. To investigate differences in the effects of music on emotion during communication at different sites, this study sets out four hypotheses.

Hypothesis 1: is that the effects of music on emotion during communication vary in spaces with different functions.

Hypothesis 2: is that visual atmosphere influences the effects of music on emotion during communication.

Hypothesis 3: is that the sound atmosphere influences the effects of music on emotion during communication.

Hypothesis 4: is that interior furnishings serve as an influential spatial factor that moderate the effects of music on communication.

Hypothesis 5: is that the effects of music on emotion during communication differ when participants are subject to different social characteristics, including the intimacy level, gender combination, and group size.

METHODOLOGY

Experimental Site

There are two main kinds of emotion-related experiments: field experiments and laboratory experiments. On the basis of reliability and authenticity (Harrison, 2003), in this study, a field experiment was conducted in different sites, respectively, under the same musical environment. In terms of the selection of experimental sites, the location and time to confront people (especially strangers) can significantly influence the communication that takes place (Weisburd, 2021). In order to avoid any influence of familiarity with the space on communication (Krupa et al., 2018), indoor places frequently visited by students were chosen for this study. In line with common student activities, experimental sites were classified into learning, dining, and residential spaces based on spatial functions (Boukhechba et al., 2018). In order to explore the influence of qualities-related factors on emotion (Maheshwari et al., 2019), such as visual and sound atmospheres, as well as interior furnishings, six typical indoor communication spaces were chosen as the experimental sites and were compared one by one based on their functional classification: classroom (CR), learning corridor (LC), coffee shop (CS), fast food restaurant (FFR), dormitory (DT), and living room (LR). Indoor layouts of the experimental sites are shown in **Figures 1A–F**. LC here refers to a corridor containing a learning space as shown in **Figure 1**. Tables and chairs arranged in the learning space are used for students' daily reading and communication. And, it is worth mentioning that the learning space (CR, LC) discussed in this study is used for students' self-study (not teaching), including learning communication and chat.

In terms of behavior mode, the CR and LC are used for self-study, and typical behaviors in these areas include learning communication and daily chat; the CS is frequently visited by students for socializing and tea breaks; FFR is a popular location for dining; and the DT (four-person) and LR in residence halls comprise the main living areas for college students, wherein typical behaviors include rest, leisure, and socializing.

A thermal measurement instrument and illuminance meter were used to ensure that indoor temperature and illumination were within the comfort range, and therefore, not likely to influence emotion or performance (Altomonte, 2017; Petersen and Knudsen, 2017). In terms of thermal factors, related experimental results have shown that performance improves as the indoor temperature approaches 23°C (Nematchoua et al., 2019) and decreases when the temperature rises above 25°C (Niemelä et al., 2002). Therefore, the experiment time was set from 9 a.m. to 4 p.m. to maintain the indoor temperature at 23–25°C. In terms of luminous factors, previous studies have shown that illuminance and light color can affect fatigue and emotion (Carlucci et al., 2015). Preferred illuminance was therefore set in the range of 310–600 lux, and a neutral white (4,000 K) space was used (Bowers et al., 2010; Hidayetoglu et al., 2012; Yang and Moon, 2018). Since it was difficult to maintain the same illuminance on all six sites, neutral white (4,000 K) light was used to decrease the effects of the light environment, and lamps in the room maintained an average illuminance of 310–600 lux.

Sound level meters (BSWA801, BSWA, Beijing, China) were located at the measurement points shown in **Figure 1** and at a height of 1.2 m from the ground, and provided multiple measures of the background sound pressure level (SPL) at each of the six experimental sites for 5 min per hour from 9 a.m. to 4 p.m., with recordings every 5 s, which were A-weighted in the uncontrolled condition without subjects (Torija et al., 2012). In addition, because the experimental behavior was face-to-face communication, reverberation time (RT) was a significant factor influencing speech intelligibility (Yang and Hodgson, 2006), which may influence the quality of communication. Therefore, using the Eyring formula (Passero and Zannin, 2010), the RT of each experimental site was calculated, including the absorption coefficient, area, and amount.

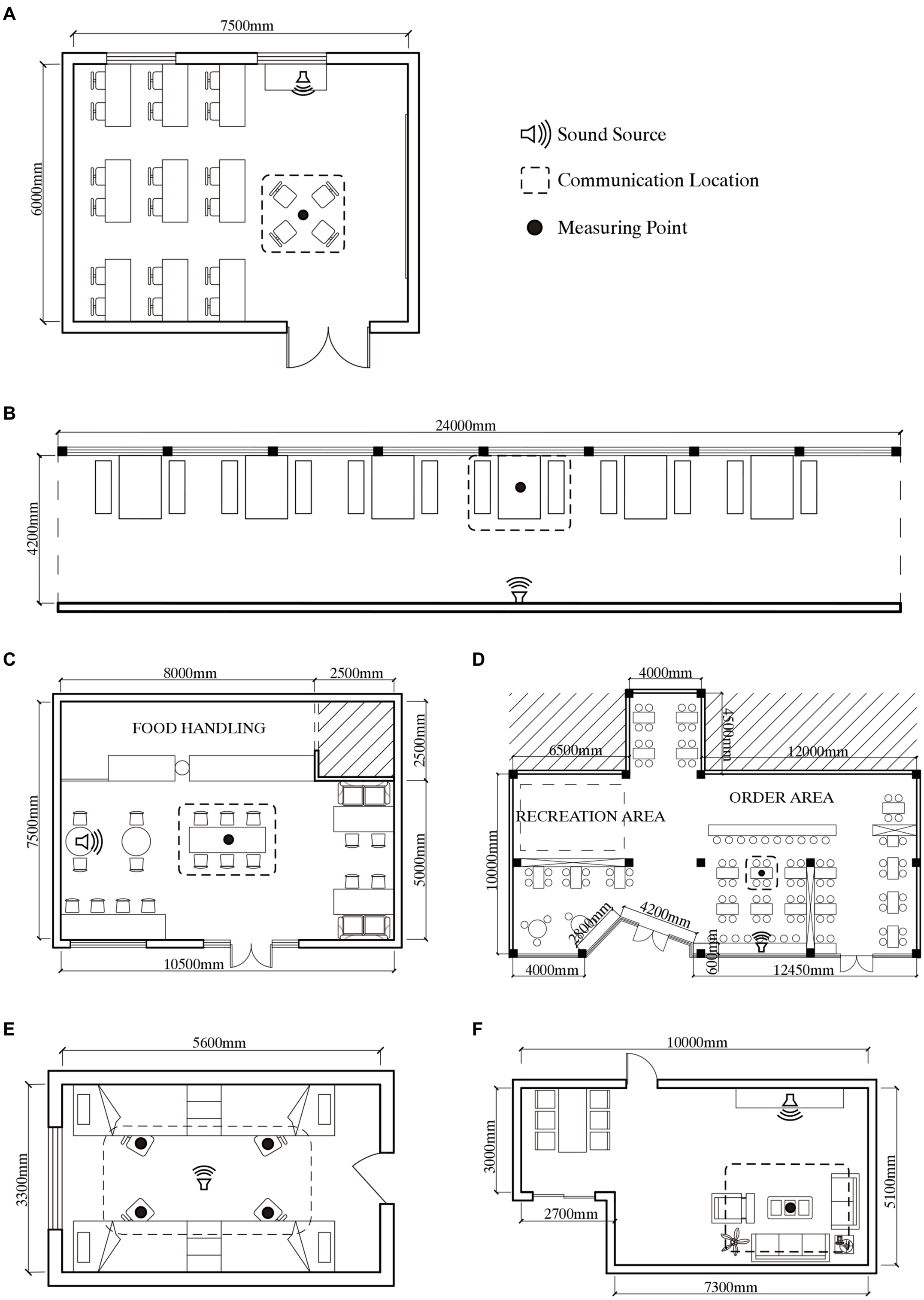

FIGURE 1 | Indoor layouts of the experimental sites: **(A)** CR, classroom; **(B)** LC, learning corridor; **(C)** CS, coffee shop; **(D)** FFR, fast food restaurant; **(E)** DT, dormitory; and **(F)** LR, living room.

The characteristics of the experimental sites, including scale, background SPL, RT, and behavior patterns, are shown in **Table 1**. The data show that the average A-weighted equivalent SPL for 5 min of background sound recording at the measurement point ranged from 32.5 to 63.2 dBA at the six sites, among which, under the same spatial function, the difference in SPL was largest (25.3 dBA) between the FFR and the CS. The sensitivity of the instrument was ±0.5 dBA. In addition, the average RT value at each site with 2–5 participants was provided.

Experimental Music

Previous research indicates that tempo, SPL, and musical emotions may also influence emotion (Hunter and Schellenberg, 2010); this phenomenon that has been assessed using behavioral, physiological, and neurological measures (Koneni, 2008). In terms of tempo, fast music can increase brain activity (Nicolaou et al., 2017). To avoid interference from the high arousal effect of music on the differences between spatial types, slow music was used in this study. Music with high SPL can also increase perceived activation and tension (Olsen et al., 2015). Excluding the FFR, the background SPLs of the other five sites were all below 40 dBA; in order to ensure the masking effect of music as well as the sound comfort (Jiang et al., 2019; Meng et al., 2020), an SPL of 50 dBA was adopted for the present study.

Musical emotional characteristics can be classified in terms of musical dimensions, such as pitch height, loudness, timbre, tempo, and intensity (Goshvarpour et al., 2017), and grouped into synonym clusters, such as happiness, sadness, fear, and neutral (Paquette et al., 2018). Related studies have shown that peacefulness is a complex emotion that overlaps with each quadrant of a circumplex model defined by the dimensions of arousal and valence (Hunter and Schellenberg, 2010) without clear emotional directivity. Thus, taking into account the evaluation of familiarity and liking by the college students (Meng et al., 2020), *A Comme Amour* (slow tempo, peaceful, 50 dBA, high degree of familiarity and liking) was chosen on the basis of restricted gene expression programming (Zhang and Sun, 2013) as the experimental music in this study. As the CR had the lowest background SPL of the six sites, the SPL of the experimental music was measured there. Under the condition with music, measurements were taken three times for 5 min each time, at 1-min intervals, with readings every 1 s, which were A-weighted (Crandell et al., 2004). Readings for the three times were averaged and recorded. To ensure the accuracy of the musical SPL, the volume of music was adjusted until the average reading of musical SPL reached 50 dBA (actual data 49.66 ± 0.5 dBA, denoted in what follows as 50 dBA).

Participants

In order to avoid the effect of identities and expectations on participants' satisfaction with communication, all participants were graduate students or undergraduate students of the university (Gudykunst and Shapiro, 1996). Further, to avoid potential confounding effects of formal training in music (Gabrielsson, 2002), all participants were non-music majors and had never undergone formal training in music. Before starting the experiment, participants were asked to maintain their emotional stability, obtain sufficient sleep, and follow the same routine as they would during the survey period, without any interference from other events such as exams or parties. To ensure adequate statistical power, G*Power (a general power analysis program) was used to analyze the minimum sample size of subjects, assuming an effect size of $d = 0.5$, $\alpha = 0.05$ and Power $(1-\beta) = 0.8$. To answer the main research question regarding the differences between different indoor spaces, the minimum average required sample size was 51 for the student's *t*-test (between-group) and 53 for one-way ANOVA (between-group) when there were three groups. Information about the participants is given in **Table 2**. Of students in the sample, 55 participated in the CR, 55 in the LC, 52 in the CS, 59 in the FFR, 54 in the DT, and 56 in the LR.

Emotional Model

Recognition and analysis of human emotions have been researched extensively in neuroscience, psychology, cognitive science, and computer science. Mainstream research on human emotion has focused on facial and vocal expressions (Gunes and Pantic, 2010). In terms of the models of perceived affective quality on soundscapes, Ma et al. (2018) illustrated the feasibility of the semantic differential method (SDM) for measuring human perceptions of sound. The quantitative measurements of the subjective meaning of things were obtained from the subjects' ratings on the bipolar adjective pairs (APs) formed by descriptors with two opposite meanings (Ma et al., 2018). The APs provided a general picture of human perceptions of the tested objects and facilitated comparison between the objects (Ma et al., 2018). Besides, Torresin et al. (2020) indicated that many of perceptional dimensions in complex acoustic environments (i.e., multiple sound types) could be coherently explained under Russel's circumplex model of affect. In order to indicate the audiovisual effects of music and spatial factors on emotion, an emotional model based on the SDM evaluation system describing emotional states was chosen in this study. The discrete emotional model and the dimensional emotion model are the most widely used models that can effectively express

TABLE 1 | Basic spatial and acoustic information of six experimental sites.

Experimental site	Indoor area (m^2)	Floor height (m)	Color scheme	Background SPL (dBA)	RT (s)	Behavior mode
CR	45	3.5	White, Wooden, and Gray	32.5	1.16	Learning, chatting
LC	100	3.0	White, Dark, and Gray	36.7	1.54	Learning, chatting, and walking
CS	72	3.0	White, Wooden, and Yellow	37.9	1.22	Dining, chatting, and dating
FFR	235	3.5	White, Wooden, and Red	63.2	1.41	Dining, chatting
DT	18	3.3	White, Wooden, and Blue	33.9	0.71	Sleeping, learning, and chatting
LR	45	2.8	White, Wooden, and Gray	35.6	0.91	Resting, chatting

TABLE 2 | Basic information on participants by experimental site.

Experimental site	Total sample size	Gender	Sample size	Mean age	SD of age
CR	55	Male	27	23.96	1.48
		Female	28	23.75	1.71
LC	55	Male	26	23.62	2.74
		Female	29	23.14	2.46
CS	52	Male	22	24.45	1.99
		Female	30	24.20	1.95
FFR	59	Male	24	24.54	3.79
		Female	35	24.14	2.56
DT	54	Male	27	24.48	1.83
		Female	27	24.70	0.95
LR	56	Male	25	24.56	1.53
		Female	31	24.48	1.41

and quantify emotion. The discrete emotion model applies emotional labels (e.g., happiness, sadness, surprise, fear, anger, and disgust), although, a single label may not reflect the complexity of the affective state conveyed by such rich sources of information (Gunes and Pantic, 2010). Instead of applying discrete categories of emotion, the dimensional emotional model analyzes and interprets the subtlety, complexity, and continuity of affective behavior in terms of latent dimensions (Havlena et al., 2010). Compared to a two-dimensional scheme – for example, arousal-valence space model of Thayer and Mcnally (1992) – the three-dimensional solution is more informative and helps to differentiate between what the cluster analysis suggests are separate basic-emotion categories (Shaver et al., 1987). Therefore, three-dimensional PAD emotional model of Mehrabian and Russell (1974) was selected for use in this study. The PAD emotional model consists of three APs, including pleasure–displeasure (P), arousal–nonarousal (A), and dominance–submissiveness (D), among which P is defined as positive vs. negative affective states, with higher evaluations of stimuli being associated with greater pleasure induced by the stimuli; A equates to judgments of high–low stimulus activity, which is defined in terms of the level of mental alertness and physical activity; and D is defined as a feeling of control and influence over one's surroundings and others vs. feeling controlled or influenced by situations and others (Mehrabian, 1996; Zhang et al., 2007). Gärling et al. (2020) proposed that self-reports on momentary states (e.g., "How do you feel right now?") in the context of emotional well-being are valid and reliable. In the current study, considering differences in the emotional states of the participants before the experiment, the PAD three-dimensional evaluation was conducted before and after the communication, respectively, and *d*-values of pleasure, arousal, and dominance were used to reflect changes in emotion during communication.

Questionnaire Design

A questionnaire was used to evaluate the participants' emotional state with a high level of reliability, because self-reports have been found to be an appropriate and natural method for studying emotional responses to music (Gabrielsson, 2002). The questionnaire consisted of four parts: basic information, overall music evaluation, overall spatial evaluation, and emotion during communication before and after the experiment (based on the three-dimensional PAD emotional model). The structure and descriptions of questionnaire are shown in **Table 3**; among them, overall musical evaluation represents the effect of music on communication and indicates participants' preference regarding the presence of music at different sites during communication. Overall spatial evaluation is composed of four spatial factors: spatial scale, perceived spatial color, sound atmosphere, and interior furnishings. Emotion during communication is evaluated from three dimensions: pleasure, arousal, and dominance. The *d*-values of pleasure, arousal, and dominance before and after the experiments are used to reflect the change in emotion during communication.

Experimental Design

In order to explore the effects of different spatial types on emotion during communication against a background of music, experiments were conducted in six typical indoor spaces. In terms of experimental means, random assignment, which has high internal validity (Morgan et al., 2000), was used to eliminate systematic differences between the treatment and control groups. Participants recruited on campus were allocated at random to groups of 2–5 people in each conversation. In addition, three levels of communicator intimacy were delineated, including stranger (all sites except DR and LR), acquaintance (all sites), and close friend (all sites). Because the background SPL was different at each of the six sites, to ensure a consistent musical environment, *A Comme Amour* (50 dBA) as measured in the classroom was played at the same volume at each of the six sites to ensure the sound pressure of the music was same at each indoor space. In terms of the duration of communication, previous studies have found 5 min to be appropriate for an analysis of communication using average and minimum chatting times (Yamaguchi et al., 2012). To avoid duration affecting people's focused attention and emotion during communication (Dong and Wyer, 2014), each communication period was limited to 5 min. The need for participants to communicate with strangers for 5 min was mentioned when recruiting the volunteers, so that we could ensure all of

TABLE 3 | The structure and descriptions of questionnaire.

The structure of questionnaire	Question	Description	
Basic information	Name, gender, age, intimacy level and group size.	Intimacy level (1 to 3): stranger (1), acquaintance (2), close friend (3) Group size (1/2): one-on-one (1), multi participants (2)	
Overall musical evaluation	How do you think the music influenced the communication? (21 points scale)	No effect (0): Music has no effect. Stimulating (1–10): Music is a little – very stimulating to communication. Distracting (−1 to −10): Music is a little – very distracting to communication. Distracting (−1 to −10): Music is a little— very distracting to communication.	
Overall spatial evaluation	Please evaluate the space you are located from four aspects. (either-or questions)	Spatial scale (1/2): small scale (1), large scale(2) Perceived spatial color (1/2): cold-toned (1), warm-toned (2) Sound atmosphere (1/2): quiet (1), noisy (2) Interior furnishings (1/2): minimal (1), abundant (2)	
Emotion during communication	Please describe your current emotional state from three aspects (P, A, and D) (10 points scale)	Pleasure (1–10):	Depressed to satisfied; Unhappy to happy; Restless to comfortable; Angry to content
		Arousal (1–10):	Peaceful to fevered; Unexcited to excited; Relaxed to stimulated; Drowsy to alert
		Dominance (1–10):	Passive to active; Controlled to uncontrolled

the participants showed a strong desire to conduct conversations with others, including strangers. In addition, participants' post-experiment feedback showed that interactions felt natural and fluent rather than artificial.

The flow chart of the experiment is shown in **Figure 2**. Following the random allocation, participants entered the experiment room and took around 2–3 min to get familiar with the experimental environment and the people they would talk to. Then, questionnaires were distributed, and participants were required to fill in their basic information according to the instructions in 2–3 min. Participants then began to communicate in the music environment, and continued chatting for 5 min until the music stopped. During the communication session, considering that participants were strangers, in order to avoid embarrassment several topics were provided for participants to discuss. Participants selected the conversation topics themselves and were then required to complete the questionnaires within 3 min, after which the experiment was deemed complete. In addition, some studies have indicated that food may facilitate communication (Dabbs and Janis, 1965; Blouin et al., 2013); therefore, snacks and nonalcoholic beverages were provided in this study.

Regarding the between-subjects design, in terms of spatial function CR, CS, and LR were chosen for comparison. Because the difference in indoor area of these three sites was within 27 m^2, the background SPLs were all below 40 dBA, and the colors of the spaces were all warm-toned, the effect of spatial scale and visual and sound environment was deemed minimal. In terms of visual atmosphere, the colors of the LC were cold-toned, which was different from the other spaces. Thus, in order to ensure consistency in the spatial function, CR and LC were chosen for comparison. In terms of sound atmosphere, excluding FFR, the background SPLs of the other five sites were all below 40 dBA; thus, in order explore the effect of sound atmosphere of the same functional spaces on communication, CS was chosen for comparison with FFR.

Statistical Methods

IBM SPSS statistics for Windows, version 23.0 (IBM Corp., Armonk, NY, United States) was used to analyze the relationship between the effects of music on communication and specific spatial factors. The Kolmogorov–Smirnov test was used to analyze the normality of the experimental data – that is, to confirm that the population followed a normal distribution hypothesis. Levene's test was used for equality of variance, and all variance was found to be equal. According to the number of treatments, ANOVA was used to test for significant differences in spaces with different functions (between-group). Independent *t*-tests were performed to assess differences between spaces with different visual and sound atmospheres and interior furnishings.

RESULTS

Spatial characteristics are expected to affect the use and feeling of a space, and even the emotions experienced during communication therein. This section presents the results of the analysis of the relationships between the spatial factors and the musical evaluations, average evaluation scores and *d*-values for PAD emotional evaluations in terms of spatial function, visual atmosphere, sound atmosphere, and interior furnishings.

Spatial Function

The experimental sites were sorted into three groups according to function (learning spaces, dining spaces, and residential spaces). CR, CS, and LR (all of which were quiet and had a similar indoor area) were chosen for comparison. The relationships between spatial functions and musical evaluations (no effect/stimulating/distracting) and the average scores for musical evaluations are shown in **Figure 3A**. The percentage who evaluated the music as stimulating to communication

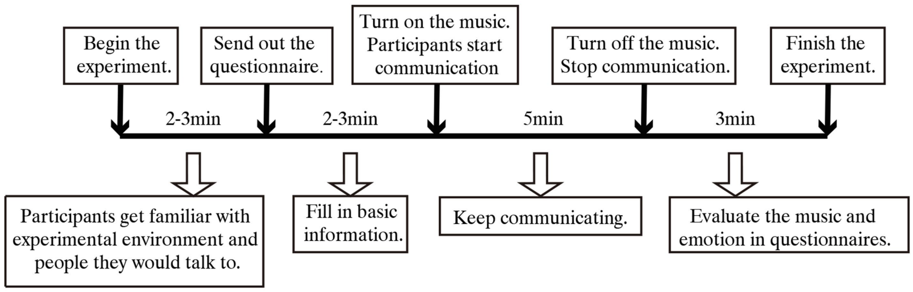

FIGURE 2 | Experimental procedure.

ranged from 52 to 64% and was highest in the residential space. The percentage evaluating the music as distracting ranged from 7 to 20% and was highest in the learning space. Average scores for musical evaluation were highest in the residential space (2.91), followed by the dining space, and then the learning space (1.47). Based on the three kinds of spatial functions, the results of the ANOVA show that there was no significant difference in musical evaluation among spaces of different functions ($df1 = 2$, $df2 = 162$, $F = 2.225$, $p = 0.111$, $d = 0.26$).

The average *d*-values for the PAD emotional evaluations in spaces of different functions are shown in **Figure 3B**. Pleasure, arousal, and dominance increased to varying degrees, and the *d*-values of pleasure and dominance were similar across the three spaces. Pleasure increased from 0.26 to 0.39 and was highest in the residential space, whereas dominance increased from 0.64 to 0.78 and was highest in the dining space. The *d*-value for arousal was lowest in the learning space (0.53). The results of the ANOVA show that there were no significant effects of different spatial functions on pleasure ($df1 = 2$, $df2 = 162$, $F = 0.061$, $p = 0.941$, $d = 0.05$), arousal ($df1 = 2$, $df2 = 162$, $F = 1.309$, $p = 0.273$, $d = 0.27$), or dominance ($df1 = 2$, $df2 = 162$, $F = 0.070$, $p = 0.933$, $d = 0.05$).

Visual Atmosphere

In accordance with subjective evaluations of perceived space color, the experimental sites were grouped into cold-toned spaces and warm-toned spaces. CR and LC (which were both quiet and of learning function but had a clear difference in color evaluation) were chosen for comparison. The relationships between visual atmosphere and percentages for the musical evaluations (no effect/stimulating/distracting) and the average scores for the musical evaluations are shown in **Figure 4A**. The percentage who evaluated the music as stimulating was higher in the warm-toned space (71%) than in the cold-toned space (58%), and the converse applied to the proportion who evaluated the music as distracting. Average scores for musical evaluation were much higher in the warm-toned space ($M = 3.16$, $SD = 2.214$) than in the cold-toned space ($M = 1.51$, $SD = 3.894$). The results of the *t*-test showed that there was a significant effect of visual atmosphere on musical evaluation ($t = -2.534$, $df = 108$, $p < 0.05$, $d = 0.50$).

The average *d*-values for PAD emotional evaluations in spaces with different visual atmospheres are shown in **Figure 4B**. Pleasure, arousal, and dominance all increased to varying degrees. The *d*-values for arousal and dominance were 0.13–0.20 higher in the cold-toned space than in the warm-toned space, while the *d*-value of pleasure in the warm-toned space ($M = 0.72$, $SD = 1.278$) was higher than in the cold-toned space ($M = 0.31$, $SD = 2.284$). The results of the *t*-test showed that visual atmosphere did not have a significant effect on pleasure ($df = 108$, $t = -1.066$, $p = 0.289$, $d = 0.21$), arousal ($df = 108$, $t = 0.285$, $p = 0.776$, $d = 0.06$), or dominance ($df = 108$, $t = 0.508$, $p = 0.613$, $d = 0.10$).

Sound Atmosphere

In accordance with subjective evaluation of background sound under the uncontrolled condition, the experimental sites were sorted into quiet spaces and noisy spaces. FFR and CS (which had the same spatial function but a clear difference in sound atmosphere evaluation) were chosen for comparison. The relationships between sound atmosphere and percentages for musical evaluations (no effect/stimulating/distracting) and average scores for musical evaluations are shown in **Figure 5A**. The percentage of evaluations that rated the music as having a stimulating effect was much higher in the quiet space (50%) than in the noisy space (26%). The proportion of evaluations that rated the music as having no effect on communication was similar in two spaces (ranging from 7 to 11%). It was noticeable that a substantial proportion of communicators (63%) in noisy spaces thought that the music had no effect on communication. Average scores for musical evaluation were higher in the quiet space ($M = 1.91$, $SD = 2.896$) than in the noisy space ($M = 0.82$, $SD = 3.402$). The results of the *t*-test showed that there was no significant effect of sound atmosphere on musical evaluation ($t = -1.801$, $df = 109$, $p = 0.074 < 0.1$, $d = 0.34$).

The average *d*-values for PAD emotional evaluations in spaces with different sound atmospheres are shown in **Figure 5B**. The *d*-values for pleasure, arousal, and dominance increased by 0.26 ($SD = 2.130$), 1.07 ($SD = 1.725$), and 0.78 ($SD = 1.910$) in quiet spaces, but decreased by 0.72 ($SD = 2.085$), 0.04 ($SD = 1.870$), and 0.23 ($SD = 1.536$) in noisy spaces. The results of the *t*-test showed that there was a significant effect of music on pleasure ($t = 2.446$, $df = 109$, $p < 0.05$, $d = 0.46$), arousal ($t = 3.243$, $df = 109$, $p < 0.01$, $d = 0.62$), and dominance ($t = 3.066$, $df = 109$,

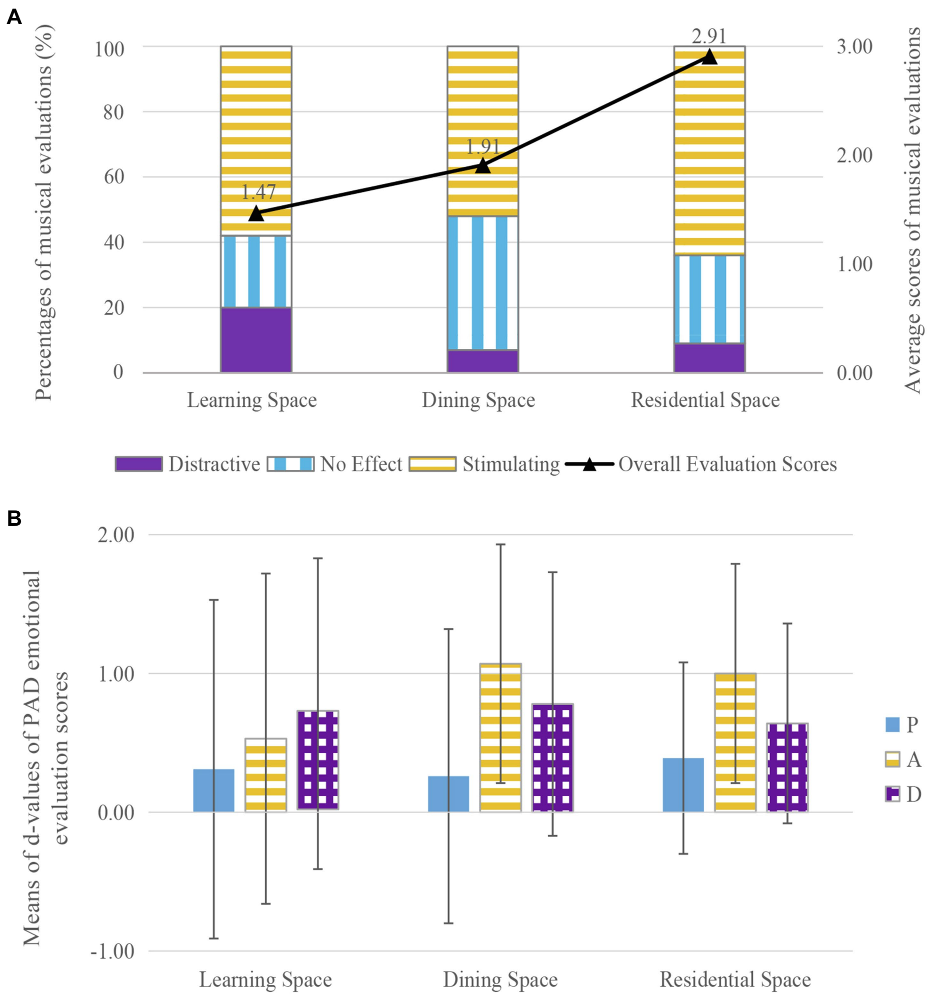

FIGURE 3 | The effects of music on communication in spaces with different functions: **(A)** the effects of music on musical evaluation, **(B)** the effects of music on pleasure–arousal–dominance (PAD) emotional evaluation.

$p < 0.01$, $d = 0.58$) in spaces with different sound atmospheres. These findings indicate that music can be effective in enhancing pleasure, arousal, and dominance during communication in quiet spaces.

Interior Furnishings

Diversity of furniture is one of the main factors to evaluate the interior furnishings (Kaye and Murray, 1982). In this study, the experimental sites were sorted into minimal spaces (within three) and abundant spaces (more than three) in terms of the number of furniture types. DT and LR which had the same spatial function and visual and sound atmospheres but a clear difference in interior furnishings were chosen for comparison. The relationships between interior furnishings and the percentages for musical evaluations (no effect/stimulating/distracting) and the average scores for musical evaluations are shown in **Figure 6A**. The proportion of evaluations that rated the music as stimulating and as distracting were similar in the two groups (from 50 to 59% and from 9 to 13%, respectively). The percentage of evaluations that rated the music as having no effect was higher in the abundant space (41%) than in the minimal space (28%). Average scores for musical evaluation were slightly higher in the abundant space ($M = 2.81$, $SD = 3.693$) than in the minimal space ($M = 2.59$, $SD = 3.853$). The results of the *t*-test showed that there was no significant effect of interior furnishings on musical evaluation ($t = -0.279$, $df = 108$, $p = 0.781$, $d = 0.06$).

The average *d*-values for PAD emotional evaluations in spaces with different interior furnishings are shown in **Figure 6B**. The *d*-values for pleasure and arousal were similar in the minimal space and abundant spaces, increasing by 0.40 ($SD = 1.515$), 0.44 ($SD = 1.703$), 0.86 ($SD = 1.673$), and 0.81 ($SD = 2.086$), respectively. The *d*-value for dominance was higher in the minimal space ($M = 0.76$, $SD = 1.379$) than in abundant spaces ($M = 0.13$, $SD = 1.185$). The results of the *t*-test showed that there was a significant effect of music on dominance in spaces with different interior furnishings ($t = 2.268$, $df = 108$,

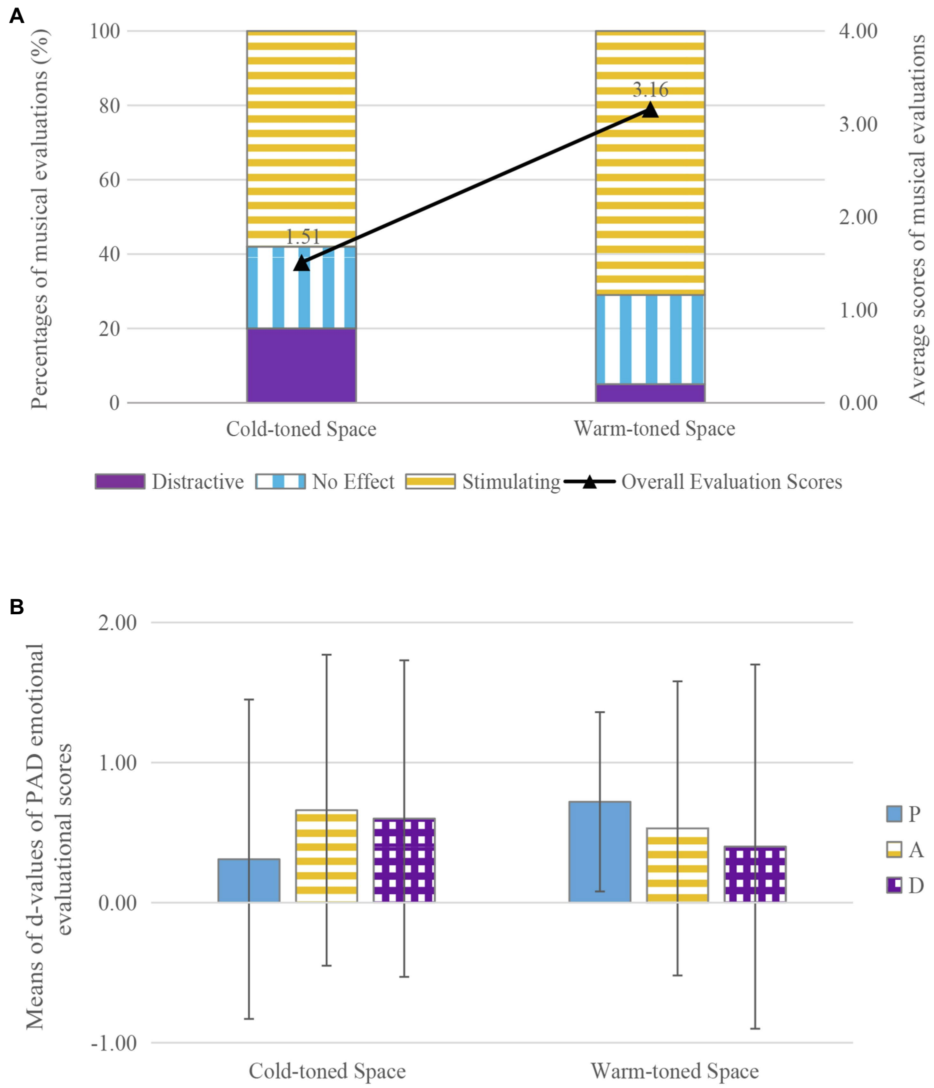

FIGURE 4 | The effects of music on communication in spaces with different visual atmospheres: **(A)** the effects of music on musical evaluation, **(B)** the effects of music on PAD emotional evaluation

$p < 0.05$, $d = 0.48$). This finding indicates that the positive effect of music on dominance during communication was significant in the minimal space.

Social Characteristics

Studies have found that social characteristics such as gender, age, and situation can lead to different emotion evaluations (Gabrielsson, 2002; Hunter et al., 2011; Schubert, 2013). In accordance with the behavioral mode of communication, this study analyzed the effects of music on participants with different intimacy levels, in different gender combinations and in groups of different sizes during communication. Based on the number of treatments, ANOVA was used to test for significant differences in the various intimacy levels (stranger, acquaintance, and close friend) of participants (Starzyk et al., 2006). Independent *t*-tests were performed to assess differences between different gender combinations and number of participants. The average scores of musical evaluation and the *d*-values of PAD emotional evaluation were summarized, and the SD was identified *via* *t*-tests. The results are shown in **Table 4**.

The effects of music on communication varied in different functional indoor spaces when participants were with different social characteristics, such as intimacy level, gender combination, and group size of communicators.

In the learning space, there was a significant effect of music on dominance during communication in different gender combinations. The results of the *t*-tests showed that in comparison to mixed-gender groups ($M = -0.02$, $SD = 1.737$), dominance ($t = 3.347$, $df = 108$, $p < 0.01$, $d = 0.64$) was enhanced by music in single-gender groups ($M = 1.23$, $SD = 2.179$).

In the dining space, compared to the intimacy levels of acquaintances and close friends, the average scores for musical

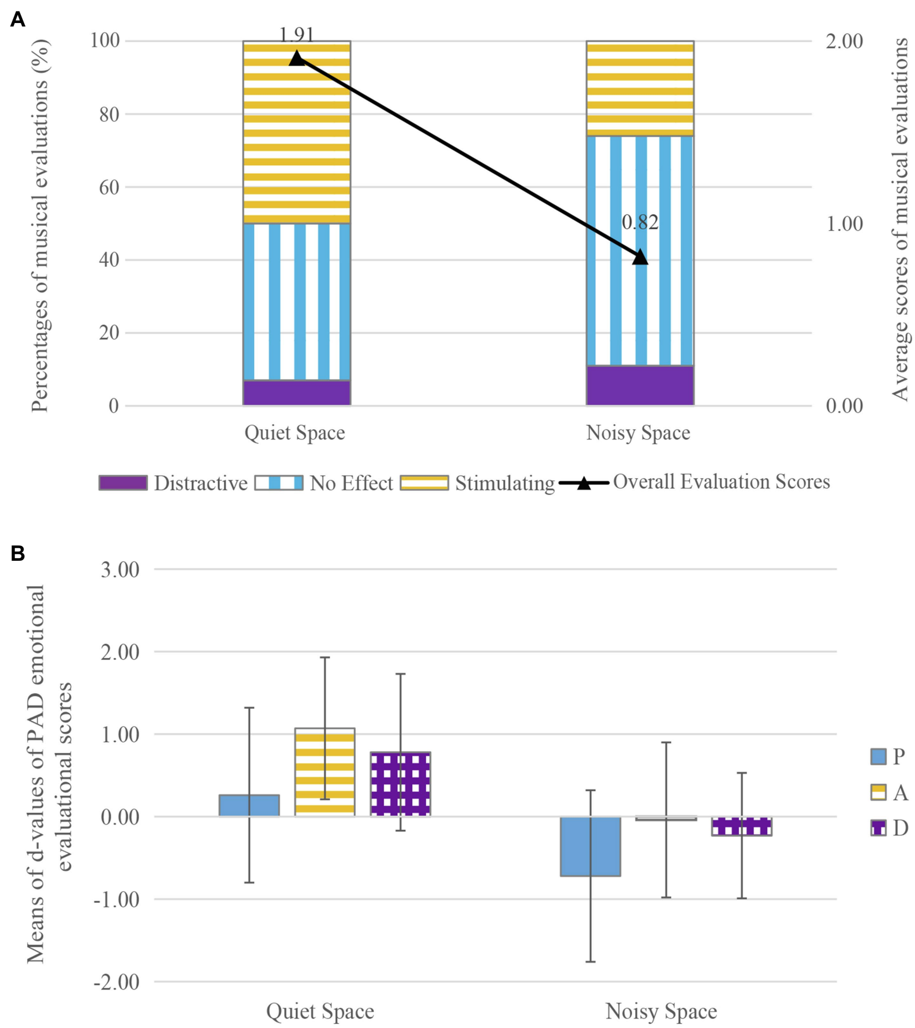

FIGURE 5 | The effects of music on communication in spaces with different sound atmospheres: **(A)** the effects of music on musical evaluation, **(B)** the effects of music on PAD emotional evaluation.

evaluation were 1.54–2.03 higher in the group of strangers. The results of the ANOVA indicated that communication was promoted to some extent when participants were strangers ($df1 = 2$, $df2 = 108$, $F = 2.639$, $p = 0.076 < 0.1$, $d = 0.28$), meanwhile, *d*-values of pleasure ($df1 = 2$, $df2 = 108$, $F = 2.541$, $p = 0.083 < 0.1$, $d = 0.48$) and arousal ($df1 = 2$, $df2 = 108$, $F = 2.369$, $p = 0.098 < 0.1$, $d = 0.49$) were higher in the stranger group. Further, all of the musical evaluation scores and *d*-values for emotional evaluations were higher when there were more than two participants, and the results of the *t*-tests show that there was an significant effect of music on pleasure ($t = -2.008$, $df = 109$, $p < 0.05$, $d = 0.38$) and arousal ($t = -2.412$, $df = 109$, $p < 0.05$, $d = 0.46$).

In the residential space, the average scores for musical evaluation were 2.66 higher in acquaintances compared to close friends. The results of the *t*-tests show that there was a significant effect of music on communication ($t = 3.448$, $df = 108$, $p < 0.01$, $d = 0.72$), and pleasure ($t = -2.008$, $df = 108$, $p < 0.05$, $d = 0.52$) and dominance ($t = -2.412$, $df = 108$, $p < 0.01$, $d = 0.67$) were efficiently enhanced by music in the group of acquaintances.

Therefore, in terms of social characteristics, there is evidence that when in the learning space, using music to promote communication is more suitable for single-gender groups. And when there are more than two communicators in the dining space, pleasure and arousal can be efficiently enhanced by music. In the residential space, when the intimacy level of roommates is not that close, music environment can be an effective way to promote communication.

DISCUSSION

This paper contributes to the body of research into the effects of audiovisual interaction on social interaction by comparing the effects of music on communication in different spaces in terms of function, visual atmosphere, sound atmosphere, and

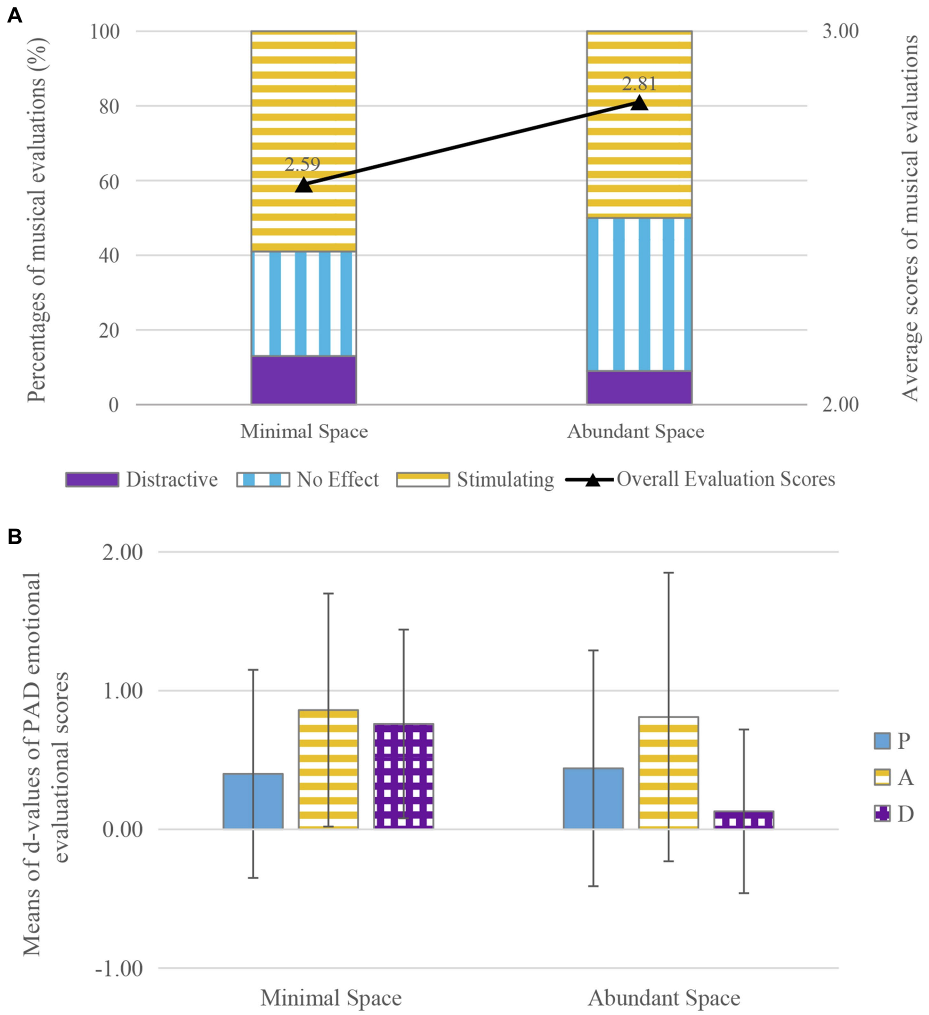

FIGURE 6 | The effects of music on communication in spaces with different indoor furnishings: **(A)** the effects of music on musical evaluation, **(B)** the effects of music on PAD emotional evaluation.

interior furnishings. In terms of spatial function, people have particular behavioral patterns in specific functional spaces (for instance, eating meals in a restaurant, or resting in a bedroom). In this study, spaces for learning, dining, and resting were chosen in accordance with the main activities of college students.

The results were inconsistent with Hypothesis 1; there were no significant differences between the effects of music on communication or emotion during communication in spaces with different functions. Post-experiment interview suggested that this result is to some extent attributable to the fact that chatting is a common behavior pattern in all the spaces, regardless of their primary function, and thus all the sites were suitable for communication. Compared to spatial function, the degree of privacy offered by a space may have a more significant effect on communication. Numerous studies have explored the need for privacy and intelligibility of speech in different spaces, such as open-plan offices, hospitals, and residences (Cavanaugh and Hirtle, 2006; Virjonen et al., 2007; Roy, 2017), finding that people's satisfaction is closely related to speech privacy. To date, most studies have focused on the analysis of emotional feelings in specific spaces, with little horizontal comparison across different functional spaces. Thus, the results of this part of the present study provide a point of reference for future research.

For Hypothesis 2 on visual atmosphere, the results show that music had greater effects on communication in the warm-toned spaces than in the cold-toned spaces. However, there were no significant differences in the effects of music on pleasure, arousal, or dominance in spaces with different visual atmospheres. The effect size of the PAD emotional evaluations did not seem to match the overall effects of music on communication. Previous studies indicate that experiences of color have their roots in conscious, subconscious, and unconscious processes of human behaviors (Reddy et al., 2012) and that the effect of music on emotional intervention plays a dominant role, followed by color (Li et al., 2018).

TABLE 4 | Musical and emotional evaluations in terms of social characteristics.

Site	Statistical test	Social characteristic		Musical evaluation	D-values for emotional evaluation		
					Pleasure	Arousal	Dominance
Learning space	ANOVA	Intimacy level	Stranger	2.03	0.93	0.67	0.60
			Acquaintance	2.06	0.66	0.28	0.72
			Close friend	2.29	0.06	0.79	0.33
	t-test	Gender combination	Single gender	1.83 (SD = 3.679)	0.57 (SD = 1.839)	0.53 (SD = 2.052)	1.23 (SD = 2.179)
			Mixed gender	2.40 (SD = 3.231)	0.40 (SD = 2.052)	0.67 (SD = 2.155)	−0.02 (SD = 1.737)
		Group size	One-on-one	2.13 (SD = 3.553)	0.34 (SD = 1.873)	0.53 (SD = 2.276)	0.49 (SD = 2.062)
			Multi participants	2.26 (SD = 2.958)	0.96 (SD = 2.225)	0.91 (SD = 1.756)	0.61 (SD = 1.924)
Dining space	ANOVA	Intimacy level	Stranger	2.71	0.29	0.81	0.86
			Acquaintance	0.68	−1.04	−0.20	0.08
			Close friend	1.17	−0.11	0.68	0.14
	t-test	Gender combination	Single gender	1.02 (SD = 3.514)	−0.09 (SD = 2.003)	0.45 (SD = 1.768)	0.13 (SD = 1.585)
			Mixed gender	1.69 (SD = 2.834)	−0.40 (SD = 2.306)	0.56 (SD = 1.998)	0.40 (SD = 1.987)
		Group size	One-on-one	1.22 (SD = 3.037)	−0.62 (SD = 1.941)	0.12 (SD = 1.767)	0.02 (SD = 1.600)
			Multi participants	1.51 (SD = 3.402)	0.20 (SD = 2.324)	0.96 (SD = 1.918)	0.55 (SD = 1.973)
Residential space	*t*-test	Intimacy level	Acquaintance	3.97 (SD = 3.551)	0.97 (SD = 1.204)	1.00 (SD = 1.901)	1.22 (SD = 1.237)
			Close friend	1.31 (SD = 3.725)	0.18 (SD = 1.642)	0.78 (SD = 1.755)	0.37 (SD = 1.270)
		Gender combination	Single gender	2.08 (SD = 3.908)	0.44 (SD = 1.609)	0.92 (SD = 1.837)	0.60 (SD = 1.357)
			Mixed gender	2.11 (SD = 3.408)	0.11 (SD = 0.928)	0.00 (SD = 0.866)	0.78 (SD = 0.667)
		Group size	One-on-one	1.32 (SD = 3.913)	0.88 (SD = 1.509)	1.28 (SD = 1.768)	0.68 (SD = 1.435)
			Multi participants	2.31 (SD = 3.833)	0.27 (SD = 1.561)	0.72 (SD = 1.790)	0.60 (SD = 1.284)

The present results may be due to the fact that music has a greater effect on emotion than color does. Against a given musical background, it may be difficult for participants to distinguish differences in the emotion during communication in spaces with different visual atmospheres, and it is likely that the complex influence mechanism of color on emotion cannot be expressed simply in terms of a three-dimensional emotion model.

In terms of sound atmosphere, the subject of Hypothesis 3, the results indicate that communication can be enhanced by music in the quiet space to some degree, although, most of the communicators thought that there was almost no effect of music on communication in the noisy space. In the presence of music during communication, pleasure, arousal, and dominance all increased in the quiet space but decreased in the noisy space. These results are in line with previous research, which found that music plus ambient noise at comfortable levels of volume increases dining pleasure, while no music or a sound environment with music that is too loud has negative effects (Novak et al., 2010). It is worth noting that noise has both negative and positive aspects, and the absence of negative sound does not necessarily create a positive environment (Iyendo, 2016). Torresin et al. (2019) conducted a systematic review of positive indoor soundscapes; among their findings, specific sound types (i.e., natural sounds and sounds from residential areas) were found to reduce annoyance caused by disturbing tonal noises. Likewise, research exploring the acoustic environment of nursing homes showed that an environment that is rich and varied in sound sources tends to perform better in terms of safety and intimacy, as well as appropriateness, compared to monotonous and uneventful soundscapes (Aletta et al., 2017). Furthermore, the results of previous research have shown that musical evaluation during communication decreases sharply (from 1.31 to −2.13) when SPL exceeds 50 dBA, becoming negative when SPL reaches 60 dBA (Meng et al., 2020). Therefore, neither playing music at an appropriate volume in a noisy space nor playing it at over 60 dBA in a quiet space is likely to improve the quality of communication.

For the evaluations in regarding minimal and abundant interior furnishings, the subject of Hypothesis 4, the results indicate that there were no significant differences between the effects of music on communication in spaces that had been furnished differently, but that music can enhance dominance during communication in the minimally furnished space. This finding may be due to the fact that complicated furnishings can distract people's attention. A related study of the effects of commercial spatial factors on shopping behavior drew a similar conclusion; a complex grocery store environment was associated with low levels of pleasantness, delays in purchasing or even departures, as high levels of complexity can produce avoidance behaviors (Gilboa and Rafaeli, 2003). Differences in the arrangement as well as the density of furniture have been studied, showing that manipulation of furniture density may nullify the effects of arrangement; that is, with increasing density there is a corresponding decrease in distance between chairs, which is associated, up to a point, with increasing intimacy and friendliness (Kaye and Murray, 1982).

Communicators in the same seats had different spatial perceptions of scale that bore no clear relation to the indoor area. Take, for example, the learning corridor, which 53% of participants thought of as a large-scale space, whereas 47% held the opposite view. According to post-experiment interviews, the ratio of the length and width of a space, the density of crowds and furniture, and the enclosure mode of a space all affect the perception of spatial scale.

For Hypothesis 5, which focused on social characteristics, the results indicate that music had a different effect on communication when participants diverged in their intimacy levels, gender combinations and group size in different indoor spaces. In terms of intimacy level, the results showed the potential of music to strengthen social bonds in residential spaces. Compared to close friends, there was significant effect of music on acquaintances during communication, pleasure and dominance were effectively enhanced by music. Consistent with Hypothesis 5, Bronwyn et al. (2014) revealed the mechanism by which music enhances social bonds, indicating that listening to music facilitates endorphin release, which plays a central role in the maintenance of non-sexual, non-kinship social bonds. In this vein, roommate conflict is a key social problem in college (Sillars, 1980), and effective communication can enhance relationships among roommates (Wang et al., 2012). Music can thus be seen as an effective way to ease dormitory conflict when roommates have a low intimacy level.

In terms of gender combination, the results indicate that dominance during communication was significantly enhanced by music for single-gender groups in the learning spaces. Numerous studies have explored the effects of gender composition on social interactions such as cooperation, group discussion, and group learning among children (Smith-Lovin, 1989; Ausch, 1994; Willoughby et al., 2009). For example, with respect to group learning, more collaborative behaviors have been found in mixed-gender than in single-gender groups (Willoughby et al., 2009). Considering these findings in combination of the *d*-values of dominance in the learning spaces shown in **Table 4**, music can be considered an effective strategy to enhance dominance within single-gender groups, and to reduce differences in groups with gender combinations, during communication.

In terms of group size, the results show that music had greater effects on pleasure and arousal during communication when there were more than two participants in the dining spaces. A study of the effects of dining style on communication in restaurants indicated that when there were four or more diners per table, conversation increased compared to when there were fewer people, and frequency of conversation in centralized style (diners sharing a dish, such as a hot pot) was higher than in the separate (diners do not share dishes with others but eat their own food) with background music (Meng et al., 2017). Therefore, further confirmation of the most appropriate group size for communication in dining spaces is needed; in addition, dining style should be considered.

SUMMARY AND CONCLUSION

Under the comprehensive pressures of academic and daily life, social anxiety is a widespread problem among college students, a particularly vulnerable group. Reliance on the Internet is an important factor in mental health, and the identification of ways to ease social barriers and to promote face-to-face communication is an important area of research. Using objective measurements of the natural sound environment and a subjective questionnaire survey of musical evaluations and PAD emotional evaluations during communication, this study examined the influence of music on emotion during communication in different indoor spaces and reached a number of conclusions. First, there were no significant differences in musical or emotional evaluation during communication in different functional spaces. Second, the positive effects of music were higher in warm-toned spaces, whereas the differences in the effects of music on emotion during communication in spaces with different visual atmospheres were not significant. Third, music had a significant effect on both musical evaluation and emotion during communication in spaces with different sound atmospheres, indicating that it can promote communication in quiet spaces. Fourth, in terms of interior furnishings, music in simply furnished spaces can enhance dominance. The effects of music on dominance were also higher in single-gender groups than in mixed-gender groups.

LIMITATIONS

The present study can help improve communication by regulating spatial factors with music in terms of visual atmosphere, sound atmosphere, and interior furnishings. However, the study has a number of limitations which indicate that certain questions need to be discussed further.

There are rich varieties of musical emotions, and musical emotion characteristics can be classified based on musical dimensions such as pitch height, loudness, timbre, tempo, and intensity (Wieczorkowska et al., 2006). For example, Hevner (1936) presented eight synonym clusters to describe emotional perceptions of music, including happiness, gracefulness, sereneness, dreaminess, sadness, dignity, vigorousness, and excitement. The level of emotional perception of music varies with regard to different musical emotions (Baumgartner et al., 2006), and the emotion evoked by music is not always consistent with the perceived emotion (Gabrielsson, 2002). However, only one excerpt of peaceful music was used in the given experimental settings, and future research should seek to combine a wider range of music with different types of spaces.

In terms of the selection of experimental sites, limitations in terms of being able to control variables when comparing two spaces might have caused the results to be confounded by uncontrolled factors. In addition to the variables listed in this research, the spatial scale, dynamism, and indoor partitions are key factors of spatial perceptions and thus impact emotions (Hogg et al., 2011; Maheshwari et al., 2019). For instance, small rooms are considered more pleasant, calmer, and safer than large rooms (Tajadura-Jiménez et al., 2010). Regarding the visual atmosphere, the colors of the spaces were simply divided into warm-toned and cold-toned, while color harmony, as well as saturation and brightness, of color also impact emotion (Shen et al., 2015). In order to minimize the effects of uncontrolled spatial factors, virtual reality (VR) technology that provides a realistic and immersive environment (Chamilothori et al., 2019) can be considered for use in further studies.

Emotions are internal and mostly conscious, and self-report is an accepted way to evaluate them (Bradley and Lang, 1994). However, individuals have no direct access to the causal connections between external forces and internal responses – they are simply limited in their ability to track the complex causal story of their emotions (Russell, 2003). In addition, self-reports frequently refer to a certain period experienced in the past, and usually only salient single moments of the episode overall are emphasized (Fredrickson and Kahneman, 1993; Fiebig et al., 2020); thus, retrospective biases also need to be taken into account (Robinson and Clore, 2002). As the results of this study are based on self-reports, future studies should collect data regarding physiological changes to support the above findings.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available from the corresponding author upon reasonable request.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by ethics committee, School of Architecture, Harbin Institute of Technology. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

JJiang participated in the investigation, data curation, and writing of the original draft. QM provided conceptualization and participated in writing and editing the manuscript and in funding acquisition. JJi participated in the methodology, validation, and formal analysis. All authors contributed to the article and approved the submitted version.

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Research on Acoustic Environment in the Building of Nursing Homes Based on Sound Preference of the Elderly People: A Case Study in Harbin, China

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Nursing homes are the facilities where the elderly conduct their daily activities. This may lead to a complicated acoustic environment which would potentially affect the ability of the elderly to function. In this study, the main indoor public space of a nursing home in Harbin was taken as the research object, and the methods of field observation, sound measurement, and questionnaire survey were used to explore the sound perception and preference of the elderly. The results revealed that in terms of the temporal and spatial distribution of sound pressure level (SPL), the unit living space had the highest SPL, which was above 60 dB (A). The reverberation time (RT) of the unit living space, medical and health care center corridor, was 2.15 and 2.13 s, respectively, at a frequency of 1,000 Hz, which was within the discomfort range. The results also revealed that an acoustic environment had a strong correlation with humidity and a weak correlation with temperature. However, no significant correlation could be assessed with a luminous environment. The elderly people were generally willing to accept the natural sound sources. The factors of gender and offspring numbers had no significant impact on the evaluation of acoustic environment comfort, whereas marriage and income status affected the comfort. This study may help improve the quality of life of the elderly in the nursing home and provide a reference for the construction and design of pension facilities.

Keywords: acoustic environment, nursing home, elderly's sound perception, elderly's sound preference, acoustic evaluation

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INTRODUCTION

The acoustic environment of care facilities for older adults is garnering widespread scrutiny from both researchers and practitioners due to increasing awareness of geriatric issues and challenges in society. Nursing homes have very peculiar functional patterns, both in terms of space use and daily routines (e.g., recurring activities and sound sources). Each nursing home possesses unique traits and experiences a continuously changing group of users (high turnovers), both in terms of residents and staff members. Assessing the acoustic environments of these facilities might require a multifaceted and more articulate approach than what is commonly deployed for other functional buildings, and tailored solutions will possibly have to be devised for better soundscapes and acoustic environments. The sound environment of nursing facilities affects the physical health of the elderly, such as sleep quality, and also affects their mental health. Studies have shown that different types of elderly people possess different auditory preferences. The elderly with hearing impairment sometimes need greater sound stimulation, and the elderly with a certain amount of cerebellar atrophy is easily averted by noise (Aletta et al., 2017). Therefore, nursing facilities have more stringent acoustic environment requirements than general buildings. It is of great significance to study the acoustic preference characteristics of the elderly in nursing facilities and improve the acoustic environment quality of nursing facilities. Previous studies have focused both on the perception (Kang, 2004; Meng and Kang, 2016) and physical aspects of the acoustic environment of such spaces (Aletta et al., 2017, 2018a; Devos et al., 2018). However, most studies were restrained to the analysis of the optimization of the sound environment in nursing homes or the perception of the sound environment by the elderly. However, the reasons for the difference in acoustic perception among the elderly in the same acoustic environment remain unclear. Little research has been conducted on the influence of individual background differences on the sound perception of the elderly in specific acoustic environments.

Pieter Thomas et al. have made an overview of the literature of sound environment research in nursing homes from 1957 to 2019. The search through the two databases and the additional manual search returned 118 results (Thomas et al., 2020). Among them, there were only four studies that combine the acoustic environment assessment of nursing homes with the difference of the social background of the elderly. Most of the research mainly discussed the optimization of soundscape in nursing homes or the sound perception of the elderly to the existing environment by means of actual measurement. Regarding the sound perception of the elderly, Janus S found that when compared with young people, the elderly are more tolerant and sensitive to sound, and changes in the sound pressure level (SPL) will affect the communication of the elderly and entail serious bodily damage to the elderly when the SPL exceeds 65dB, such as sleep disorder, tinnitus, hypertension, and cardiovascular disease (Janus et al., 2021). Mu et al. (2021) found that the elderly preferred quiet activities and the evaluation of low-decibel (A) and high-decibel (A) activities depended on participation and personal preference. For example, when performing an activity in a public place, participants generally rated sounds more positively than bystanders, and activity sounds associated with music (singing, dancing) were rated being more comfortable than vocal activity sounds (playing chess, playing cards). People have different acoustic perceptions when using different functional spaces (Kawai and Yano, 2002), especially in a socially disadvantaged group. The patients and the elderly have a higher demand for the acoustic environment (Suzuki, 2010; Lin and Lin, 2014; Aletta et al., 2018b).

Acoustic comfort can be defined as the presence of opportunities for acoustic activities that do not annoy others, whereby undesired sound is absent (Thomas et al., 2020). Typical indoor sound sources include fan noise, music, TV, and vocal communication (Torresin et al., 2020). Sound sources are an important factor in sound comfort (Wang et al., 2018; Yi and Kang, 2019). According to the research on indoor acoustics in recent decades, it was found that only Leq A or NC does not suffice to express all the properties present in noise. Therefore, more psycho-acoustic parameters are gradually defined by indoor acoustics researchers. Studies have demonstrated that perception of people of sound in the environment (liking or irritability) depends on the level of Leq A, and on numerous other factors, such as the spectrum characteristics of the sound source, sound volatility, time-varying noise, etc. (Thomas et al., 2020). Thomas et al. (2018) assessed that changing the SPL and controlling the sound source type could effectively improve the psychological pleasure of the elderly. According to Joosse (2011), the sound of the working staff is also an important factor affecting the nursing home acoustic environment, and the noise generated by mechanical equipment can also reduce indoor acoustic environment comfort and increased annoyance (Wu et al., 2012). Another common sound in nursing homes is background music, and studies have shown that both background and foreground music can enhance the appeal of the environment to individuals and boost their levels of happiness (Xie et al., 2020). With an increase in the activities of elderly people and the purchase of new activity equipment in nursing homes sound types have also increased, resulting in more complex acoustic environments. This can cause residents to perceive discomfort in a noisy environment or in an environment devoid of efficient communication. Therefore, as a place with a complex acoustic environment, the sound source and its influence must be systematically studied in the nursing home to improve the acoustic environment of the living indoor space.

Sound preference refers to the preferences of people for sounds. From the perspective of cognitive psychology, people need to comprehend sound and sound events through complete environmental information, not just through mere sounds (Schafer, 1993). Sound has different meanings in different acoustic environments. Tamura found that the majority of people surveyed liked natural sounds such as running water, rain, and birdsong and almost half disliked mechanical sounds (Tamura, 1998). When mechanical sounds are predominant, the degree of relaxation decreases, resulting in reduced acoustic comfort (Wu et al., 2020a). Yang and Kang also stated that in the same environment, acoustic comfort and sound sensitivity levels in women are higher than that of men (Yang and Kang, 2005). Kang further investigated the evaluation of age on acoustic comfort and found that older people prefer the sound of chirping birds (Wang and Kang, 2020). The acoustic environment of nursing facilities possesses the same trend in the sound preferences of the elderly. However, different social backgrounds and experiences lead to disparities in the sound preferences of the elderly (Aletta et al., 2017). The difference of sound source leads to the threshold of ambient sound comfort (Xie et al., 2020).

The objective of this study is to conduct an overall assessment of the acoustic environment in the public space of nursing homes based on the measurement of SPL and reverberation time (RT). Moreover, the study was set to investigate the impact of personal and social factors of elderly people on acoustic environment evaluations and analyze the sound preference of the elderly people in nursing homes. In this study, a typical nursing home including different scales of activity space in Harbin, China, was set as the research site. Objective acoustic parameters, subjective behavioral observations, and questionnaires were used as data-gathering instruments. This study mainly focused on how the personal and social factors of elderly people affect acoustic environment evaluations and the sound preferences of the elderly in nursing homes. The conclusions yielded in this study can provide a reference for the construction and design of facilities for the elderly.

METHODOLOGY

In this present study, relevant data were collected using questionnaires and field measurements, and the credibility of the answers to the questionnaire was enhanced using presurveys and trap questions. The 801 Sound level meter was utilized to record the SPL and calculate the RT. An illuminometer and a microclimate tester were employed to record the indoor luminous and thermal environment, respectively. Furthermore, an HD camera was used to record the activities of the elderly. This research was approved by the ethics review board of the surveyed department, Aixin Nursing Home.

Survey Site

The definition of nursing homes might vary between countries. For European countries, this should be generally understood as a "public or private facility with a domestic styled environment providing 24 h functional support and care for persons who require assistance and who often have complex health needs and increased vulnerability" (Sanford et al., 2015). For Chinese nursing homes, however, a broader definition of long-term care facility for older adults might apply.

According to a survey, there are 16 nursing homes in Harbin, China. The nursing home selected should meet established standards and be well-equipped, so that the elderly will not be affected by their own conditions when evaluating the acoustic environment in the nursing homes. Moreover, the selected case should have a large sample size, which can improve the questionnaire distribution and increase the reliability of the data. The selected cases should be exposed to high noise in urban areas, so as to reflect real acoustic problems. Through visits, cases with a small number of people and cases with a better sound environment in the outer suburbs were excluded. Finally, the Aixin Nursing Home with a large number of people, large scale, and perfect facilities in the urban area was selected as the research site.

The layout and indoor public space of the selected research area were typical layout patterns of nursing homes in Harbin. Moreover, this research site is also the most well-known nursing home serving the most customers in Harbin. Its nursing building covers a total area of 25,200 square meters and accommodates 596 beds with a total of 19 floors. Floors 1–3 are for medical and health care functions, providing daily medical consultation, physical examination, physical therapy, rehabilitation, and other services for the elderly. Floors 4–18 are designated to be the elderly living quarters, mainly double-bedrooms. Each floor is equipped with unit living space. The 19th floor is the sunshine hall designed to provide a public indoor activity place for the elderly (**Figure 1**). According to the different acoustic environments and behavior patterns, the test site was divided into two types of spaces: public space, including sunshine hall, unit living space, and corridor of health care center; and private space, including the bedroom. The tests were conducted at fixed points, and the behavior patterns of the elderly were captured by surveillance cameras in public spaces.

SPL and RT Measurement

According to previous studies, SPL and RT are the main factors affecting human sound perception (Tavossi, 2003). When the indoor environmental SPL is 65dB (A), it will affect human health and produce cognitive issues (Berglund et al., 1999; Stansfeld and Matheson, 2003). In this paper, the SPL and RT in different spaces of the conservation house were selected as the factors to evaluate the indoor sound environment. The test instrument was arranged in a network format. This study focuses on the influence of existing environmental sound sources on space. Therefore, no fixed sound source points were set. The distribution of measured points is illustrated in **Figure 1**.

The SPL was measured from 4 A.M. to 8 P.M. when the space was in use during winter in 2020. During each measurement, the window was closed without air-conditioning. The 801 sound level meters were set to slow mode and recorded A-Weighting Leq every 10 s. To avoid the variability of the sound sources, an average of 10 SPL measurements per hour at each measuring point on the same day was taken (Zannin and Marcon, 2007; Meissner, 2008). To study the impact of different types of activities of the residents on the evaluation of the acoustic environment, the sound lever meter took instant readings every 10 s after completion of each questionnaire. At each measurement point, measurements were made 10 times to obviate sound source variability. A total of 1 min of data was obtained from each survey position (Stansfeld and Matheson, 2003). The mean value was calculated to obtain the corresponding SPL (Zahorik, 2002; Meng et al., 2017).

The RT was tested at night with the door closed and devoid of occupants, and an OS002 omnidirectional instrument was used to playback white noise at the measuring point in **Figure 1**. After stabilization, the sound source was turned off and 30 dB (A) (T_{30}) [after extrapolation to 60 dB (A)] was recorded (Bautmans et al., 2007). For the large space in **Figure 1C,** T_{30} is used instead of T_{60} for calculation. The test standard was ISO3382 (Barron, 2005).

Acoustic Comfort Survey

According to the preliminary interview survey, it was found that the elderly in nursing homes may have a polarization trend in their irritability to sounds. Moreover, loneliness is common among the elderly, especially among those who are widowed. Literature analysis shows that there may be a certain relationship between the sound preferences of the elderly and their physical and mental conditions. In order to clarify the perception of the elderly in a nursing home on the acoustic environment, trap

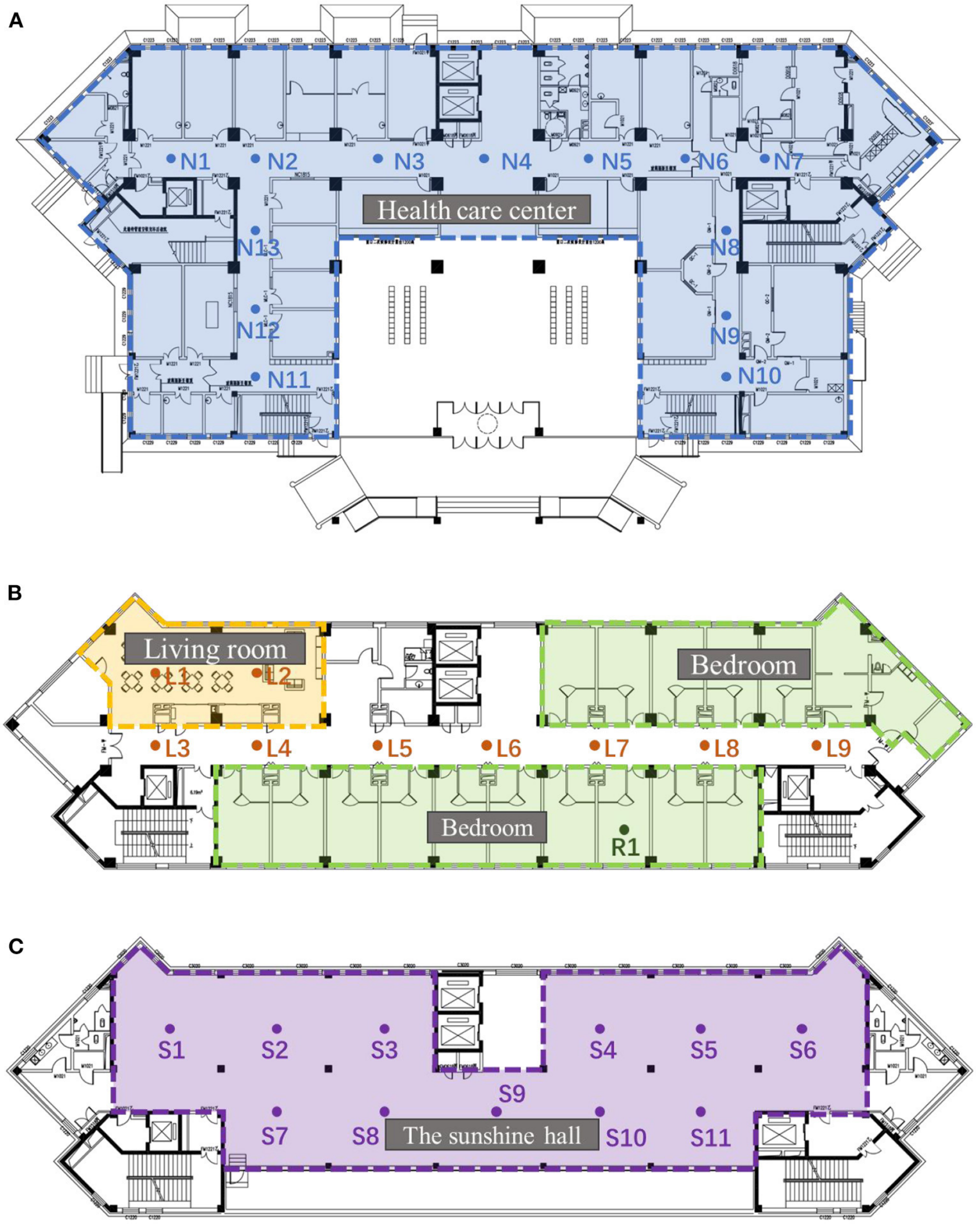

FIGURE 1 | Layout of different space **(A)** Healthcare spaces layout **(B)** Living space **(C)** Sunshine Hall.

questions were set. The comfort of the acoustic environment in nursing homes might be related to the following factors:

1. Gender, age, and other social factors.
2. Loneliness and other psychological parameters.
3. Hearing, physical, and other physiological parameters.
4. Luminous environment, humidity, and other environmental factors.
5. Properties of sound field such as sound pressure level (SPL) and sound source in the building.

In the questionnaire, the attitudes of the elderly were measured using a five-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). A total of 348 elderly people were surveyed from September 2020 to March 2021. The reliability coefficient of the questionnaire was estimated at 0.87 (Cronbach's alpha). The KMO coefficient was 0.705, and Bartlett spherical test results were significant ($P < 0.001$).

TABLE 1 | The content of the questionnaire.

Category	Questions	Scale
Background	1. Gender, age 2. Education level 3. Marital status, offspring 4. Income (per month) 5. Hearing status 6. Sleeping status	1. very good 2. good 3. normal 4. bad 5. very bad 1. very good 2. good 3. normal 4. bad 5. very bad
ULS-8 Loneliness rating	1.Lack of company 2. There was no one to turn to for help 3. I am a person who likes to make friends 4. I feel left out 5. I felt alienated from other people 6. I feel sad because I have so little society 7. I can find someone to accompany me when I need them 8. I feel lonely	1. Never 2. seldom 3. Sometimes 4. all the time
PHQ-9 Depression	1. Work with little enthusiasm or interest 2. Feeling down, depressed, or hopeless 3. Difficulty falling asleep, restlessness, or excessive sleep 4. Feeling tired or without energy 5. Feeling you're a failure, or you've let yourself or family down 6. Have trouble focusing on things 7. Move or speak slowly enough for others to notice? Or just the opposite, fidgety or fidgeting and moving more than usual 8. Loss of appetite or eating too much 9. Suicide or want to harm yourself	0: never 1: several days 2: half 3: always
ADL	Use of public vehicles. Walk. Cooking. Do housework. Take medicine. Dining. Garb. Wash clothes. Bathing. Shopping. Ring up	0: yes 1: slightly difficult 2: need help 3: no
Satisfaction with the living environment	Sound environment Luminous environment Thermal environment Humid environment Smell	Very comfortable: 5 Comfortable: 4 Generally: 3 Uncomfortable: 2 Very uncomfortable: 1
Degree of sound preference	Voice Musical sound Sound of snoring Ring tones TV sound Washing machine sound Sound of rain and wind Chirp Traffic noise Construction noise Decoration noise	Enjoy: 5 Like: 4 Generally: 3 Dislike: 2 Hate: 1

To ensure that the participants had the appropriate physiological and psychological status to enroll in the study, the questionnaires were taken using a one-to-one method and completed within 5 min, and at least 10 interviews were conducted at each survey point. The residents who participated in the survey were considered qualified according to the frailty scales proposed by Rockwood et al. (2005), belonging to the scale range of 1–4. A total of 348 questionnaires were distributed, of which 329 were found to be valid.

Statistics and Analysis

SPSS 20.0 was used to establish a database of the subjective and objective results (Zhang et al., 2018). One of the main research contents of the questionnaire was the influencing factors of the evaluation of the comfort level of the acoustic environment. Correlation between data was mainly calculated through correlation analysis. **Table 2** lists correlation analysis methods and the choice behind different types of data.

RESULTS

Space-Time Distribution of Sound Source and Soundscape

Acoustics Characteristics of Different Functional Spaces

According to the measured data, the variation of SPL in different spaces in the nursing building with time is depicted in **Figure 2**. The SPL in the living space of the unit was higher, and two peaks

TABLE 2 | Correlation analysis and calculation methods of different independent variables and dependent variables.

Independent variable	Dependent variable	Statistical mode	Index	Reasons for choosing mode and index
Gend	Evaluation of acoustic environment comfort level	Independent-samples *t*-test	Mean difference	Dichotomous variables - Ordinal variables
Marital status				
Income level		Crosstabs	Crammer's V	Classified variables - Ordinal variables
Age		Bivariate correlation	Pearson correlation coefficient	Interval variables - Ordinalvariables
Length of stay				
The number of children				
The activity of daily living (ADL)				
Loneliness index				
Depression rating scale				
SPL				
Hearing status		Crosstabs	Camma correlation coefficient	Ordinal variables - ordinal variables
Sleep status				
Other				
SPL at different locations at the same time		Bivariate correlation	Pearson correlation coefficient	Interval variables-Interval variables

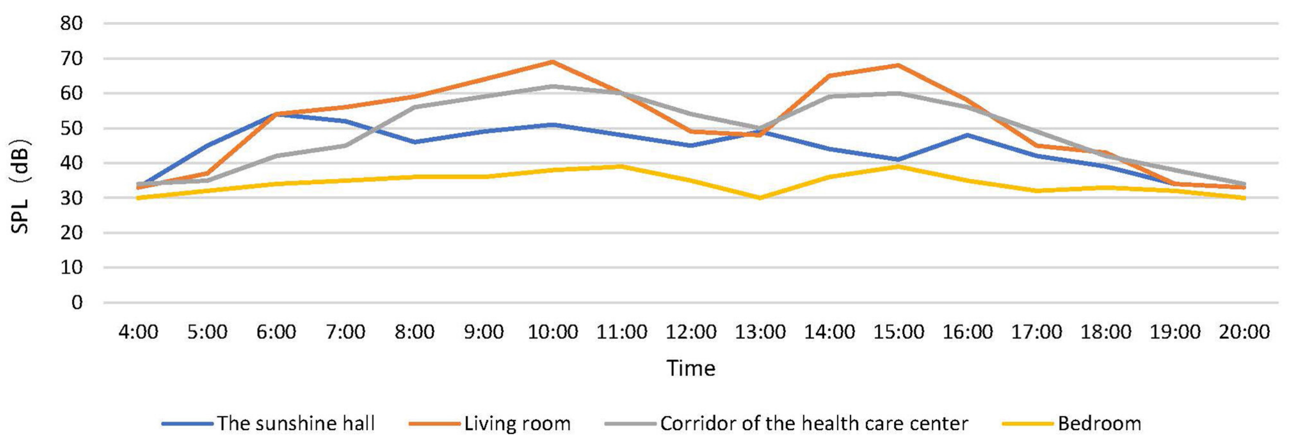

FIGURE 2 | Daily SPL(A) distribution in four kinds of spaces.

were noted. The highest one reached more than 60 dB(A). The average SPL in the Sunshine Hall was 45dB (A), and there was a peak between 5 A.M. and 7 A.M., followed by a slight increase at noon and at night. The SPL in the bedrooms of the elderly remained roughly between 30 and 40 dB (A) throughout the day and were slightly higher in the afternoon than in the morning and evening. The SPL of the corridor of the health care center was high during the working hours but did not exceed 60 dB, and it stayed at 32 dB in the morning and evening.

The distribution of SPL in specific places in several main spaces was analyzed at 3 P.M. when there were a lot of personnel activities, as shown in **Figure 3**. The SPL distribution of the sunshine hall was relatively uniform due to the large area of the hall, and the number of users was relatively scattered. The distribution of SPL in the living space of the units and corridors of the health care center was regionally enhanced. The areas with higher SPL were located near the main vertical traffic and near the entrances and exits of functional rooms.

The Artemis S was used to carry out the spectrum analysis of sound samples. **Figure 4** shows the sound spectrum analysis of the four kinds of public spaces selected. The spectrum measurement range in the figure was 20 Hz—20 kHz, and

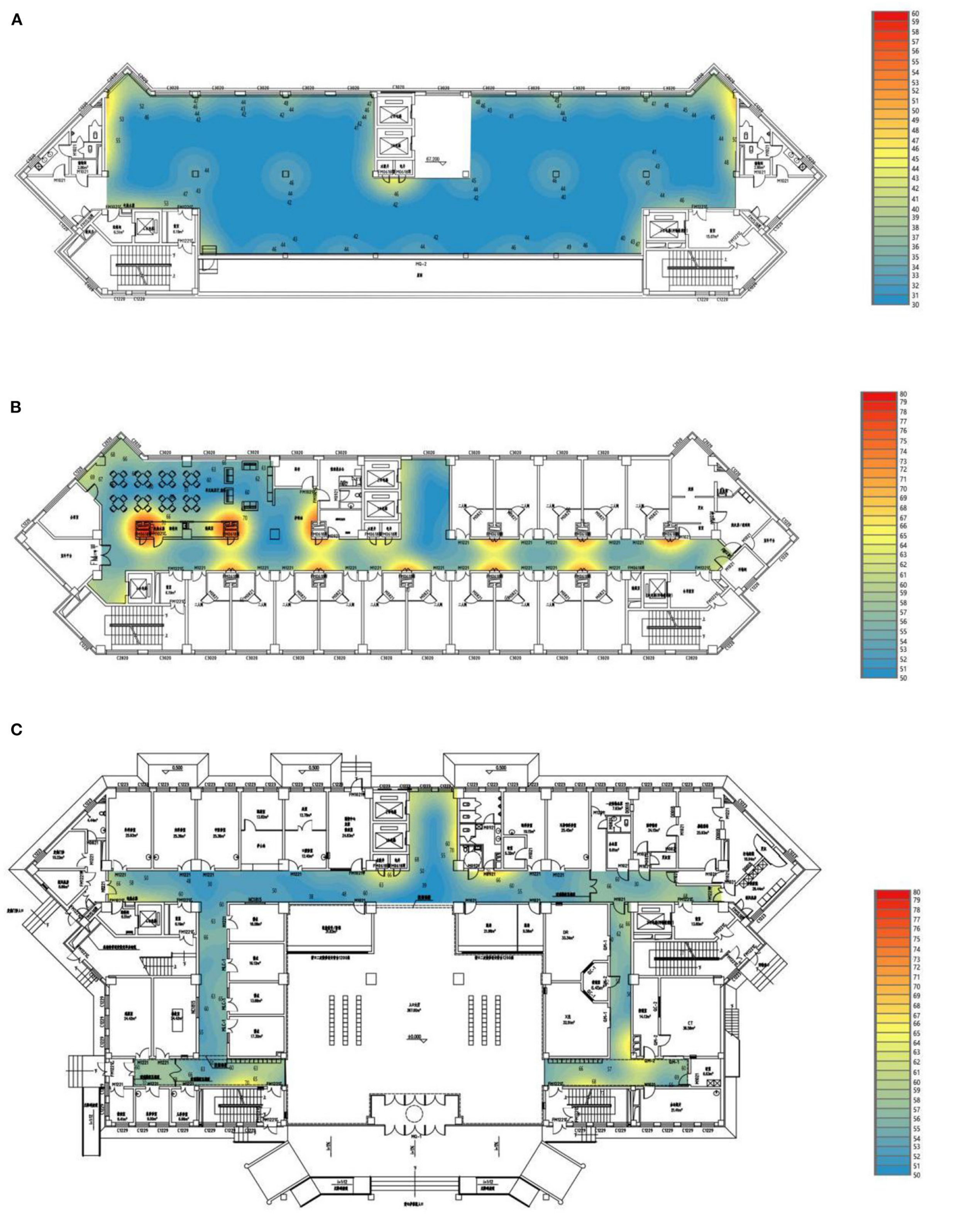

FIGURE 3 | SPL distribution of different space (A) sunshine hall (B) living room (C) corridor of the health care center.

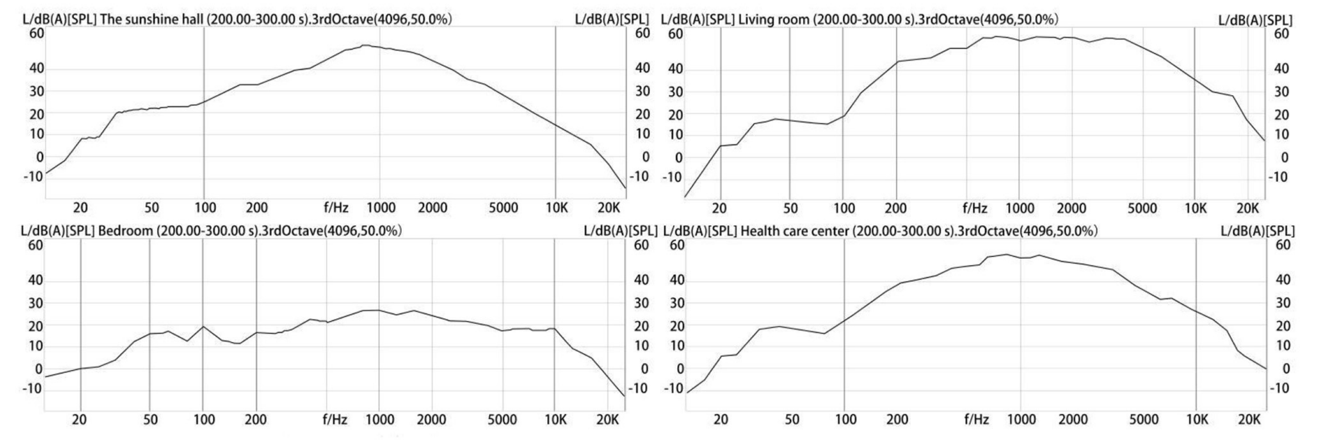

FIGURE 4 | Sound spectrum analysis of the nursing home.

the image format was recorded with a continuous spectrum of 1/3 octaves.

It can be inferred from the figure that the frequency of noise in the sunshine hall was mainly concentrated between 250 Hz and 4 kHz, which was also the main frequency range of human language voice frequency distribution. This means the main component of the background noise in the sunshine hall was a human voice. The SPL in the bedrooms of the elderly was generally lower than 30dB (A), indicating that the indoor space of the elderly was a relatively quiet space which was due to the slow movement of the elderly. The unit living space was noisy, with a frequency ranging from 200 Hz to 10 kHz, indicating that the space was not only filled with human voice but also contained a certain high-frequency noise. The spectrum of the corridor of the health care center shows that in addition to human speech, there was a certain amount of high-frequency noise in this space, but it was slightly quieter than the unit living space.

RT of Different Functional Spaces

Reverberation time is one of the important indicators in indoor acoustic design. It is the time required from the moment when the sound source stops sounding to the attenuation of the sound energy density of 60dB (A) after the indoor sound field reached a stable state. Excessive RT in a room will cause the sound to lack clarity, whereas an excessively short RT will cause the sound to be dry and lack vitality. **Table 3** shows a list of RTs at different frequencies for the sun hall, unit living spaces, bedrooms, and corridors of the health care center.

It can be inferred from the table that the RT in the sunshine hall was relatively long, and the average RT value at the frequency of 500–1,000 Hz was 2.33 s, which was well-beyond the recommended value of the reverberation time in the normal hall. The reason for this phenomenon is that the area of the sunshine hall is larger and the story height is higher, such a large volume and without any sound absorption device will seriously affect the sound transmission in the hall. In contrast, the RT in the bedrooms of the elderly is ideal. The average RT value of the unit living space and corridor of the health care center was 2.2 and 2.4 s, respectively, at the frequency of 500–1,000 Hz. Therefore, some measures should be taken to control the acoustic parameters such as the RT within the ideal range.

Sound Preference and Sound Comfort of the Elderly

The Influence of the Background of the Respondents on the Comfort of the Acoustic Environment

In the questionnaire, the major factors that influence the evaluation of acoustic environment comfort include gender, marital status, income level, age, hearing condition, and sleep condition of the respondents. In the actual survey, there were only two types of the marital status of the elderly in nursing homes: married and widowed. Therefore, both marital status and gender belong to the two categorical variables. As illustrated in **Table 4**, an independent sample *t*-test was conducted for gender and marital status to assess any difference in the evaluation of the acoustic environment comfort level of the elderly under different classifications. It can be inferred from the table that gender factors had no significant influence on the evaluation of acoustic environment comfort of nursing homes. However, marital status had a significant influence on the evaluation of acoustic environment comfort, and the average value of the married elderly (3.44) exceeded that of the widowed elderly (3.29).

In the actual survey, the actual income of the elderly was not clearly compiled, and the income of the elderly was related to the income of their children. Therefore, the income factor was set as a qualitative variable, which was divided into three grades: high, middle, and low. Hence, Crammer's V coefficient in the SPSS cross table was used to calculate the correlation coefficient between this variable and the evaluation of the comfort level of the acoustic environment. As inferred from **Table 4**, the correlation between the comfort level of the acoustic environment and income was $0.336^{**}(P < 0.01)$. However, since Cramer's V coefficient is a symmetric measurement, the coefficient had no positive or negative points. Through the analysis of the mean value of the data, it was found that the mean

TABLE 3 | RT at different frequencies in public space.

Type	125 HZ(s)	250 HZ(s)	500 HZ(s)	1,000 HZ(s)	2,000 HZ(s)	4,000 HZ(s)
The sunshine hall	1.42	1.87	2.32	2.35	2.55	2.16
Living room	2.03	2.35	2.25	2.15	2.13	1.95
Bedroom	1.33	1.25	1.22	1.13	1.02	0.98
Health care center (Corridor)	1.85	2.97	2.68	2.13	2.05	1.76

value of the evaluation of the low-income elderly was 3.45**($P < 0.01$), the middle income was 3.33**($P < 0.01$), and the high income was 3.27**($P < 0.01$), indicating that with the increase of income, the evaluation the elderly on the comfort of the acoustic environment showed a downward trend.

Time of residence, age, and a number of children are all continuous quantitative variables, and a Pearson correlation coefficient was adopted for calculation. As inferred from **Table 4**, there was a significant correlation between age and comfort evaluation of acoustic environment, with a correlation coefficient of 0.356**($P < 0.01$), indicating that with the increase of age, the evaluation of the elderly on the comfort level of acoustic environment exhibited an increasing trend, and the elderly had a higher tolerance to the acoustic environment than the younger ones. Moreover, the *P*-values of the significance test of the number of children and the time of stay all exceeded 0.05, indicating an insignificant correlation between these two variables and the comfort level of the acoustic environment.

It can be inferred from **Table 4** that the correlation between the acoustic environment comfort and the hearing condition was−0.515**($P < 0.01$), and the correlation between the acoustic environment comfort and sleep quality was 0.273*($P < 0.05$). The results showed that older people with better hearing conditions had a worse evaluation of the comfort level of the acoustic environment, whereas the older people with better sleep conditions had a higher evaluation of the comfort level of the acoustic environment.

Influence of Physical and Mental Health Indexes on Acoustic Environment Comfort

Physical and mental health indexes include loneliness index (LI), depression rating scale (DRS), activities of daily living (ADL). As these three variables are equidistant quantitative variables, a Pearson correlation coefficient was used to calculate correlation analysis. The specific calculation results are listed in **Table 5**.

As **Table 5** shows, LI, DRS, ADL were all significantly correlated with the evaluation of comfort level of the acoustic environment, and the correlation coefficients were −0.627**($P < 0.01$), −0.532**($P < 0.01$), and 0.355*($P < 0.05$), respectively. It can be concluded that the elderly with greater loneliness and depression had a worse evaluation of the acoustic environment, whereas the elderly with better physical ability have a higher evaluation of the acoustic environment. Notably, the correlation coefficient between LI and DRS was as high as 0.844**($P < 0.01$). This showcases the strong correlation between the two variables. Modern psychology believes that loneliness and depression represent two different psychological states, but also stem from different reasons. Therefore, the two psychological states are discussed as independent factors, instead of being combined into one variable.

Correlation Analysis of Different Types of Environmental Comfort

Numerous pieces of literature show that there is a correlation between human perception of the acoustic environment and other environmental indicators (Yu and Kang, 2010; Meng and Kang, 2013; Wu et al., 2020b). This study lists illumination, temperature, RH, smell, and the overall evaluation of six main sensory comfort evaluation indices in the questionnaire. Since each variable is a 5-level scale, the gamma coefficient was used to calculate the correlation coefficient between other environmental comfort evaluations and acoustic environmental comfort evaluation. The specific parameters are listed in **Table 6**.

As shown in **Table 6**, the evaluation of the elderly of the luminous environment was the highest at 3.43, followed by smell at 3.42, and acoustic environment comfort at 3.36. The average value of RH was 3.34, whereas temperature accounted for the lowest value at 2.74. The mean of the overall evaluation was 3.26, lower than the average except for temperature. The acoustic environment had the closest relationship with humidity, with the specific parameter value of 0.486**($P < 0.01$), and the correlation coefficient between the acoustic environment and the luminous environment was 0.419**($P < 0.01$). The correlation between acoustic environment and smell failed to pass the significance test. The correlation between the two could therefore not be proved. The correlation with temperature was 0.232*($P < 0.05$). It can be inferred that the evaluation of the acoustic environment was correlated with all the environmental factors except smell. Moreover, the correlation coefficient between the evaluation of acoustic environment comfort and the overall environmental evaluation was very high, reaching 0.515**($P < 0.01$), indicating that the evaluation of acoustic environment also affects the overall environmental evaluation of nursing homes to a large extent.

In this paper, 40 elderly people (10 people per function space) were randomly surveyed in various locations of the nursing home. They were surveyed regarding the sound comfort of the environment, and the sound in the acoustic environment was recorded at the same time. The SPL and Speech Transmission Index (STI) were calculated and compared with the subjective evaluation of sound comfort, and the relevant lists of sound environment comfort, SPL, and STI were obtained. There was a significant correlation between the sound environment comfort and the measured SPL. The higher the SPL was, the worse

TABLE 4 | Correlation analysis of evaluation of acoustic environment comfort level and social background.

Dependent variable	Independent variable	Statistical model	Correlation analysis							
				F	**Si g.**	**t**	**df**	**Sig.**	**Mean difference**	**Standard error**
Evaluation of acoustic environment comfort level	Gender	Independent-samples *T*-test	variance is equal	0.358	0.546	1.676	111	0.094	0.361	0.215
			variance is not equal	–	–	1.681	107.76	0.093	0.361	0.215
	Marital status		variance is equal	0.485	0.486	0.664	111	0.504	0.141	0.212
			variance is not equal	–	–	0.668	108.13	0.501	0.141	0.211
	Income level	Crosstabs				**Value**			**Approximation Sig.**	
			Scalar	ϕ		0.473*			0.000	
				Cramer V		0.336**			0.000	
				N in the valid case					113	
				Pearson					**Sig. (bilateral)**	
	Age	Bivariate correlation		0.356**					0.000	
	Number of children			0.164					0.075	
	Time of residence			−0.78					0.415	
		Crosstabs	**Value**		**Asymptotic standard error**		**Approximation T**		**Approximation Sig.**	
	Hearing status		−0.515		0.135		−3.315		0.001	
	Sleep status		0.273		0.116		2.226		0.028	

***indicates that the two-tailed test is significant at the level of 0.01, and *indicates that it is significant at the level of 0.05.*

TABLE 5 | Correlation analysis of loneliness index, depression degree, and activity ability with acoustic environment comfort.

	Correlation coefficient/Significance level			
	Acoustic environment evaluation	**LI**	**DRS**	**ADL**
Acoustic environment evaluation	1	−0.627/0.000(**)	−0.532/0.000(**)	0.355/0.000(**)
LI	–	1	0.844/0.000(**)	−0.389/0.000(**)
DRS	–	–	1	−0.299/0.022(*)
ADL	–	–	–	1

***Indicates that the two-tailed test is significant at the level of 0.01, and * indicates that it is significant at the level of 0.05.*

TABLE 6 | Correlation analysis of different types of environmental comfort.

	Parameter statistics of sensory comfort evaluation					Correlation analysis of other environmental factors and comfort of the acoustic environment			
	Mean value	**Standard deviation**	**The standard error**	**Kurtosis**	**Skewness**	**Value**	**Asymptotic standard error**	**Approximation T**	**Approximation Sig.**
Acoustic environment	3.36	1.120	0.103	−0.875	−0.080	-	-	-	-
Luminous environment	3.43	1.042	0.098	−0.475	−0.230	0.419	0.146	2.591	0.010
Temperature	2.74	1.265	0.118	−0.946	0.204	0.232	0.117	2.226	0.025
RH	3.34	0.996	0.095	−0.242	−0.035	0.486	0.116	3.654	0.000
Smell	3.42	0.862	0.082	0.736	−0.559	0.303	0.153	1.863	0.062
Global assessment	3.26	0.882	0.085	0.694	0.049	0.515	0.143	3.285	0.001

the comfort evaluation, and the correlation coefficient was $-0.711^{**}(P < 0.001)$. There was also a significant correlation between STI and comfort level, with a correlation coefficient of $0.755^{**}(P < 0.001)$.

The results of the subjective and objective correlation analysis can be combined with the schematic diagram of the evaluation of acoustic environment comfort, as depicted in **Figure 5**, to yield a complete schematic diagram of the subjective and objective influence of acoustic environment comfort. The correlation coefficients in the table were decimals between 0 and 1. Although the magnitude of the correlation coefficient can indicate the strength of the correlation between data, it is the only representative of the correlation trend.

Evaluation of the Sound Environment Based on the Sound Types and Sources

Correlation Between Acoustic Evaluation and Sound Source in Different Areas

The elderly people were asked about their subjective feelings when hearing different sound sources in different areas to assess the presence of a correlation between sound environment evaluations and sound types in different areas (**Figure 1**).

Column A in **Table 7** lists the mean and standard deviation of the acoustic comfort evaluations of the elderly residents. Among them, the Sunshine hall was rated higher than all the other areas for all sound types, with an average close to 4. The elderly frequenting the area mainly enjoy the sunshine or practice sports. Moreover, vegetation is generally placed in the sunshine hall, and the pleasant environment improves the evaluation of the acoustic environment by the elderly, confirming Mu et al.'s study that a pleasant landscape or appealing visual scene can boost hearing comfort (Yu and Kang, 2010). Mechanical sounds were most annoying to the elderly, with a minimum rating of 1.73. The reason is that the sound of conversation and activities of the elderly has little influence on the surrounding area of the large space of the sunshine hall. However, the equipment room located on the roof had a greater impact. It can be inferred that the design of nursing homes should fully consider the behavioral pattern of the elderly and the influence of the acoustic environment, to arrange different functional areas.

Due to the short time people spend in the corridor, the sound sources might be multidirectional, and the elderly have a reduced ability to capture sound. In this area, the respondents least liked the sound of talking and singing. Nevertheless, it had high voting regarding background music (3.42), and when voices were combined with background music, the ability of elderly residents to perceive and differentiate the sounds was affected. Therefore, the acoustic comfort of the elderly could be significantly improved by adding background music to the corridor.

The ratings for the living room's acoustic environment were low due to the poor overall sound environment. In this area, the most insufferable sound was renovation noise and construction noise garnering votes of 1.51, 1.72, respectively. Seat and table moving sounds, ring tones, and singing sounds were also shown to be insupportable. The most popular sound residents preferred was the background music. The reason for this result is that the elderly were engrossed in their activities, ignoring external activity and background sounds in the living

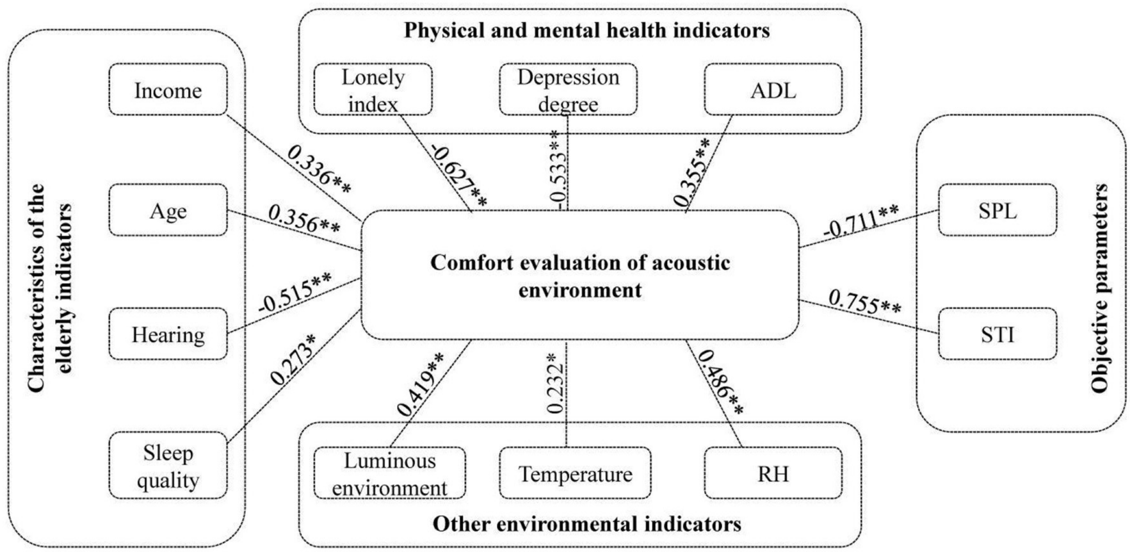

FIGURE 5 | The relationship between different variables and comfort evaluation of acoustic environment. **indicates that the two-tailed test is significant at the level of 0.01, and *indicates that it is significant at the level of 0.05.

room; high-frequency sounds could distract their attention and create discomfort.

The bedroom received the lowest overall evaluation of the acoustic environment. Talking on the phone sounds was the most unpopular sound source with the lowest voting of 1.44. Snoring sounds also disturbed the elderly. It's worth noting that in private spaces, other people's voices were the most unbearable sound source rather than activity sounds and mechanical sounds.

From **Table 7**, it can be concluded that the function of the building determines the sound source. For nursing homes, old people staying in a relatively narrow space (including the corridor and bedroom) require some background ambient sound and reduce the impact of human sounds. For large multifunctional spaces (including the hall and the living room), mechanical sounds have become the most intolerable sound source to the elderly. Besides, different sounds are mixed together, and when elderly people are unable to recognize and judge the content of sounds, they may become anxious, thereby impacting comfort levels.

Analysis on the Influencing Factors of Sound Preference of the Elderly

In this study, the 11 kinds of common sound sources that are summarized above were listed in the questionnaire scale. As there are numerous sound sources, a single analysis is of little significance. Therefore, this study conducted a factor analysis on 11 kinds of sound sources in nursing homes, seeking common characteristics and classification of different sound sources.

The KMO coefficient of the sound preference scale was 0.705, indicating the suitability of the data for factor analysis. The factor extraction method in this study was the iterative method based on principal component analysis, and the default factor extraction quantity in the calculation was based on the number of components extracted when the characteristic root exceeded 1. It can be inferred from **Table 8** that a total of four factors were extracted according to the principle that the extraction feature root exceeded 1, and the cumulative contribution of the four factors to all 11 variables was 77.368%, indicating that the interpretation degree of the model was good.

The model of the factor load matrix was rotated by the orthogonal rotation method with Kaiser standardization. The rotated factor load matrix is illustrated in **Table 9**. To facilitate reading, the analysis software reordered and simplified the table, and coefficients <0.1 were suppressed and output in the table. The common factor 1 is mainly related to the sounds of people talking, music, snoring, ringtone, TV, and washing machine. These factors are closely related to the daily behaviors of people and are common sounds in the nursing home. Common factor 2 is mainly related to wind and rain sounds, insect and bird sounds. This common factor is the common natural sound outside the conservation house. Common factor 3 mainly includes traffic noise, construction noise, and indoor maintenance noise, belonging to the common public noise in the maintenance yard.

As inferred from **Table 9**, the scores of natural sound sources such as wind and rain and insects and birds sound are relatively high, reaching 3.42 and 3.31. It shows that elderly people are generally willing to accept such voices. However, the score of outdoor noise such as vehicle driving is very low, especially the score of indoor maintenance sound is only 1.48, indicating that such noise must be avoided in the acoustic environment. In addition, older people also rated mobile phone ringtones, music and TV sounds more highly, indicating that these sounds can meet their needs.

TABLE 7 | Correlation between sound sources and acoustic comfort.

Name of area	Sound types	Sound sources	A: Average value/variance	B: Correlation Coefficient/*p*-value
Sunshine hall	Activity sound		3.556/1.031	0.186/000(***)
		Walking sounds	2.925/1.884	0.16/0.064
		Sport sounds	2.842/1.636	0.425/000(***)
	Background music	Sound of rain and wind	3.63/0.925	0.222/0.105
	Mechanical sound	Device running sound	1.733/1.277	0.343/0.09(*)
	Speech sound	Talking sounds	2.761/1.414	0.577/0.00(***)
Corridor	Activity sound		2.764/1.244	0.325/0.022(*)
		Walking sounds	3.196/1.032	0.314/0.015(*)
		Seat and table moving sounds	2.296/1.434	0.222/0.087
		Playing card sounds	2.048/1.785	0.151/0.00(**)
	Background music	Background music	3.42/1.344	0.425/0.02(**)
	Foreground music		2.297/0.999	0.408/0.00(**)
		Music from electronic devices	3.024/1.597	0.259/0.001(**)
		Singing sounds	1.728/0.556	0.223/0.086
	Mechanical sound		2.452/1.245	0.420/0.02(**)
		Air conditioning sounds	2.471/1.286	0.057/0.655
		Trolley sounds	2.546/1.241	0.220/0.004(**)
	Speech sound		2.385/1.076	0.188/0.187
		Talking sounds of staff	1.965/0.636	0.225/0.08
		Talking sounds of onlookers	2.732/1.835	0.153/0.009(*)
Living room	Activity sound		3.061/1.345	0.595/0.000(***)
		Playing card sounds	3.261/1.702	0.341/0.005(**)
		Seat and table moving sounds	1.963/1.745	−0.024/0.816
		Dancing sounds	3.02/1.941	−0.035/0.719
		Chess sounds	2.944/1.223	0.334/0.001(**)
	Background music		2.78/1.638	0.495/0.001(**)
		Background music	3.171/1.445	0.451/0.000(***)
		TV sounds	2.261/1.778	−0.094/0.340
	Foreground music		1.542/1.402	0.539/0.000(***)
		Ring tones	1.747/1.585	0.268/0.002(**)
		Singing sounds	1.463/1.687	0.349/0.000(***)
	Mechanical sound		1.604/1.327	0.244/0.112
		Decoration noise	1.511/1.402	0.319/0.000(***)
		Construction noise	1.721/1.585	0.148/0.002(**)
	Speech sound		3.165/1.512	0.538/0.000(***)
		Talking sounds	3.645/1.644	0.215/0.000(***)
		Explanation sounds	2.868/1.675	−0.211/0.033(*)
		Talking sounds of staff	2.924/1.863	0.035/0.756
		Talking sounds of onlookers	2.932/1.828	0.097/0.324
Bedroom	Activity sound	Walking sounds	2.331/0.838	−0.038/0.713
	Background music	TV sounds	2.47/1.401	0.691/0.000(***)
	Foreground music	Chirp	2.14/1.043	0.358/0.061
	Mechanical sound	Washing machine sound	2.50/1.037	0.662/0.000(***)
	Speech sound		1.772/0.915	0.414/0.030(*)
		Talking on the phone sounds	1.442/1.402	0.539/0.000(***)
		Sound of snoring	1.947/1.585	0.268/0.002(**)

DISCUSSION

Through a literature review, Mu et al. (2021) carried a field measurement and questionnaire in another nursing home in Harbin in 2021. Despite varying research directions, old people in the same function but different building types have different sound perceptions. In their research, the acoustic environment of the activity space is the most unbearable which clashes with this

TABLE 8 | Factor analysis explained the total variance.

Factor	Initial eigenvalue			Extract sum of squares load			Rotation sums of squared load		
	Sum	Variance %	Accumulation %	Sum	Variance %	Accumulation %	Sum	Variance %	Accumulation %
1	4.883	40.712	40.712	4.876	40.698	40.698	3.485	29.082	29.086
2	1.742	14.523	55.234	1.739	14.521	55.232	2.586	21.608	50.692
3	1.619	13.514	68.745	1.612	13.515	68.752	2.010	2.019	67.459
4	1.038	8.612	77.371	1.036	8.613	77.371	1.179	1.192	77.368
5	0.858	7.168	84.542	–	–	–	–	–	–
6	0.556	4.645	89.213	–	–	–	–	–	–
7	0.402	3.341	92.545	–	–	–	–	–	–
8	0.283	2.335	94.886	–	–	–	–	–	–
9	0.245	2.012	96.875	–	–	–	–	–	–
10	0.164	1.335	98.223	–	–	–	–	–	–
11	0.152	1.278	99.512	–	–	–	–	–	–

TABLE 9 | Total variance explained by factor analysis.

	Factor				Mean value and standard deviation of different sound sources	
	1	2	3	4	Mean value	Standard deviation
Voice	0.826	−0.396	−0.133	−0.152	2.65	0.473
Musical sound	0.721	0.485	—	—	3.03	0.841
Sound of snoring	0.765	0.182	0.341	—	2.32	0.647
Ring tones	0.792	0.290	—	0.242	3.13	0.662
TV sound	0.739	0.352	0.196	0.206	3.05	1.012
Washing machine sound	0.425	0.296	0.193	—	2.38	0.572
Sound of rain and wind	0.186	0.935	—	—	3.42	0.691
Chirp	0.260	0.890	0.183	—	3.31	0.872
Traffic noise	0.469	0.335	0.658	—	2.16	0.776
Construction noise	—	0.241	0.795	0.335	1.73	0.706
Decoration noise	—	−0.203	0.829	—	1.48	0.643

study. The perception of the same sound sources also differs in the elderly. By comparison, the layout of space and management mode was found to be the cause of the difference. In their case, the living room, activity space, and bedroom are mixed together on 1–3 floors, but separately located on 4–19 floors in our case. The spatial function determines the acoustic environment. Therefore, it should not only consider the sample size of the survey population but also consider the different layout cases in acoustic questionnaires.

There are significant differences in sound perception among the elderly from different social and life backgrounds. Gender factor had no significant influence on the acoustic environment comfort evaluation of nursing homes, whereby different case studies yielded varying outcomes. However, marital status had a significant effect on the comfort level of an acoustic environment which was similar to other studies. With the increase of income, the elderly people evaluation of the comfort of acoustic environment exhibited a downward trend and with the increase of age, the elderly people evaluation of the comfort of acoustic environment showcased an increasing trend, and the elderly have a higher tolerance to the acoustic environment than the younger ones. Moreover, the correlation between the number of children and the comfort level of the acoustic environment was negligible. The older people with better hearing conditions had worse evaluation on the comfort of the acoustic environment, whereas the older people with better sleep conditions had higher evaluation on the comfort of the acoustic environment.

This study presents some limitations. The main point is related to the generalizability of the results of the current study to other test sites and contexts. In particular, the perceived effectiveness of the acoustic correction interventions might be specific to the analyzed case study. However, the contribution of this work should be considered methodological and aimed at proposing a combined quantitative and qualitative approach in applications where only one is generally adopted.

CONCLUSIONS

This research focuses on the evaluation of elderly residents of their acoustic comfort according to an on-site observation, sound measurements, and a questionnaire conducted in a public space in a nursing home in Harbin, China. On the basis of previous research, this study has been expanded to compare the acoustic perception of the elderly in public spaces and private rooms.

In general, the participants evaluated the acoustic environment in the case with a low rating. The SPL measurement found that the SPL in the unit living space in the nursing home was the highest and can exceed 65 dB (A) when using high frequency. The average SPL in the sunshine hall was 45 dB (A). The SPL in the bedrooms of the elderly remained roughly between 30 and 40dB (A) throughout the day and were slightly higher in the afternoon than in the morning and evening. The RT of the unit living space was 2.15 s at a frequency of 1,000 Hz, and the corridor of the health care center was 2.13 s, which exceeded the acceptable range. The evaluation of the acoustic environment also affected the overall environmental evaluation of the nursing home to a large extent. In terms of sound preferences, elderly people were generally willing to accept the sound of natural sound sources.

Acoustic comfort, preference, and noise levels are all affected by subjective perceptions, and loudness and clarity are affected by physical conditions. The evaluation of an acoustic environment is related to the social background and living background of the elderly. Marital status and income level are the main impact factor on the evaluation of the acoustic environment. Moreover, older people have a higher tolerance to the acoustic environment than younger ones. The layout of space and management mode of the nursing homes leads to different sound sources, altering the correlation with acoustic evaluation results in other cases. Future studies could improve the conciseness of the questionnaire more concisely and consider the visual factors and spatial function factors in an acoustic environment survey.

Regarding the acoustic design of nursing homes, the following strategies should be considered. In the cases investigated, the reverberation time of public space is too long, thereby affecting the semantic intelligibility of the elderly. The reverberation time should be controlled in public spaces and sound-absorbing materials should be in place. The addition of natural music to the public space can also make the residents more delighted. Moreover, humidifiers could be placed in public spaces to improve the acoustic comfort of the elderly. High-frequency noise should be controlled through the addition of perforated sound-absorbing panels in the bedroom. The loneliness index and ADL of the elderly markedly impact their acoustic perception. It is therefore recommended for nursing homes to organize more group activities in public spaces and enhance geriatric care toward the elderly suffering from behavioral difficulties.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

Ethical review and approval was not required for this study on human participants in accordance with local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

JZ: investigation, data collection, methodology, formal analysis, visualization, and writing–original draft. PC: supervision, investigation, and writing–review and editing. TL: resource, investigation, and software. All authors contributed to the article and approved the submitted version.

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Soundscape Preference of Urban Residents in China in the Post-pandemic Era

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This research aims to explore the reality of the soundscape preferences of Chinese urban residents in general public landscape in the post-pandemic era, and then to propose design recommendations to meet the practical needs of people's preferences for landscape—especially soundscapes—in the post-pandemic era. In this study, we utilized the subjective evaluation method to conduct an online questionnaire in 29 Chinese provinces which experienced severe pandemic caseloads and collected 860 valid responses. This study revealed people's preference for landscape and soundscape in the post-pandemic era. We further studied the correlation between landscape preference and soundscape preference, analyzed the influence of living conditions on soundscape preference, founded the effects of personal characteristics and living conditions on soundscape preference, and explored the strongest influence factors on soundscape preference through the establishment of automatic linear model. The results revealed a positive correlation between life happiness and soundscape preference, whereas wearing masks significantly reduced soundscape perception ratings and people who have been vaccinated are more tolerant of various noises. Moreover, based on these analysis results, the design recommendations on landscape (overall landscape, plant, and tour space), soundscape construction of caring for vulnerable groups (teenagers and children, elderly people, and disabled and unhealthy) has been discussed.

Keywords: COVID-19, soundscape preference, survey, China urban, public landscape, post-pandemic era

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INTRODUCTION

The novel coronavirus pneumonia (COVID-19) is the most impactful and deadly global public health event in the world in the past 100 years (Xu, 2020). Many countries around the world have chosen lockdown and restrictions on people's mobility (home and community isolation) as the main strategies to combat the COVID-19 pandemic. These policies have increased residents' psychological anxiety and have caused harm to their physical and mental health (Liu et al., 2020). These actions have significantly modified urban soundscape, opening up an unprecedented opportunity for research in soundscape field (Asensio et al., 2020). Under the influence of pandemic, urban residents' desire for tourism, fitness, and leisure has increased, and residents have shown a strong physical and mental demand for urban public landscape (Wang et al., 2020; Lenzi et al., 2021), meanwhile, urban public landscape is facing substantial challenges as a result of the measures taken to limit the spread of the virus (Fu et al., 2020). It is a topic for reflection whether and what changes have taken place in people's soundspace preference in the urban public landscape in the post-pandemic era (Chen and Bai, 2021). In the pandemic and post-pandemic era, the change in the soundscape preference in general landscape space has become an essential factor to consider when designing public space. The preference for landscape and soundscape will continue to evolve as the pandemic continues and actions are taken to prevent its spread. This article aims to explore the reality of the soundscape preferences of Chinese urban residents in general landscape spaces under the influence of COVID-19 and then to propose design recommendations to meet the practical needs of people's preferences for landscape—especially soundscapes—in the post-pandemic era.

At present, the pandemic has put forward new requirements for the landscape and soundscape design of urban public spaces. Urban public space refers to the open space between architectural entities in a city or urban environment, mainly contains natural environments, such as mountains, forests, water systems, as well as artificial parks and green spaces, it is used for urban residents to conduct public communication and hold various life and social activities (Carr et al., 1993; Xi, 2021). At present, few method based on soundscape design was adopted for visual-centered tendency in landscape plan (Lian et al., 2020), but a large number of studies have shown that soundscape has a critical impact on people's viewing experience (Zhang, 2014; Kogan et al., 2021). Soundscape design attempts to discover principles and to develop techniques by which the social, psychological, and esthetic quality of the soundscape may be improved (Alfredo et al., 2014; Kogan et al., 2021). Soundscape (acoustic environment perceived and understood by an individual or society) can impact human health (Aletta et al., 2018a), and an upbeat soundscape is often associated with faster stress recovery and better self-reported health status (Kang, 2006; ISO, 2014; Aletta et al., 2018b; Liu et al., 2019a). Studies have found that natural sound can reduce the human heart rate (HR), respiratory frequency (RF), and respiratory depth (RD) (Li and Kang, 2019), natural sounds—such as bird songs—can reduce anxiety, relieve stress, and promote emotional stability (Annerstedt et al., 2013). Acoustics also has a significant impact in the medical and health field (Baird and Samson, 2015). Therefore, pleasant sounds can enhance people's viewing experience in an urban environment (Aletta et al., 2018a,b; Liu et al., 2019a). So far, many scholars have conducted detailed studies on cities (Zhang, 2016), villages (Ren, 2016), airports (Kitapci and Galbrun, 2019), and commercial spaces (Song et al., 2011; Meng and Kang, 2018), urban pedestrian streets (Yu et al., 2014) and historical districts (Zhou et al., 2012), etc. Although emerging studies have discussed the potential benefits of soundscape in mental restoration, few have investigated how soundscape renews and re-energizes people, especially in the face of the current public challenge of the COVID-19 crisis. In view of the pandemic, a moderated mediation model to reveal that natural soundscapes have great restorative benefits for visitors (Qiu and Zhang, 2021); a set of descriptors is outlined which better enables the application of more novel approaches to the evaluation of the effect of this new soundscape on people's subjective perception under the pandemic (Asensio et al., 2020). A case study of the human perception of environmental sounds in an urban neighborhood, discussed how such changes in the acoustic environment of the site under the pandemic (Lenzi et al., 2021). An online survey administered to 464 home workers in January 2021 in London, utilized a previously developed model for the assessment of indoor soundscapes to describe the affective responses to the acoustic environments (Torresin et al., 2021). These new literature make many ground-breaking contributions to the soundscape of the pandemic, and these results influence the further exploration of urban public space soundscape and the consideration of questionnaire questions in this study. However, the research on soundscape preferences in urban public landscape in the pandemic and post-pandemic era requires additional exploration. Under the demand of both pandemic prevention and leisure and fitness, exploring the residents' preference for urban general landscape and soundscape can guide the urban public landscape design in the post-pandemic era.

To achieve this result, this study used the subjective evaluation method to conduct an online questionnaire in 29 Chinese provinces with a high incidence of COVID-19 cases, from which 860 valid questionnaires were collected. This study revealed people's preference for landscape and soundscape after the pandemic, studied the correlation between landscape and soundscape preference, analyzed the influence of living conditions on soundscape preference, founded the effects of personal characteristics and living conditions on soundscape preference, and explored the strongest influence factors on soundscape preference through the establishment of automatic linear model. The main findings of the study revealed the direct impact of epidemic prevention measures on soundscape evaluation, summarized the main influencing factors of soundscape preference in the post-pandemic era, found the impact of individual factors on soundscape evaluation under the pandemic influence. Moreover, based on these analysis results, the design recommendations on landscape (overall landscape, plant, and tour space), soundscape construction of caring for vulnerable groups (teenagers and children, elderly people, and disabled and unhealthy) has been discussed.

METHODOLOGY

This study adopts theoretical research-question, investigation-data, analysis-proposed, and strategy research-design recommendations (**Figure 1**). Based on the concept and academic background of urban public space soundscape preferences, a questionnaire surveyed urban residents within 29 Chinese provinces with a high pandemic incidence to study the soundscape preferences of general landscape spaces in the post-pandemic era.

Research Area

To ensure the comprehensiveness of the questionnaire, the study mainly selected Hunan Province (29.81%, 256 responses),

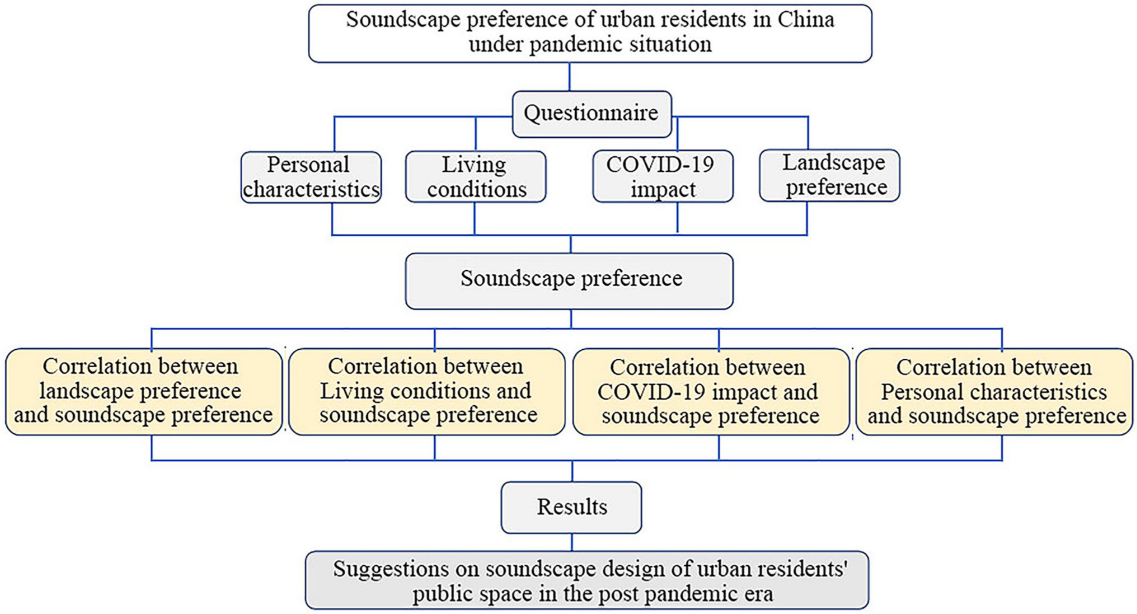

FIGURE 1 | Research concepts.

Guangdong Province (11.86%, 102 responses), Hubei Province (8.56%, 74 replies), Hainan Province (7.65%, 66 responses), Zhejiang Province (5.02%, 43responses), Hebei Province (4.40%, 38 responses), and an additional 23 provincial most severely infected administrative regions. Among them, Hubei Province is the most seriously affected by the pandemic. In total, 860 valid questionnaires were collected. The distribution and proportion of questionnaires in each province are shown in **Figure 2**.

Survey Object and Questionnaire Design

To ensure scientific rigor, this study uses questionnaires to conduct soundscape perception research (Ren et al., 2012, 2015; Meng and Kang, 2018; Pickens et al., 2019). This method is more suitable for research on the subjective evaluation of a population. We conduct a random sampling survey of people aged 10–60 who (have normal sound hearing) can subjectively evaluate public landscape and soundscapes in selecting survey subjects. The proportion of the essential characteristics of the respondents is shown in **Figure 3**.

The survey was conducted during a relatively stable time in the pandemic and post-pandemic era within China, from January to February 2021. This period is the Chinese New Year holiday; as such, people have more free time for exercise, leisure activities, and stress reduction than usual.

The research uses "Questionnaire Star" as the research tool. "Questionnaire Star" is a professional online questionnaire platform in China, which has been used to conduct more than 120 million questionnaires. We use random sampling to generate a QR code and distribute the questionnaire through WeChat.

This study summarized literature to produce 65 questions to survey the overall soundscape preferences of the respondents on three parts: the basic situation of the respondent (question 1-18), the landscape preference and overall feeling (question 19–30), and the soundscape preferences (question 35–64). The basic information of the respondents includes gender, age, occupation, annual family income, personal health, whether they have been infected with the coronavirus, and whether they have been vaccinated against the coronavirus. Questions about the surrounding greening environment were designed to investigate the greening rate, distance to the nearest green space, and the frequency of public landscape space use in the post-pandemic era. After the pandemic, the general landscape space preference includes several common public landscape space types, such as business districts, streets, squares, grasslands, forests, rivers, seashores, and fields (Guo, 2010). The comprehensive questionnaire is mainly designed to evaluate the preference of the soundscape. According to the ecological and semantic nature of the soundscape, the evaluation divides the sounds into six categories: traffic sounds, mechanical sounds, human activity sound, natural sound, livestock sound, and melody (Brown et al., 2011). Moreover, the Likert five-level scale was used to give evaluation levels for the soundscape: −2: immensely dislike, −1: dislike, 0: no preference, 1: like, and 2: immensely like (Zube, 1984). In addition, in order to avoid order effect, the second group (question 19–30) and the third group (question 35–46), When the respondents answer the questions in the "Questionnaire Star" mobile applet, the questions order will be randomly selected in group. Moreover, for the third group (question 35–46), half of the survey questions option is random adjustment has become from "2: immensely like, 1: like, 0: no preference, −1: dislike, and −2: immensely dislike", while the other half the survey questions option order are "−2: immensely dislike, −1: dislike, 0: no preference, 1: like, and 2: immensely like".

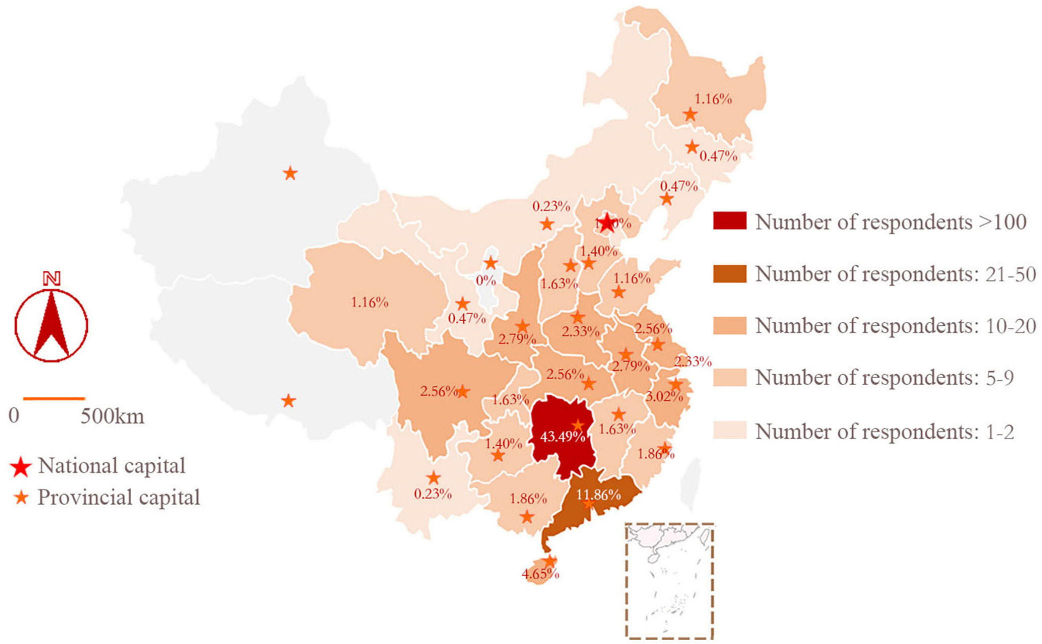

FIGURE 2 | Survey area and quantity distribution.

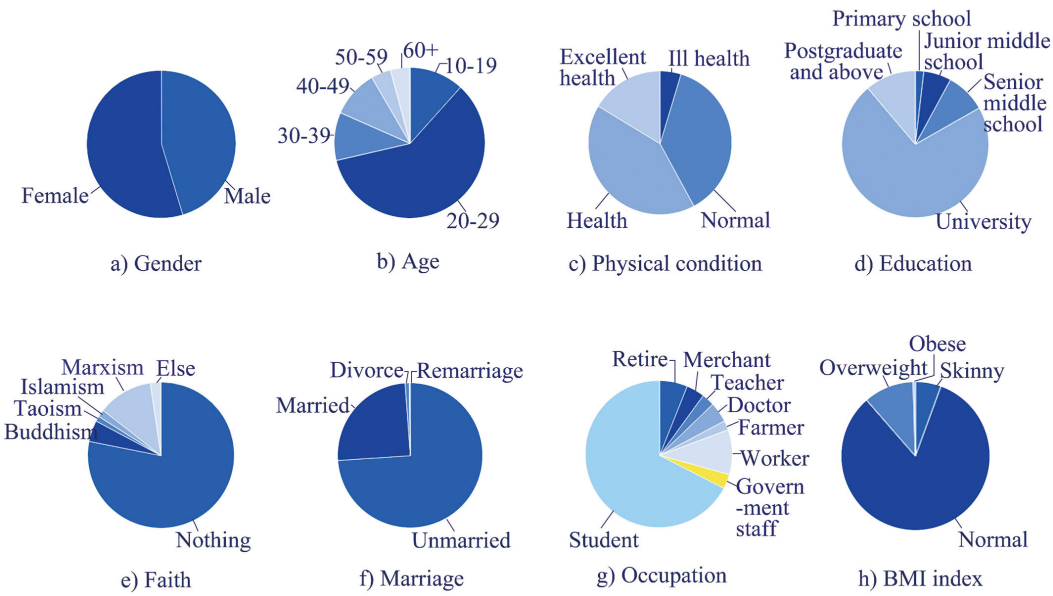

FIGURE 3 | Distribution of essential characteristics of respondents. BMI is a commonly used index to measure the degree of obesity and health in the world. The average value of BMI is between 20 and 25, more than 25 is overweight, and more than 30 is obesity. **(a)** Gender. **(b)** Age. **(c)** Physical condition. **(d)** Education. **(e)** Faith. **(f)** Marriage. **(g)** Occupation. **(h)** BMI index.

Appear with each question, audio is played (35 groups of sounds, 3 s each) to ensure that the respondent receives the same sound when making an evaluation (Ren et al., 2015); Before the questionnaire was distributed, 20 people were tested, the total average time to fill in the questionnaire is about 5 min (5 s to answer a question on average), it is considered reasonable to answer the questionnaire for no more than 10 min (Meng and Kang, 2018); a progress bar is provided to check the progress of the questionnaire. Furthermore, there is a lottery at the end of the questionnaire designed to increase the enthusiasm for participating and sharing. To remove invalid questionnaires and improve the survey's reliability, two questions

TABLE 1 | Average description of overall soundscape preference of Chinese urban residents in public space under the pandemic situation.

	Sound category			Description data	
Sound classification	**Code**	**Icon**	**Sound**	**Average**	**Total average**
Traffic sound	1		Farming sound	−0.93	−1.08
	2		Vehicle engine noise	−1.20	
	3		Road traffic noise	−1.31	
	4		Bicycle bells	−0.37	
	5		Ambulances sirens	−1.34	
	6		Police sirens	−1.33	
Mechanical sound	7		Construction noise	−1.53	−1.02
	8		Handmade sound	−0.50	
Human activity sound	9		Footsteps	−0.20	−0.67
	10		Conversational voice	−0.31	
	11		Strangers call	−1.07	
	12		Children frolic	−0.36	
	13		Babies crying	−1.07	
	14		Busking	−0.16	
	15		Dialect Hawking	−0.21	
	16		Coughing	−1.09	
	17		Crowd noise	−0.98	
	18		Sneezing	−1.21	
Natural sound	19		Rustle of leaves	0.83	0.55
	20		Wind howling	−0.02	
	21		Flowing waters	0.89	
	22		Torrential rain	0.30	
	23		Birds singing	0.77	
Livestock sound	24		Cockcrow	−0.43	−0.37
	25		Livestock call	−0.43	
	26		Pigs, cows, and sheep noises	−0.56	
	27		The chirping of cicadas	−0.12	
	28		Croaking of frogs	−0.30	
Melody	29		Temple bells	0.29	−0.19
	30		Pop music	0.30	
	31		Festival songs	0.03	
	32		Wedding March	0.10	
	33		Funeral music	−1.33	
	34		Local folk music	−0.05	
	35		Square dance music	−0.70	

are designed (e.g., please select 0) to eliminate weak responses (Ren et al., 2012).

Reliability and Validity Analysis of Questionnaire

The reliability and validity of the questionnaire data were tested using SPSS26.0 software. The research uses Cronbach α to analyze the reliability of the questionnaire. Literature suggests that if the value of Cronbach α is above 0.5 to 0.6, the results are reliable (Lu, 2004). The calculated responses of the questionnaire all meet this reliability standard: traffic machinery (0.835), human activity sound (0.879), natural sound (0.857), livestock sounds (0.889), and music (0.799). The overall perception factor reliability is 0.926. It can be concluded that the reliability of this questionnaire meets the survey requirements. To test the validity of the questionnaire, the study applied factor analysis to test the validity of KMO. The result was 0.907, which satisfies the conditions for factor analysis (KMO $\geq$ 0.6) (Lu, 2004), indicating that the validity of the questionnaire also meets the requirements. The Bartlett sphere test approximates the chi-square value of 9252.826, which corresponds to a probabilistic value of 0.000 ($P < 0.01$), suggesting that the questionnaire has a significant correlation and that its analytical data is valid.

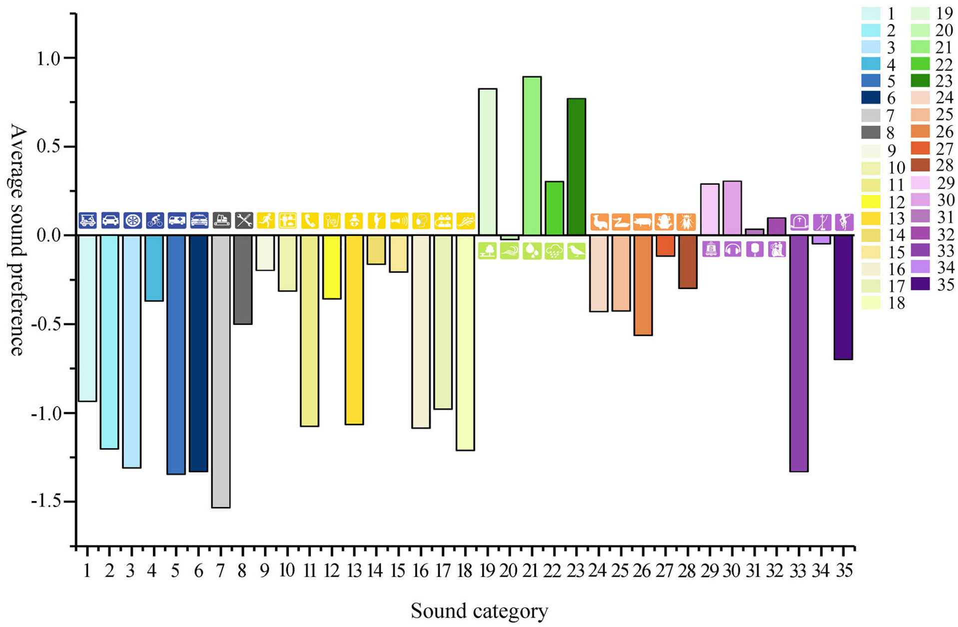

FIGURE 4 | Columnar distribution of the mean value of soundscape preference (code is shown in **Table 1**).

RESULTS

Soundscape Preference Overview in the Post-pandemic Era

As shown in **Table 1**, the most preferred sounds of urban residents in public landscape spaces in the pandemic and post-pandemic era are the sound of natural flowing water (0.89), wind blowing leaves (0.82), bird songs (0.77); popular music (0.32), heavy rain (0.31), temple bells (0.28), wedding music (0.09) and festival singing and dancing (0.03), indicating that people prefer natural sounds and music in public landscape spaces. The results of previous studies support these findings (Kang and Yang, 2002; Liu et al., 2019b).

The sounds that are highly disliked by urban residents include construction noise (−1.54), ambulance sounds (−1.34), funeral music (−1.33), police car sirens (−1.33), and road traffic noise (−1.31). These results are similar to previous conclusions (Zhang et al., 2018). However, it is worth noting that people's sensitivity to emergencies and deaths has increased under the influence of the pandemic, and the aversion of ambulance sounds, funeral music, and police car sirens is significantly higher than the noise of road traffic. Studies have shown that people's preferences often do not lie in the sound itself but their positive or negative emotions. Some long-term soundscape memories are preserved, which will produce different soundscape emotions (Liu and Kang, 2016). The conclusion further verified that positive or negative feelings brought about by sounds impact the degree of soundscape preference and that in the pandemic and post-pandemic era, specific sounds can have a particularly negative effect on people's psychological perception, the specific data is shown in **Figure 4**.

Correlation Between Landscape and Soundscape Preference in the Post-pandemic Era

According to the correlation analysis (**Tables 2**, **3**), the type of public landscape space, landscape structural design, and water landscape all affect the subjective evaluation of soundscape. In terms of overall landscape perception, those who prefer commercial areas demonstrate relatively acceptable to the sound of police car sirens. Still, they prefer the sound of children's frolicking, babies crying, frogs, cicadas, wind blowing leaves, birds, chickens, and square dancing. People who prefer in urban environments have a higher degree of preference for square dances and a relatively lower degree of preference for natural sounds. Those who prefer rural areas—grasslands, woods, mountains, rivers, seaside, and field landscape—show preference for natural sounds, sounds of livestock, children's frolicking, and farming work have a higher degree of preference.

In the selection of landscape structural design, those who use walkways have a relatively low preference for the sound of wind blowing leaves, while respondents who prefer water pavilions, waterside trails, and forest paths have a higher preference for the sound of wind blowing leaves. Individuals who prefer forest paths have a relatively high preference for the howling of the wind, while those who favor sports and benches have a low preference. In terms of water landscape preferences, those who favor the sea have a higher preference for pop music while individuals who prefer fountains are more receptive to the sound of square dancing.

Data analysis shows that wearing a mask has a significant impact on the correlation of soundscape preferences. The results

TABLE 2 | Correlation between public landscape space preference and soundscape preference under pandemic situation (code is shown in **Table 1**).

Sound classification		22. Purpose of going to urban park green space under the pandemic situation						23. Impact of the pandemic situation on living conditions				Landscape preference	
		View	Rest	Play	Recuperate	Motion	Walking pets	Family Day	Life state	Appreciation mood	Mask experience	Sculpture	Waterscape
Traffic sound	1	−0.027	0.088	0.003	0.013	−0.087	−0.031	0.007	−0.005	0.032	0.080	−0.035	0.080
	2	0.026	0.057	0.021	−0.006	−0.095*	0.023	−0.043	0.087	0.031	0.105*	−0.020	0.030
	3	−0.041	−0.001	−0.020	−0.008	0.000	−0.030	0.017	0.034	0.044	0.097*	−0.012	0.025
	4	0.068	0.062	0.034	0.000	−0.030	0.004	0.005	−0.003	−0.031	0.113*	0.012	0.014
	5	0.024	0.056	−0.004	0.044	0.063	−0.028	−0.010	0.098*	0.019	0.110*	−0.072	−0.069
	6	−0.006	0.084	0.039	0.012	0.076	−0.012	−0.028	0.132**	0.039	0.106*	−0.071	−0.014
Mechanical sound	7	−0.015	0.037	0.011	0.005	−0.035	−0.064	0.026	0.046	0.064	0.090	−0.056	−0.056
	8	0.074	0.086	0.061	0.014	−0.005	0.045	−0.015	−0.070	0.029	0.046	−0.038	−0.040
Human activity sound	9	0.036	0.045	0.050	−0.068	0.085	−0.031	0.043	−0.015	0.008	0.083	0.037	0.058
	10	0.030	0.052	0.034	−0.026	0.030	−0.057	0.075	0.007	−0.010	0.051	0.041	0.021
	11	0.040	0.132**	0.049	0.000	0.002	−0.052	0.038	0.094	0.045	0.088	0.025	−0.016
	12	0.027	0.031	0.047	0.020	0.006	−0.114*	0.145**	0.025	−0.069	0.069	−0.010	0.076
	13	0.054	0.027	−0.072	0.032	0.023	−0.059	0.081	0.071	−0.048	0.117*	0.086	−0.029
	14	−0.013	0.065	0.090	0.022	0.097*	−0.031	0.054	−0.059	−0.102*	0.059	0.003	0.065
	15	0.012	0.061	0.046	−0.004	0.007	−0.063	0.003	−0.081	−0.036	0.062	0.034	0.045
	16	0.003	0.055	0.044	0.004	0.036	0.006	0.071	0.059	−0.002	0.092	0.037	−0.017
	17	−0.081	0.061	0.016	0.041	0.077	−0.047	0.041	0.013	−0.010	0.032	0.011	−0.006
	18	−0.004	0.076	0.014	0.050	0.015	−0.034	−0.001	0.053	0.033	0.116*	−0.017	−0.016
Natural sound	19	0.057	0.068	0.065	−0.117*	0.061	−0.052	0.055	−0.088	−0.009	−0.077	0.114*	−0.059
	20	0.069	0.109*	0.071	−0.012	−0.059	−0.035	0.048	−0.053	0.058	0.031	0.104*	0.010
	21	0.117*	0.080	0.097*	−0.076	0.083	0.035	0.066	−0.090	0.015	−0.086	0.044	0.022
	22	0.087	0.138**	0.068	0.063	0.057	0.061	0.012	−0.073	0.021	−0.022	0.048	0.009
	23	0.108*	0.051	0.060	0.002	0.108*	−0.002	0.047	−0.137**	−0.046	−0.023	0.104*	0.011
Livestock sound	24	0.062	0.000	0.074	0.022	−0.083	0.000	0.083	0.105*	−0.003	0.056	0.060	0.005
	25	0.070	−0.050	0.027	−0.005	−0.044	−0.024	0.089	0.082	0.003	0.016	0.046	0.028
	26	0.049	−0.050	0.043	−0.017	−0.055	−0.011	0.062	0.032	0.005	0.062	−0.022	0.056
	27	0.079	0.062	−0.008	0.001	0.050	−0.049	0.042	−0.071	−0.044	−0.067	0.004	0.055
	28	0.075	0.016	−0.010	0.009	−0.025	−0.045	0.111*	0.072	0.038	−0.003	0.058	0.007
Melody	29	0.075	0.017	0.069	0.047	0.024	0.058	0.019	−0.038	−0.012	−0.060	0.032	0.048
	30	0.008	0.058	0.080	−0.021	0.050	0.032	0.001	−0.039	−0.025	−0.009	−0.006	0.136**
	31	0.099*	0.003	0.085	0.010	0.042	0.004	0.002	0.032	−0.027	0.042	0.003	0.051
	32	0.037	−0.021	0.061	−0.061	0.047	−0.031	0.010	0.011	−0.065	−0.001	−0.019	−0.008
	33	−0.037	0.035	−0.039	−0.014	0.053	−0.075	0.039	−0.002	−0.055	0.061	−0.032	−0.071
	34	0.053	0.007	0.071	0.021	0.103*	−0.015	−0.003	0.030	−0.077	0.066	−0.012	0.008
	35	0.015	0.005	0.084	−0.049	0.072	−0.059	0.026	0.068	−0.137**	0.075	0.027	−0.102*

Spearman correlation coefficient significance (for $P \leq 0.05$, **for $P \leq 0.01$).*

TABLE 3 | Correlation between public landscape space preference and soundscape preference 2 (code is shown in **Table 1**).

Sound classification		22. Purpose of going to urban park green space under pandemic situation					27. Preferred public landscape under pandemic situation									
		View	Rest	Play	Recuperate	Motion	Business zone	Street	Square	Stadium and	Lawn	Woods	Forest	Rivers	Sea	Field
Traffic sound	1	−0.136**	0.007	−0.003	−0.038	0.158**	−0.094	−0.058	−0.087	−0.033	0.028	0.178**	0.081	0.101*	0.013	0.110*
	2	−0.125**	0.001	−0.004	−0.035	0.139**	0.031	0.064	−0.003	−0.001	−0.017	0.059	−0.044	−0.053	−0.088	−0.060
	3	−0.043	0.048	0.061	0.011	0.022	0.034	0.024	−0.036	−0.001	0.018	0.030	−0.073	−0.069	−0.087	−0.064
	4	−0.063	−0.008	0.091	−0.032	0.105*	−0.061	−0.007	−0.051	0.012	0.037	0.089	0.007	0.067	−0.028	0.106*
	5	−0.030	0.058	0.057	0.013	−0.010	0.092	0.074	−0.017	−0.012	0.050	0.081	0.029	−0.040	−0.083	−0.052
	6	0.008	0.058	0.066	0.020	−0.039	0.106*	0.082	0.028	0.000	0.020	0.031	0.001	−0.028	−0.043	−0.051
Mechanical sound	7	−0.041	0.017	−0.005	0.073	0.037	−0.034	0.013	−0.034	−0.009	0.055	0.097*	−0.073	−0.079	−0.117*	−0.040
	8	−0.052	−0.003	0.070	0.094	0.046	0.000	0.012	−0.032	0.008	0.122*	0.116*	0.016	0.081	0.040	0.024
Human activity sound	9	−0.030	−0.054	0.139**	0.026	0.081	−0.068	−0.030	−0.040	−0.011	0.073	0.120*	0.083	0.054	−0.030	0.073
	10	−0.027	−0.062	0.097*	0.021	0.048	−0.032	0.029	−0.011	−0.039	0.075	0.116*	0.024	0.068	−0.039	0.087
	11	0.030	−0.029	0.028	0.078	0.040	0.000	0.064	0.028	0.064	0.070	0.110*	0.043	0.037	0.007	0.049
	12	−0.027	−0.040	0.070	−0.022	0.139**	−0.207**	−0.094	−0.074	−0.050	0.062	0.137**	0.064	0.076	−0.021	0.139**
	13	−0.024	−0.023	0.044	0.010	0.039	−0.135**	−0.072	−0.045	−0.041	0.081	0.094	−0.011	0.019	−0.060	0.030
	14	0.057	0.013	0.051	0.015	−0.024	0.047	0.004	−0.006	0.020	0.012	0.002	−0.073	−0.016	−0.008	−0.070
	15	0.057	−0.057	0.065	−0.009	0.028	0.004	−0.058	−0.025	−0.025	−0.023	0.038	0.019	0.012	−0.035	−0.002
	16	0.071	−0.042	0.002	0.051	0.024	0.022	0.020	0.022	0.046	0.018	0.047	−0.016	−0.009	−0.077	−0.019
	17	0.071	−0.042	0.060	0.016	−0.044	0.001	0.003	0.003	0.006	0.024	0.031	−0.055	0.034	−0.047	0.001
	18	0.049	−0.027	0.006	0.028	0.018	0.016	0.013	0.012	0.052	0.031	0.020	−0.089	−0.005	−0.051	−0.033
Natural sound	19	−0.013	−0.054	0.137**	0.010	0.060	−0.098*	−0.135**	−0.113*	−0.038	0.088	0.087	0.203**	0.132**	0.063	0.114*
	20	−0.037	−0.023	0.077	0.031	0.059	−0.062	−0.098*	−0.019	−0.042	0.098*	0.136**	0.163**	0.094	0.053	0.032
	21	0.014	−0.078	0.135**	0.065	0.068	−0.077	−0.093	−0.082	−0.053	0.125**	0.124**	0.217**	0.179**	0.100*	0.141**
	22	−0.035	−0.045	0.063	0.095*	0.078	−0.057	−0.099*	−0.042	−0.028	0.130**	0.104*	0.082	0.144**	0.048	0.039
	23	−0.022	−0.061	0.110*	0.023	0.127**	−0.102*	−0.106*	−0.101*	−0.072	0.114*	0.115*	0.177**	0.143**	0.069	0.146**
Livestock sound	24	−0.108*	−0.049	0.071	0.095*	0.195**	−0.107*	−0.036	−0.015	−0.049	0.137**	0.145**	0.150**	0.127**	−0.045	0.117*
	25	−0.046	0.011	0.084	0.102*	0.195**	−0.078	−0.069	−0.043	−0.043	0.105*	0.131**	0.170**	0.121*	−0.005	0.130**
	26	−0.080	0.007	0.055	0.140**	0.186**	−0.097*	−0.036	−0.051	0.011	0.069	0.143**	0.174**	0.126**	0.036	0.126**
	27	−0.028	−0.082	0.128**	0.052	0.148**	−0.170**	−0.079	−0.036	0.019	0.140**	0.218**	0.141**	0.146**	0.011	0.132**
	28	−0.071	−0.080	0.098*	−0.003	0.187**	−0.166**	−0.069	−0.041	−0.065	0.188**	0.220**	0.204**	0.167**	0.007	0.125**
Melody	29	−0.043	−0.067	0.171**	0.075	0.048	−0.027	−0.026	−0.058	−0.060	0.132**	0.167**	0.134**	0.181**	0.093	0.071
	30	−0.020	0.113*	0.097*	0.064	0.023	0.093	0.042	−0.039	0.003	−0.060	−0.051	−0.006	0.019	0.040	0.005
	31	−0.022	0.002	0.148**	0.073	−0.018	−0.008	0.020	−0.011	−0.030	0.007	0.018	0.022	0.069	−0.042	0.050
	32	−0.053	0.033	0.115*	0.019	0.027	−0.020	0.037	−0.078	−0.021	0.061	0.027	0.009	0.040	−0.071	0.031
	33	0.033	−0.018	0.039	−0.005	0.014	0.015	−0.002	−0.007	−0.015	0.001	0.005	−0.103*	−0.046	−0.110*	−0.090
	34	−0.038	0.044	0.178**	0.047	0.021	0.006	0.038	−0.037	−0.006	0.053	0.028	0.061	0.122*	−0.025	0.069
	35	0.064	−0.028	0.106*	−0.034	−0.007	−0.111*	0.097*	0.104*	−0.033	0.061	0.066	0.020	0.026	−0.140**	0.050

Spearman correlation coefficient significance (for P ≤ 0.05, * * for P ≤ 0.01).*

TABLE 4 | Correlation between personal living conditions and soundscape preference (code is shown in **Table 1**).

Soundscape preference			Greenspace		
Sound classification	**Code**	**Icon**	**(19)**	**(20)**	**(21)**
Traffic sound	1		0.101*	−0.026	0.034
	2		0.107*	−0.036	0.014
	3		0.033	0.008	0.025
	4		0.073	−0.027	−0.035
	5		0.083	−0.097*	0.024
	6		0.083	−0.079	−0.008
Mechanical sound	7		0.017	−0.029	−0.002
	8		0.121*	−0.046	−0.030
Human activity sound	9		0.081	−0.051	0.037
	10		0.063	−0.043	0.058
	11		0.076	−0.106*	−0.025
	12		0.044	0.003	0.003
	13		−0.002	−0.017	−0.013
	14		−0.031	−0.004	0.037
	15		−0.018	−0.026	0.053
	16		0.012	−0.119*	−0.036
	17		0.030	−0.076	0.005
	18		−0.018	−0.031	−0.066
Natural sound	19		−0.031	−0.044	−0.020
	20		0.049	−0.053	0.040
	21		0.019	−0.016	0.019
	22		−0.067	0.030	0.029
	23		0.023	0.047	0.037
Livestock sound	24		0.104*	0.018	0.109*
	25		0.060	0.043	0.110*
	26		0.047	−0.004	0.097*
	27		0.034	−0.024	0.075
	28		0.081	0.029	0.054
Melody	29		−0.019	−0.007	0.027
	30		0.062	0.007	0.022
	31		0.021	−0.027	0.065
	32		0.042	0.002	0.059
	33		−0.060	0.007	−0.048
	34		0.052	0.034	0.048
	35		−0.019	−0.008	0.041

Spearman correlation coefficient significance (for P ≤ 0.05).*

show that if low numbers of people wear masks while viewing the scenery, there is a lower preference for the sounds of traffic, mechanical sounds, and stranger calls, babies crying, coughing, and sneezing. Conversely, people who wear mask when viewing the scenery will give a relatively lower soundscape evaluation on the noise.

On the whole, soundscape preference is inseparable from the environmental conditions and the atmosphere created by the public landscape space. Visual landscape preference indirectly affects the overall soundscape preference through the perceived incidence and loudness of sound (Liu et al., 2019b). The results verify that people's subjective evaluations of soundscapes are closely related to the soundscape conditions that typically appear in specific environments and the usual atmosphere. In the case of a long-term pandemic, public landscape designers need to consider the impact of wearing masks on people's perception of soundscapes.

Influence of Living Conditions on Soundscape Preference in the Post-pandemic Era

The results (**Table 4**) show that the greening rate (19), the distance (20) of the green space, and the frequency of going to the public green space are related to the purpose (21) and the degree of soundscape preference. Based on the correlation results obtained, it can be inferred: in terms of greening rate, the higher the surrounding greenery, the higher the degree of people's preference for industrial noise, farming work, chicken crows, and vehicle engine noise. In terms of green space distance, the closer the residents are to the green space, the higher the tolerance for strangers' calling, people clearing their throats, and ambulances. In terms of the frequency of going to the green space, the higher the frequency of going to the green space, the more people like the sound of livestock. This may mean that green spaces can bring people closer to nature, therefore people prefer animals more. In general, the results of this study combined with the theory of stress reduction and the theory of attention recovery (Wen, 1989), can further speculate that the surrounding greening rate can relieve people's stress and fear in the post-pandemic era in the city.

The Influence of Other Factors on the Soundscape in the Post-pandemic Era

Personal Characteristics

Gender

This study found that gender has a negligible effect on soundscape preference in the post-pandemic era, which is consistent with the results of previous studies (Yu and Kang, 2010). The results (as shown in **Figure 5**) show that men have a lower preference for square dance sounds than women, but they have a higher acceptance of howling winds. In China, square dance activities are dominated by women, and women are more sensitive and emotional than men, this also provides an explanation to why woman's soundscape preference for the wind and whistling sounds is lower for men (Meng et al., 2010).

Age

According to related studies, age and soundscape preference are significantly correlated (Meng et al., 2010; Aletta et al., 2019). It can be seen from **Figure 6**, that the respondents' age is positively correlated with natural sounds such as the sound of people's activities in the post-pandemic era, the sound of wind and leaves, running water, domestic animals, festival songs and dances, and the sound of local folk music; but it is negatively correlated with pop music. This suggests that as residents grow older, their evaluation of the soundscape of human activities, natural sounds, domestic animal sounds, and music increases while their auditory preferences of pop music decreases. These results are consistent with the results of previous studies (Zhou et al., 2012). This result suggests that the older adults favor children and conversation over other auditory stimuli in the post-pandemic era.

Occupation

According to the correlation analysis, it is found that occupational factors have a significant impact on the subjective evaluation of soundscape preferences. As shown in **Figure 7**, doctors, retirees, and teachers have relatively high preferences for human activity sounds, natural sounds, and music, while workers and government workers have low preferences for human activity sounds and natural sounds. Retirees have the highest preference for the sound of wind blowing leaves. Students have a lower preference for the sound of domestic animals, babies crying, local folk music, and square dancing. The results suggest that professionals who have more contact with people—such as doctors and teachers—generally have a higher tolerance for acoustic disruptions than other occupations and that migrant workers, government workers, and students have fewer soundscape preferences in the post-pandemic era.

Faith

As shown in **Figure 8**, Islamic people have a lower degree of preference for the sound of pigs, cattle, and sheep, while Marxists have a lower degree of preference for the sound of howling wind. Respondents who do not identify as religious have a highest preference for popular music while those who

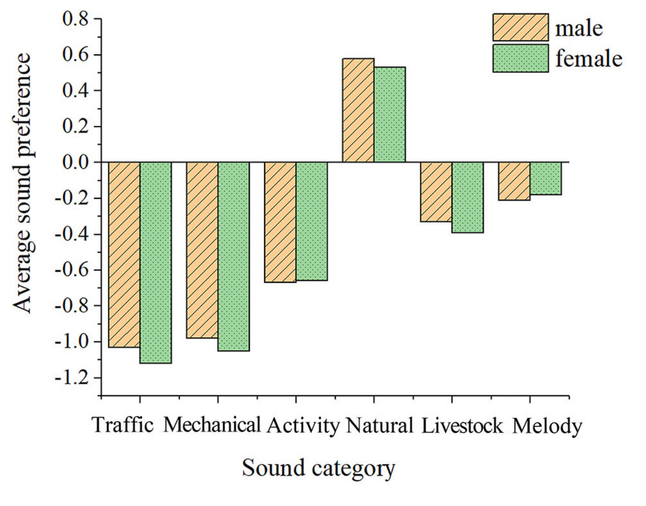

FIGURE 5 | Average soundscape preference of people of different genders.

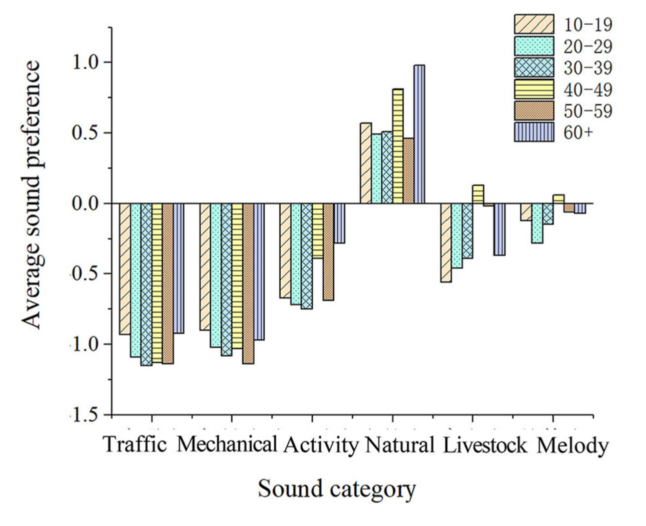

FIGURE 6 | Average soundscape preference of varying age groups.

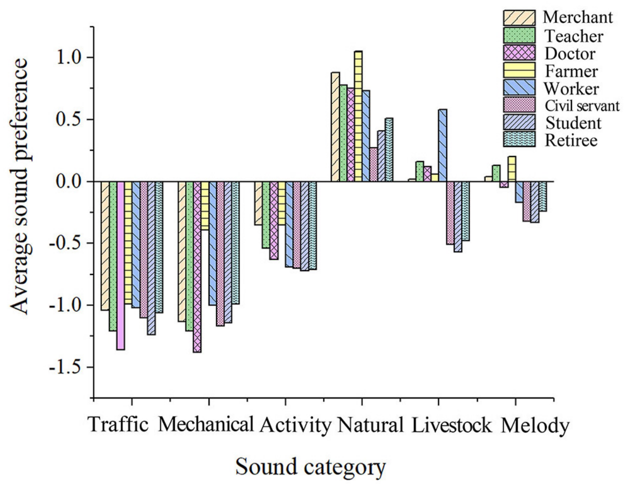

FIGURE 7 | Average soundscape preference of different occupational groups.

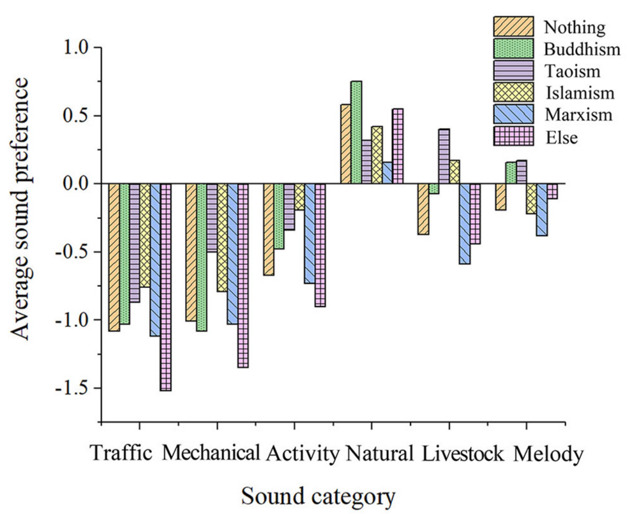

FIGURE 8 | Average soundscape preference of people of different beliefs.

identify as Buddhists and Marxists have the lowest. Islamic practitioners' preference for funeral music is higher than that of other religious believers. Religious ideology impacts the degree of soundscape preference; it is possible that the living habits and specific religious belief of an individual can indirectly affect the evaluation of soundscape in the post-pandemic era.

Education

As shown in **Figure 9**, the level of education is negatively correlated with the soundscape preferences of square dances, livestock sounds, wedding music, children's frolicking, babies crying, farming operations, and vehicle engine sounds in the post-pandemic era. This study supports the conclusion that the higher the level of education, the lower their soundscape preferences and comfort (Meng et al., 2010).

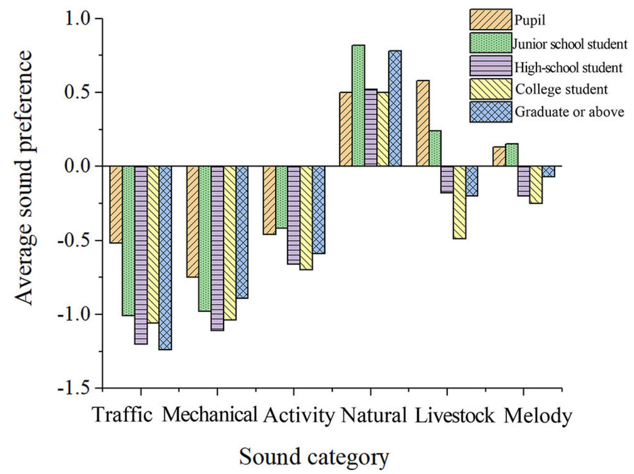

FIGURE 9 | Average soundscape preference of differently educated people.

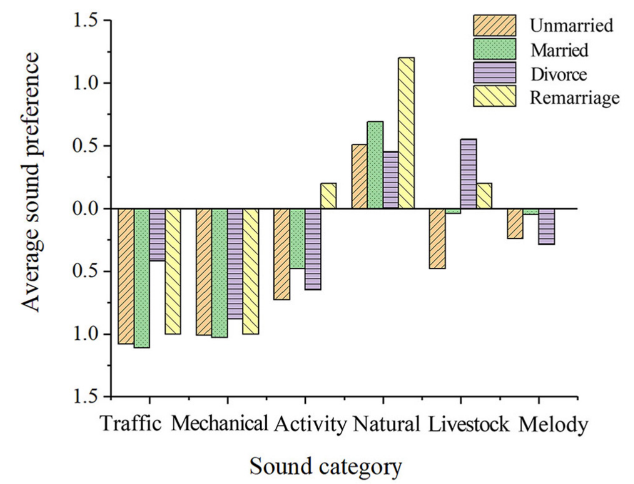

FIGURE 10 | Mean value of soundscape preference of different marriage groups.

Marriage

As shown in **Figure 10**, married people have a higher preference for conversation, children's frolicking, and baby crying, while unmarried people have a lower preference for cock crowing in the post-pandemic era. The surveyed results suggest married people are more tolerant of crowds and children and that they are more inclined to social gatherings than unmarried people.

Number of Children

As shown in **Figure 11**, with the increase in the number of children, people's preference for children's frolicking, human speech, domestic animal sounds, square dances, and local folk music increases. This result may reveal that families with more children are more likely to participate in social activities in the post-pandemic era.

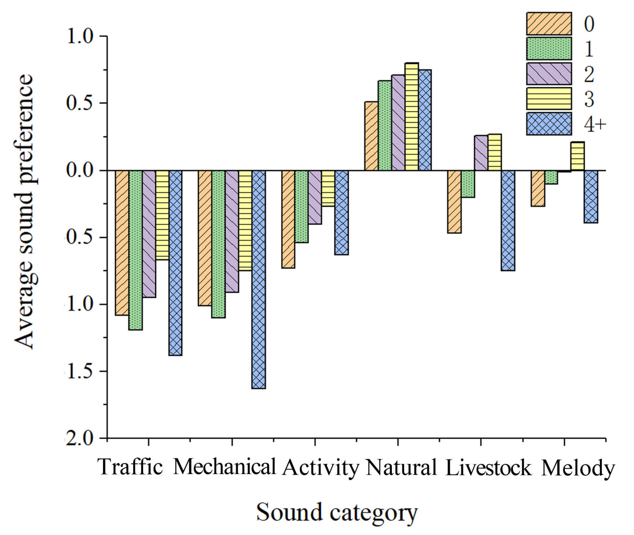

FIGURE 11 | Sound preference of families with different numbers of children.

Family Housing Situation

According to the correlation analysis, the annual household income has no significant impact on the soundscape preference evaluation. Still, the family housing situation is correlated with soundscape preferences (**Figure 12**). The results show that the better housing conditions are, the lower the tolerance for acoustic disturbances. However, individuals who rent houses and villas have a high degree of preference for children's frolicking, in contrast, residents living in white-collar apartments and high-rise buildings have less preference for children's frolicking. It may be revealing that young working-class people have increasing economic and reproductive pressures, and have a lower preference for children in the post-pandemic era.

Overall, under the impact of COVID-19, in terms of personal characteristics, family environment, age, occupation, education, and family housing are the main factors affecting soundscape preference. Gender, beliefs, marriage, and other factors have a certain degree of influence on auditory preference. Physical condition, BMI, annual family income, and the number of people in the family have no significant impact on soundscape preferences in the post-pandemic era.

Life State Under the Impact of the Pandemic

The Impact of Vaccination

To explore whether the COVID-19 vaccination impacts the preference of the soundscape, this manuscript analyzes the correlation coefficient and significance level of the Chinese respondents' vaccinations of the vaccine (12) and the preference of the soundscape (**Table 5**).

(10) Compared with before the pandemic, has your BMI changed?
(11) Have you been infected with COVID-19?
(12) Have you and your family or friends infected with COVID-19?
(17) Compared with before the pandemic, do the soundscapes make you feel more nostalgic?

The study found that people have a lower preference for ambulances and construction noise regardless of whether they are vaccinated with the vaccine. The pandemic has caused many deaths and illness and has caused an increase in people's sensitivity to grief events and noise. Interestingly, the injection of the vaccine brings people a sense of psychological security. The results show that vaccinated people have a slightly higher preference for road noise, handicraft noise, throat coughing, live street performances, and wind whistling sound than unvaccinated individuals. Furthermore, they have a slightly higher preference for human footsteps as well as for having conversations in the post-pandemic era.

Influence of Hometown Attachment and Happiness

After investigating whether respondents reside in their hometown, their attachment to their hometown, and the happiness in their life, this article finds that soundscape preference is somewhat affected by homesickness and joy. The results show that people who reside in their hometown have a higher preference for the sound of heavy rain, livestock, and temple bells, while respondents who feel nostalgic toward their hometown have a higher preference for the sound of vehicle engines, human conversations, children's frolicking, festive singing, and dancing. Individuals who identify as having high happiness in their lives have a high degree of preference for wedding music and square dance sounds. Their preference for the sound of human footsteps, human conversation, festival singing, dancing, and local music and art is also higher than those with lower happiness levels. This is consistent with previous studies which have suggested that people with higher happiness are more likely to report positive soundscapes. Conversely, people with lower happiness levels are more likely to have negative attitudes toward the sound environment (Aletta et al., 2019). It can be inferred that happiness and hometown attachment can increase an individual's soundscape evaluation in the post-pandemic era.

The Influence of Socioeconomic Status on the Perception of Soundscape

The socioeconomic status of an individual or family is often considered comprehensively based on factors such as income, education, and occupation (Wen, 1989). Evidence suggests that the better the family's housing situation, the lower the degree of people's preference for noise such as traffic sounds. In the post-pandemic era, it is worth noting that among those with a high socioeconomic status, individuals who live in villas and those with extreme affluence have a high degree of preference for the sound of children's frolicking. In contrast, residents who live in white-collar apartments and high-rise buildings have less preference for the noises of children's frolicking. The higher the level of education, the higher preference for most music and human activity sounds—especially children's frolicking and babies crying—while preference for livestock sounds and traffic noise is lower. In terms of occupation, doctors and teachers have a relatively high preference for human activity sounds, natural

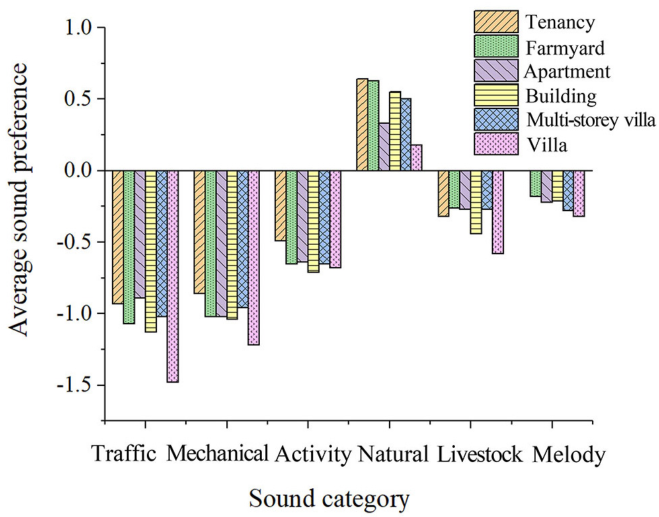

FIGURE 12 | Sound preference of people with varying conditions of housing.

sounds, and music. Government workers have a low preference for human activity sounds and natural sounds.

Overall, It can be inferred that the higher the socioeconomic status, the lower the tolerance for noise. With the different attributes of different occupations, the soundscape preferences of people with high socioeconomic status are more targeted, which is related to the nature of their careers in the post-pandemic era.

Soundscape Preference of Vulnerable Groups

Soundscape Preference of the Elderly

The elderly people are prominent participants in the public landscape space, and their preference for soundscape landscape is a critical indicator of soundscape optimization. At present, scholars have researched the auditory needs of the elderly and found that they prefer natural sounds and stimulating music (Wang and Kang, 2020). However, their preference is often affected by the type of activity in which they are participating. For example, when playing ball or sitting they tend to prefer sound while when they are playing or watching chess, they do not want to hear any sounds, including soothing music. On the whole, amongst the elderly there is a significant positive correlation between the general sound environment and the preferences for additional natural sounds (Wang et al., 2020). This study shows that people aged 50–59 and over 60 have a high preference for human activity sounds, natural sounds, domestic animal sounds, and music. They have a low preference for pop music sounds under the influence of the pandemic.

Soundscape Preferences of Teenagers and Children

Studies have shown that the soundscape of urban parks can promote children's psychological and physiological recovery (Shu and Ma, 2020). Therefore, the soundscape preference of teenagers and children is essential when considering soundscape design in environments with many adolescents. The results of this study show that teenagers have a higher preference for the sound of wind blowing leaves, running water, bird songs, festive singing and dancing, and pop music. Under the influence of the pandemic, they have a high preference for the sounds of footsteps, conversations, children's frolicking, and babies crying, besides, the soundscape preference for the sounds of chickens, domestic animals, cicadas, frogs, and square dancing are relatively low. This suggests that adolescent soundscape preferences are biased toward soothing natural sounds and modern music and are not interested in human activities, domestic animal sounds, and natural sounds and traditional music in the post-pandemic era.

Soundscape Preferences of Unhealthy and Obese People

The survey results show that, under the influence of the pandemic, people in poor physical condition (9) have a higher preference for the sound of wind blowing leaves, while obese people (10) have a higher preference for square dancing. This suggests that unhealthy people desire the related healing effect of natural sound, while obese people have the desire to do outdoor-related exercise under the influence of the pandemic.

In general, the elderly people, adolescents, and unhealthy people have a higher preference for natural sound, especially the elderly. The soundscape preferences of teenagers and children are more inclined toward popular music. Obese people have a higher preference for square dancing—perhaps due to their desire for exercise. The Soundscape preferences of disadvantaged groups are affected by their own psychological and physical requirements, and the soundscape can alleviate their physical and mental needs to a certain extent in the post-pandemic era.

Automatic Linear Model of Soundscape Preference in the Post-pandemic Era

To further analyze the preference of soundscape, the automatic linear model is applied with SPSS26.0, andsoundscape preference

TABLE 5 | Correlation between life state and soundscape preference in the post– (code is shown in **Table 1**).

M	Life state					
Code	(10)	(11)	(12)	(16)	(17)	(18)
1	−0.028	−0.083	−0.043	0.087	−0.077	0.049
2	0.003	0.006	−0.071	−0.009	−0.115*	−0.012
3	−0.004	−0.083	−0.102*	−0.024	−0.068	−0.043
4	−0.064	−0.051	−0.082	0.036	−0.095*	0.006
5	0.033	−0.097*	−0.056	0.039	−0.019	0.015
6	0.037	−0.078	−0.075	0.017	−0.011	0.032
7	−0.021	−0.162**	−0.086	−0.001	−0.060	−0.025
8	−0.077	−0.128**	−0.150**	0.094	−0.018	0.013
9	0.025	−0.007	−0.133**	0.021	−0.091	0.139**
10	−0.003	−0.032	−0.147**	−0.052	−0.195**	0.135**
11	−0.015	−0.043	−0.088	0.008	−0.082	0.071
12	0.018	−0.043	−0.068	−0.004	−0.150**	0.083
13	0.018	−0.052	−0.084	0.027	−0.085	0.021
14	−0.024	−0.097*	−0.098*	0.032	−0.050	0.081
15	−0.040	−0.043	−0.075	0.019	−0.116*	0.064
16	−0.045	−0.085	−0.061	0.036	−0.060	0.039
17	0.010	−0.057	−0.114*	−0.014	−0.065	0.024
18	−0.040	−0.079	−0.073	0.046	−0.033	0.005
19	0.042	0.043	0.005	0.013	−0.028	0.026
20	−0.002	0.031	−0.047	0.042	−0.052	0.086
21	0.005	0.002	−0.090	0.092	−0.063	0.027
22	−0.005	−0.047	−0.073	0.105*	0.022	0.032
23	0.052	0.013	−0.059	0.013	−0.071	0.017
24	−0.002	−0.016	−0.057	0.067	−0.074	0.039
25	−0.019	−0.028	−0.087	0.052	−0.075	0.049
26	−0.075	0.006	−0.065	0.108*	−0.040	0.047
27	0.010	−0.021	−0.039	0.026	−0.058	0.042
28	0.044	0.017	−0.095	0.056	−0.053	0.078
29	−0.061	−0.076	−0.035	0.106*	−0.022	0.025
30	−0.012	−0.018	0.000	−0.020	−0.065	0.093
31	0.055	−0.069	−0.071	0.063	−0.114*	0.104*
32	0.054	−0.026	−0.035	0.018	−0.137**	0.065
33	0.014	−0.059	−0.011	0.042	−0.019	−0.031
34	0.022	−0.028	−0.057	0.067	−0.087	0.088
35	0.107*	−0.007	−0.044	−0.023	−0.103*	0.032

Spearman correlation coefficient significance (for $P \leq 0.05$, * * for $P \leq 0.01$).*
M, sound type.

evaluation is divided into the target variable. The relationship between 52 other predictive variables is shown in **Figure 13**.

In the overall factors, happiness and the soundscape preference for the personal assessment show a strong positive correlation. It can be assumed that if the pandemic reduces people's happiness, it will directly force the soundscape preference to decrease, which indicates that the pandemic has a weakening effect on soundscape preference. In addition, it is found that people who like the landscape of the forest path, more sensitive to the sound of police sirens, babies crying, footsteps, busking, and torrential rain have a higher soundscape preference evaluation score in the post-pandemic era.

In particular, it can be inferred that people who are unwilling to wear a mask to enjoy scenery have a relatively higher total subjective evaluation score. This suggests that wearing masks directly reduces people's evaluation of soundscape, revealing that the epidemic affects soundscape evaluation in another way. In addition, it is found that people who like water environment—with preference for rivers, fountains waterfalls—had a negatively correlated soundscape evaluation in the post-pandemic era. This may be because people who like water scenes tend to be quiet and reflective, rather than disturbed by other sounds. Moreover, this study found that people who like do leisure sports—with preference for benches and sports equipment—had a negatively correlated soundscape preference evaluation. This may be because people who enjoy leisure and exercise do not like to be disturbed, so they have lower soundscape evaluation score.

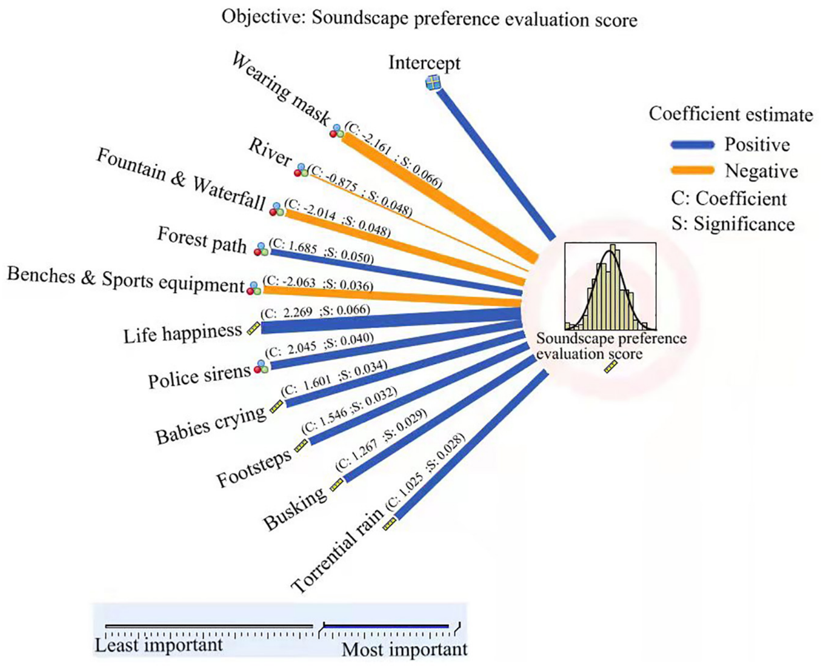

FIGURE 13 | Automatic linear model of soundscape preference evaluation score as target.

CONCLUSION

This study used the subjective evaluation method to conduct an online questionnaire survey in 29 Chinese provinces with high infection rates. By analyzing the correlation and reasons for different landscape and soundscape preferences, it was found that people with different attributes have different perceptions of landscape and soundscape in the post-pandemic era. The main findings are summarized as follows:

Direct Impact of Pandemic Prevention Measures on Soundscape Evaluation

Wearing Masks

Among common quarantine measures during the pandemic, wearing masks significantly reduced soundscape perception ratings, especially for sounds that people did not like before the pandemic, such as traffic, babies crying, construction, and stranger calls. People also show great aversion to audible hints of possible infection, such as clearing their throats and sneezing.

Vaccine

People who have been vaccinated are more tolerant of various noises. Their preference for road noise, handicraft noise, people clearing their throats and coughing, live street performances, and gale screaming is slightly higher than that of unvaccinated individuals. Their preference for human footsteps and human conversations is higher, revealing that they showed relative trust and security toward strangers.

Main Influencing Factors of Soundscape Preference in the Post-pandemic Era

Main Influencing Factors

The study confirms that the overall soundscape preferences of urban residents in public spaces were affected by the pandemic. The results revealed natural sound and music have the highest overall impact on soundscape preference, whilst the overall value of soundscape preference for traffic sounds is the lowest. Among the natural sounds, the top 3 preference are natural running water, wind blowing leaves, and bird song.

Impact of the Epidemic

Under the pandemic situation, people show high sensitivity to emergencies and deaths, which affects the evaluation of soundscape preferences to a certain extent. Ambulance sounds, funeral music, and police car sirens accounted for higher aversion than road traffic noise which are usually the least preferred.

Impact of the Landscape

Under the influence of the pandemic, people's subjective evaluation of soundscape is closely related to the landscape. Public landscape space type, landscape structure design, and water landscape are the three most important landscape factors that affect the soundscape preference, which reaffirms that people can indirectly affect the overall sound landscape preference through the spectrum and loudness of perceived soundscape.

Impact of the Greening Rate

In the post-pandemic era, the high correlation of data analysis shows that increasing the greening rate can improve the evaluation of sound landscape to a certain extent, and the closer the distance between residents and green space, the higher tolerance of noise to a certain extent. Moreover, people who visit green Spaces more often are likely to enjoy animals more.

Impact of Individual Factors on Soundscape Evaluation Under the Pandemic Influence

Main Influencing Factors

Among personal characteristics, age, occupation, education, and family housing are the main factors that affect soundscape preference. In contrast, gender, belief, marriage, and other factors have a secondary degree of influence on auditory preference. Physical condition, BMI value, annual family income, and the number of older people in the family do not affect soundscape preferences.

Disadvantaged Groups

The soundscape preferences of disadvantaged groups are often affected by their own psychological and physical needs. Some elderly people are fonder of physical activities, natural sounds, livestock sounds, and music. They express their yearning for the natural environment and lively crowds. Children's soundscape preferences tend to be soothing natural sounds and trendy music which is more energetic. Obese people have a higher preference for square dancing due to their own fat loss needs in the post-pandemic era.

Life Happiness

In the overall subjective factors, life happiness and the soundscape evaluation for the personal assessment show a strong positive correlation.

DISCUSSION

Based on the above conclusions, in this section, we presented some discussions on applying the findings to the design recommendations of urban public space in the post-pandemic era.

Design Recommendations of Landscape to Enhance Soundscape Experience in the Post-pandemic Era

Overall Landscape Design

The study found that the subjective evaluation of soundscape is closely related to the acoustic conditions of the place and the landscape. Within the overall landscape design, the integration of soundscape must be fully considered; a harmony can be created through architectural landscape structural design, waterscape, plant design, as well as other methods. The soundscape interacts with different landscape to form a good environment of audio-visual integration. Secondly, it is necessary to enrich the space with activities to guide people's behavior and reduce people's perception of unfavorable soundscape factors.

Green Environment Design

Studies have found that the greening rate, the distance to green space, as well as the purpose and frequency of public green space use, impacts soundscape preference. Previous studies have also found that increasing exposure to green plants can reduce stress, thereby affecting the soundscape evaluation. Green landscape, walkways, and trails can be set up to produce the sound of wind blowing leaves, thereby triggering people's resonance with natural sounds. However, it is not suitable to set up a natural soundscape beside promenade, sports equipment, benches, and other sports and leisure facilities, which mainly emphasis the soundscape of human activities.

Blue Environment Design

According to the research results, people show a greater willingness to approach blue environment in the post-pandemic era. Landscape design should increase the capacity of blue environment, as far as possible to make people close to or watch the water, fountains or listen to the sound of rain. If some devices can be properly set up, the water can be enlarged or activated, which will help people relax, more contact with nature, and improve the scenery experience.

Tour Space Design

This study found that the comfort of wearing a mask has a significant impact on evaluating soundscape preference. People who have a worse viewing experience when wearing a mask have a lower preference for traffic sounds, mechanical sounds, and human activities. On the contrary, people who wear masks are more inclined to traffic sounds, mechanical sounds, and human activity sounds. Wearing masks in the post-pandemic era has become the norm. Considering the characteristics of individuals with negative experiences of wearing masks, the distance between people should be considered in the design of tour routes and transition space should be constructed to form the appropriate distance between individuals, thereby reducing the epidemic impact on human activities.

Soundscape Construction of Caring for Vulnerable Groups

Soundscape Design for Teenagers and Children

According to the data analysis of the survey, families with many children are averse to police sirens, popular music, and funerals; they prefer the sound of human activities, nature, domestic animals, and festive sounds. This shows the importance of sound landscape design for children's activity space design. To make children have a better experience, designers should create a natural and beautiful soundscape environment while fully integrating natural elements into the site design. Natural materials can be used to make game facilities and environments that are esthetically pleasing. Soundscape design is not limited to traditional forms and can include direct sounds, such as horns, background music, or sounds produced by the natural environment, such as water, wind, insects, and birds. Unique and exciting shapes and sounds can create a compelling space for children to play.

Soundscape Design for the Elderly

According to questionnaire analysis, it is understood that families with many older people do not like to rest; instead, they want to exercise. They also like to go to places with mountains, rivers, and forests. Still, designers should not only create landscape that the older people prefer but must also take their physical condition and safety into consideration. In this regard, we can put forward the following landscape suggestions:

① Construct barrier-free design and transform the road system. For example, set up safe passages for the elderly people on the main routes, increase safety handrails, non-slip pavement, and warning signs.

② Rest areas design for the elderly people. Even though the elderly people may not like to rest very much, they are prone to fatigue when walking outside. Therefore, constructing seats in activity spaces is necessary to allow them to perform rest and setting up trash cans near the seat to facilitate the collection of waste. Developing corresponding service facilities will allow comfort and security to be brought to the elderly people.

③ Regarding the layout of outdoor space plants, it is necessary to consider the coordination of the overall layout. Making a reasonable plan for the shape and color of the plants, while considering outdoor attractions that the elderly people enjoy is essential to overall design. The effect of the plants, plant distributions, plant types, and terrace designs can be used to divide the area for the elderly people. Furthermore, different plant areas can be set for the elderly people with different plant preferences and physical health conditions. Waterscapes should also be added near the plant area to play a role in esthetics and adjustment of the microclimate of the area.

Soundscape Design for the Disabled and Unhealthy

For people with poor health—including people with physical disabilities—the survey results show that they have no preference for going out and exercising. Still, they favor the sound and melody of square dances. In this case, the scenery for people with poor health is not essential as they do not frequently use the facilities. Instead, a space should be placed a little further way where people can dance. The environment can be equipped with speakers to play music so that it will not be too noisy for those in poor health. For people with hearing disabilities, visual cues such as text, lights and guardrails should be added to ensure their safety and improve their viewing experience as much as possible. These design recommendations could satisfy their soundscape preference and attract them to hang out in the space, which will benefit for their physical and mental health.

Reflection

Through the research process, the methodology is valid and can be investigated on a variety of people. This article only studies the impact of the COVID-19 pandemic on the soundscape preferences of Chinese urban residents from the perspective of relevance. It does not consider the changes brought by the pandemic comprehensively. Moreover, because this study was based on statistical correlations, conducted in the post-pandemic era after the outbreak was contained, it could not show absolute cause and effect from the pandemic, the correlations shown by certain factors do not rule out the possibility of some kind of coincidence. In the future, the study and discussion can be strengthened to provide more powerful theoretical support for constructing soundscapes in urban environments.

LIMITATIONS AND STRENGTHS

This study focuses on social hotspots and the new changes of soundscape preferences of urban residents in China in the post-pandemic era, the limitations and strengths are as follows:

Limitations

(1) Because soundscape preference is indirectly affected by the pandemic, there are not only two factors ("wearing masks" and "getting vaccinated") related to pandemic, but in fact, all thoughts and all aspects of life will be affected by the pandemic, indirectly causing unknown influence on soundscape preference. In this context, the purpose and conclusion of this study are uniformly focused on people's behaviors, habits and preventive measures to find the new soundscape preference, and reveal the links between soundscapes and other aspects in the post-pandemic era.

(2) Because of a lack of related information collection in the pre-pandemic, the research results cannot reveal the changes of soundscape preference during the pandemic process, nor can they fully demonstrate the causal relationship of soundscape preference under the influence of the pandemic. The correlation between the investigated factors can only be demonstrated from the perspective of data analysis.

Strengths

(1) Compared with other studies on soundscape preference, this study adopted the first plateau period after the outbreak of the pandemic, which can reflect people's subjective feelings.

(2) In order to maximize the influence of different factors on soundscape preference, this study summarized literature to produce 65 questions to survey the overall soundscape preferences of the respondents on three parts: the basic situation of the respondent (question 1–18), the landscape preference and overall feeling (question 19–30), and the soundscape preferences (question 35–64). Based on the above relatively rich and complete questionnaire structure, the study contributed more convincing conclusions. Although some results inevitably overlapped with relevant studies, it could further verify the conclusions of previous studies.

(3) In terms of research methods, "automatic linear model of soundscape preference evaluation score as target" has been established, the positive and negative correlation intensity of different factors on soundscape preference can be clearly and intuitively observed.

(4) In addition to questionnaire survey and statistical analysis, this study realistically proposed landscape design methods to increase soundscape preference in the post-pandemic era and proposed soundscape design schemes for vulnerable groups.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

JL: develop research ideas, design research scheme, data collection and analysis, main author of the manuscript, and final revision. JX: research scheme, method guidance, and data analysis. ZW: guidance for revision. YC and YG: data sorting and analysis. JR: text modification. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2021.750421/full#supplementary-material

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Evaluation of the Visually Impaired Experience of the Sound Environment in Urban Spaces

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Visually impaired people have unique perceptions of and usage requirements for various urban spaces. Therefore, understanding these perceptions can help create reasonable layouts and construct urban infrastructure. This study recruited 26 visually impaired volunteers to evaluate 24 sound environments regarding clarity, comfort, safety, vitality, and depression. This data was collected in seven different types of urban spaces. An independent sample non-parametric test was used to determine the significance of the differences between environmental evaluation results for each evaluation dimension and to summarize the compositions of sound and space elements in the positive and negative influence spaces. The results suggested that visually impaired people (1) feel comfort, safety, and clarity in parks, residential communities, and shopping streets; (2) have negative perceptions of vegetable markets, bus stops, hospitals, and urban departments; (3) feel anxious when traffic sounds, horn sounds, manhole cover sounds, and construction sounds occur; and (4) prefer spaces away from traffic, with fewer and slower vehicles, with a suitable space scale, and moderate crowd density. These results provide a reference for the future design of activity venues (i.e., residential communities, vegetable markets, bus stops, parks, shopping streets, hospitals, and urban functional departments) and the planning of accessibility systems for visually impaired urban residents.

Keywords: visually impaired people, sound environment evaluation, urban design, urban space, independent sample non-parametric test

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INTRODUCTION

According to several surveys, including the second sampling survey of Chinese people with disabilities, there were approximately 85 million disabled people in China in 2018, with the total number predicted to be nearly 100 million by the end of 2021 (Kang et al., 2019). In addition, the World Health Organization survey report indicated that, among people with disabilities in China, approximately 17 million are visually impaired, accounting for 20% of the global total and making China home to the largest number of visually impaired people in the world, most of whom live in its cities (Jianghua and Juhui, 2012). Visually impaired people suffer from varying degrees of visual impairments. To illustrate, they cannot obtain information about the external environment through vision and their ability to interact with space is extremely limited. Some research has shown that vision is the main perceptual channel from which humans access external information. Furthermore, information acquired through vision accounts for 83% of the total information processed by humans. If visual problems arise, human perception of the spatial environment is almost completely lost (Treichler and Agee, 1983). However, visually impaired people can feel the characteristics of various urban spaces through the sound environment. Therefore, through visually impaired people's perception and evaluation of the sound environment, we can understand their needs for the use of different spaces in a city. This is important to optimize the urban spatial layout and improve the construction of urban barrier-free service facilities.

The study of the behavior of visually impaired peoples began in the early twentieth century. From 1985 to 2000, Shields (1994), Dunlop et al. (1996), Boyce et al. (1999), and other researchers studied the evacuation speed among people with disabilities (visually/hearing/motion-impaired people) in buildings with different functions. They showed that the walking speed of visually impaired and hearing-impaired people was not much slower than that of non-disabled people under the same conditions. Moreover, Pearson and Joost (1983) investigated the evacuation speed in the living environments of the visually impaired, elderly, and wheelchair-bound disabled people. Clark-Carter et al. (1986) investigated the relationship between the complexity of the external environment and the evacuation speed of visually impaired people. In addition, Robertson and Dunne (1998) conducted experiments in buildings to compare the effects of spatial guidance system designs on the activities of visually impaired people in external environments. Sørensen and Dederichs (2015) found that the walking speed of visually impaired people was the same as the walking speed of non-disabled adults and was not affected by density on the stairs. However, other studies have shown that the average free walking speed of visually impaired people may depend on the degree of vision loss. There is sufficient research on evacuation behavior of people with a visual impairment.

Some scholars conducted research on the interaction between visually impaired people and urban spaces. For example, Bentzen et al. (2004) analyzed the mental image representation of the environment created by visually impaired people and suggested that they focus on the connection points between different roads (intersection information). To illustrate, Gaunet (2006) proposed that the information required for the travel of visually impaired people should mainly include the path information within a 5–10 m radius during walking and the environmental information within a 30 m radius of an intersection. Additionally, Koutsoklenis and Papadopoulos (2011) evaluated the olfactory experience of visually impaired people to explore factors affecting their travel in an urban environment. Furthermore, Kan-Kilic and Dogan (2017) conducted field route perception experiments for visually impaired people and concluded that the sound of the city and the echo of the environment were the most important factors for participants in dense urban environments. Campisi et al. (2021) evaluated the walkability of urban environments from the perspective of visually impaired people, analyzed the impact of street material elements on their activities, and evaluated their psychological experience of walking along a path. These studies are mainly qualitative involving observing people with a visual impairment, communicating with them, or conducting some experiments. However, due to the limited spatial scope of these studies and the single type of urban space, these conclusions have certain limitations and cannot provide reference for a larger region or other cities.

With in-depth research on visually impaired individuals, related research on urban space environmental assessments is gradually being conducted. For example, Steyvers and Kooijman (2009) conducted an environmental cognitive map experiment on visually impaired people and normal vision subjects in a virtual environment. The results suggested that the two groups showed significant differences in generating cognitive maps based on the auditory environment. Jianxi and Xinren (2020) classified the urban walking space affecting the use of visually impaired people into three sections—visually impaired people, landscape space, and urban space—and found that sound was the core factor affecting security. Thus, it is evident that sound elements have an important impact on visually impaired people's cognition of the urban environment, which is important for relevant research in the future.

In China, there is a lack of relevant research on people with a visual impairment in the field of urban construction, with existing research focusing on improving barrier-free facilities. For example, Chuan-sheng et al. (2009) analyzed the walking speed of people with disabilities and elderly people using an experiment and proposed a barrier-free design strategy. Wen (2013) investigated the physiological, behavioral, and demand characteristics of people with a visual impairment and proposed "blind painting entertainment equipment" to meet their daily life needs. Jiang (2018) took the Xi'an subway as an example, analyzed the behavior characteristics of people with a visual impairment, and constructed a complete set of subway barrier-free guidance systems. Zhang S. et al. (2018) collected data on the walking characteristics and ability of visually impaired people by utilizing a questionnaire survey and testing walking speed, redefining the service radius of urban shelters, designing the layout of shelter and blind tracks, building a suitable multilevel evacuating system, and making some suggestions to urban safety construction. Thus, these related studies are relatively superficial. The research method is also relatively simple, mainly questionnaire surveys or interviews, and the conclusion only puts forward some conceptual suggestions. That is, the research conclusions are not sufficient to support urban construction. This is also closely related to the particularity of people with a visual impairment. They rarely participate in various social activities; thus, it is difficult to recruit volunteers and conduct research.

At present, China is in a stage of rapid urbanization; however, the urban and social structure are not stable enough. Concurrently, the main goal of urban construction should meet the living needs of all kinds of people. Therefore, further research on people with a visual impairment is of great practical significance to improve urban construction and ensure social fairness and stability. Existing research shows that the sound environment plays an important role in the perception of urban spaces for people with a visual impairment. Based on this, visually impaired people were selected for this study and asked to evaluate the sound environment of different urban spaces. According to the evaluation results, the elements of the acoustic environment and urban spaces were analyzed. By comparing evaluation differences, we determined the urban sound elements and space composition that positively impacted the visually impaired.

DATA AND METHODS

The volunteers with a visual impairment in this experiment were from the Tianjin Blind Association. In this study, some typical urban public spaces for audio and video recording were selected. Subsequently, visually impaired people conducted a perceptual evaluation of the acoustic environment. Through the independent sample non-parametric test based on IBM SPSS Statistics V22, from the two aspects of urban space type and equivalent sound pressure level, the urban space elements and sound elements under different evaluation dimensions were identified.

As of 2021, the number of people registered with a visual impairment in Tianjin was approximately 40,000. The scope of this study was limited to Heping District, the core urban area of Tianjin, China. The Heping District performs important urban functions containing facilities for economic, cultural, and political activities. It is also a densely populated urban area, with a permanent population of approximately 350,000. In this study, the 26 volunteers with a visual impairment were from this area and were between 30 and 65 years old. **Table 1** provides basic information about the volunteers.

Urban Public Space Selection

According to relevant research results (Jaeger and Bowman, 2005; Wen et al., 2014; Qianwen et al., 2016; Sen et al., 2021), seven types of urban spaces—residential communities, vegetable markets, bus stops, parks, shopping streets, hospitals, and urban functional departments—have high travel frequency. Based on these urban spaces, a total of 24 scenes were selected in this study; all scenes were outdoors. Among them, three scenes were randomly selected for each type of space, and six scenes were selected for the residential community space (as shown in **Figure 1**). The recording time was from March 20 to 21, 2021, 10:00 a.m.–12:00 a.m. A TES-1357 sound level meter was used for sound pressure level measurement. A SONY PCM-A10 two-channel recorder was used for environmental sound recording, and the iPhone 12 Pro Max was used for environmental video recording.

TABLE 1 | Basic information describing visually impaired volunteers.

		Frequency	Percentage
Age	30–35	6	23.08%
	36–59	10	38.46%
	60–65	10	38.46%
Gender	Male	14	53.85%
	Female	12	46.15%
Employment status	Yes	15	57.69%
	No	11	42.31%
Education level	Elementary school and below	10	38.46%
	Junior and senior high schools	16	61.54%
	University and above	0	0.00%
Spouse	Live together	20	76.92%
	Live alone	6	23.08%

Questionnaire Design

The perception and evaluation of urban spaces is an important research topic in urban planning, geography, environmental psychology, and other major fields (Lynch, 1960; Ulrich, 1983; Kaplan and Kaplan, 1989; Zhang F. et al., 2018). Based on the related research results of urban space evaluation, the questionnaire used in this study identified five evaluation dimensions: clarity, comfort, safety, vitality, and depression. Each dimension was evaluated on a scale from 1 to 5.

Clarity refers to the degree to which visually impaired individuals can distinguish various sound sources in a scene, with a higher score indicating higher discrimination of the sound source. Comfort refers to the degree to which visually impaired people feel relaxed and let go of their mental vigilance, with a higher score indicating a higher degree of relaxation. Comfort refers to the degree to which a visually impaired person feels relaxed and drops their mental alertness, with a higher score indicating a higher level of relaxation. Safety refers to the degree to which visually impaired individuals are threatened by the surrounding environment, with a higher score indicating a higher threat. Vitality is used to judge the attractiveness of the scene to the visually impaired, with a higher score indicating a more attractive scene. Depression refers to the degree of disgust and negative emotions of the visually impaired, with a higher score indicating a higher negative sentiment.

Experimentation

In a previous study, we found that volunteers with a visual impairment were unable to participate in experiments in more professional experimental settings. Therefore, the activity room of the Tianjin Blind Association was selected as the experimental site. This was also the main place for their daily activities. There were no other facilities in the activity room except for tables and chairs. The experiment used a Bose Soundlink Revolve + 360° surround sound amplifier device to play sound. During the experiment, 24 scene recordings were played, and each scene lasted 30 s. Before the start of the experiment, we measured the sound pressure level of the recording material through the sound level meter and adjusted the volume. In this way, the sound pressure level received at each seat was as close as possible to that recorded on site to ensure the accuracy of the experimental results. The experiment was conducted in two groups, with 13 visually impaired volunteers and four experimental assistants in each group (as shown in **Figure 2**). After each scene was played, the experimental assistant recorded the results of each person's evaluation. All experiments lasted approximately 80 min in total.

RESULTS

Scene Sound Information Statistics

According to the video and audio recording material, the sound element information of each scene was counted by the research

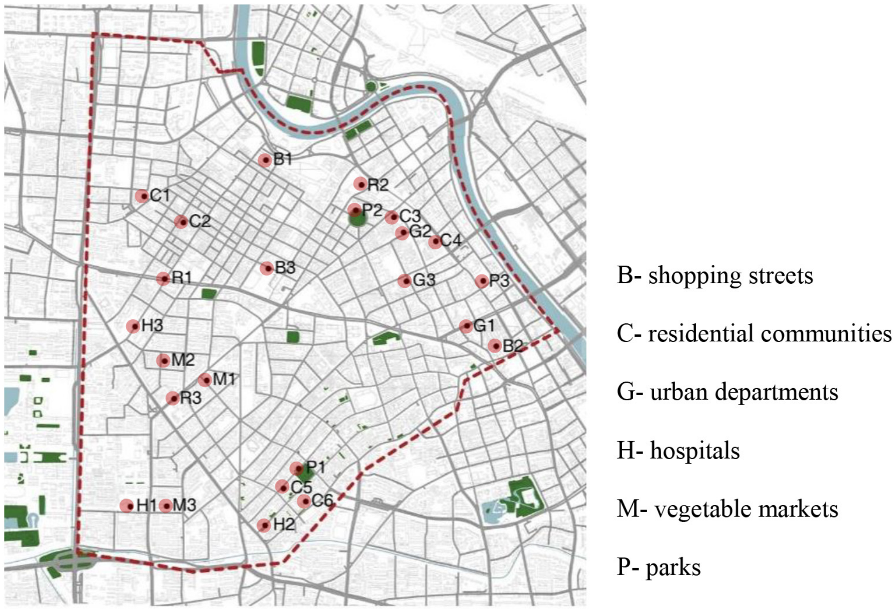

FIGURE 1 | Distribution of scene recording points.

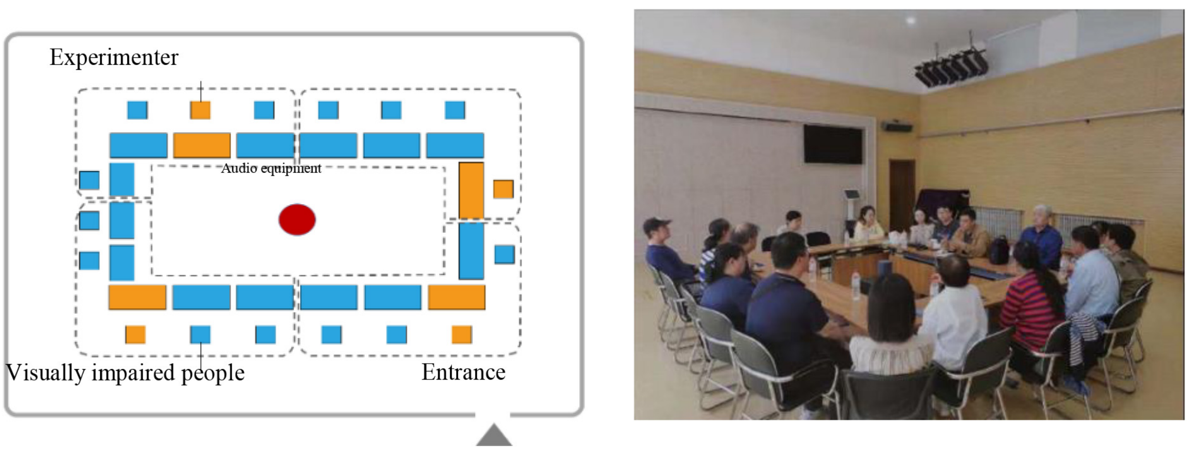

FIGURE 2 | Layout and photo of experiment setup.

team. A total of seven types of sounds occurred: traffic sounds, horn sounds, manhole cover sounds, chat sounds, walking sounds, hawker sounds, and construction sounds. The traffic sound was the sound of tires rubbing against the ground, the horn sound of motor vehicles and non-motorized vehicles sounding their horns, the manhole cover sound of car tires hitting the top of the manhole cover, the chat sound of conversations between passers-by within the scene, the walking sound of passers-by walking, and the hawker sound of a building or individual advertising their goods, such as a shop or supermarket. The distribution of sound information for each scene is shown in **Table 2**. Almost every scene contained traffic and horn sounds, and a few spaces contained sound sources such as building construction noises.

Figure 3 shows the statistical results for the equivalent sound pressure levels and minimum and maximum sound pressure levels for each scene. The equivalent sound pressure levels ranged between 40 and 80 dB, with a more pronounced difference between scenes. The maximum sound pressure level in Scene 4 and Scene 5 exceeded 90 dB. The minimum sound pressure level in the park was less than 40 dB. The maximum and minimum sound pressure levels of bus stations, parks, hospitals, and government departments were quite different. Referring back to the video, there were multiple horn sounds in these scenes. This gap is closely related to road traffic conditions.

Figure 4 shows the average score statistics for each evaluation dimension. Regarding clarity, the park had the highest average score of 4.333. Regarding comfort, parks had the highest average

TABLE 2 | Sound information of each scene.

	Scene number	Traffic Sound	Horn sound	Manhole cover sound	Chat sound	Walking sound	Hawker sound	Construction sound
Market	1	•		•			•	
	2	•		•			•	
	3	•		•			•	
Bus stop	4	•	•				•	
	5	•	•					•
	6	•	•				•	
Park	7				•	•		
	8	•	•		•	•		
	9	•			•			
Shopping streets	10				•	•		
	11	•			•		•	
	12				•		•	
Residential community	13	•	•		•			
	14	•	•		•			
	15	•	•					
	16	•	•					
	17	•	•	•				•
	18	•	•					
Hospital	19	•	•	•				
	20	•						
	21	•	•		•		•	
Urban department	22	•	•		•			•
	23	•	•					
	24	•	•				•	

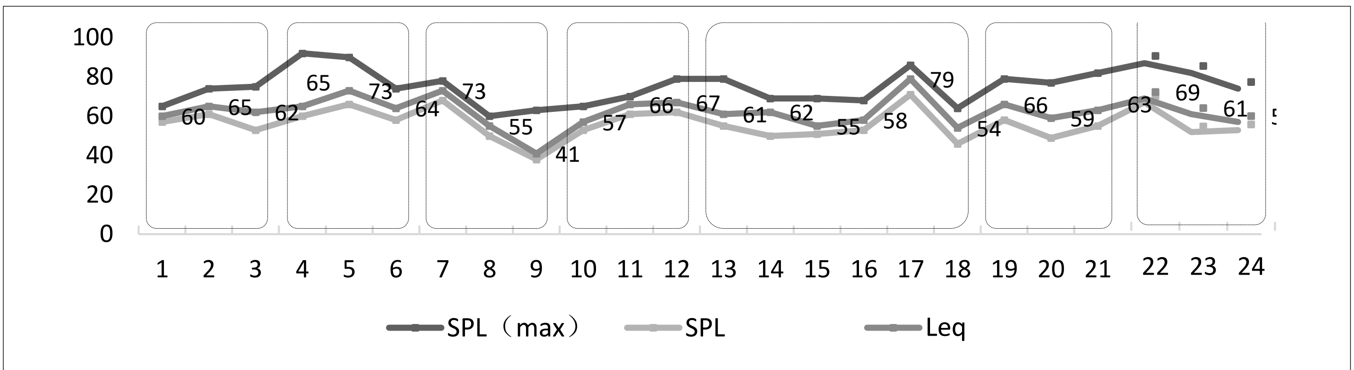

FIGURE 3 | Statistical results of the sound pressure level of each scene.

rating of 3.333, followed by residential community and shopping streets with 3.026. Regarding safety, parks had the highest average rating of 3.179, followed by residential community and shopping streets with 2.821 and 2.872, and vegetable markets and hospitals with lower ratings of 2.000 and 2.026. Regarding vitality, the evaluation of each scene was quite different; the highest evaluation of parks was 3.333, and the lowest evaluation of hospitals was 2.923. Regarding depression, the highest evaluation of commercial blocks was 2.744, and the lowest evaluation of park scenes was 2.051. Furthermore, when there were horn, manhole cover, and construction sounds in the scene, the visually impaired felt anxious and afraid. Some people stated that "I will not move, I can only wait for help."

Comprehensive results of sound environment evaluation, sound type recognition, and sound pressure level statistics were obtained. Parks, residential communities, and shopping streets were better evaluated regarding safety and comfort. From the audio and video materials, it was evident that there were no traffic elements in these spaces; therefore, relevant sounds were rarely produced. Vegetable markets, bus stops, and hospital spaces had a complicated sound environment due to the large traffic volume and mixed traffic of people and vehicles. Accordingly, the equivalent and maximum sound pressure levels were higher. Visually impaired people generally had certain negative comments in these types of spaces. In the next stage of the study, the acoustic environmental conditions and urban

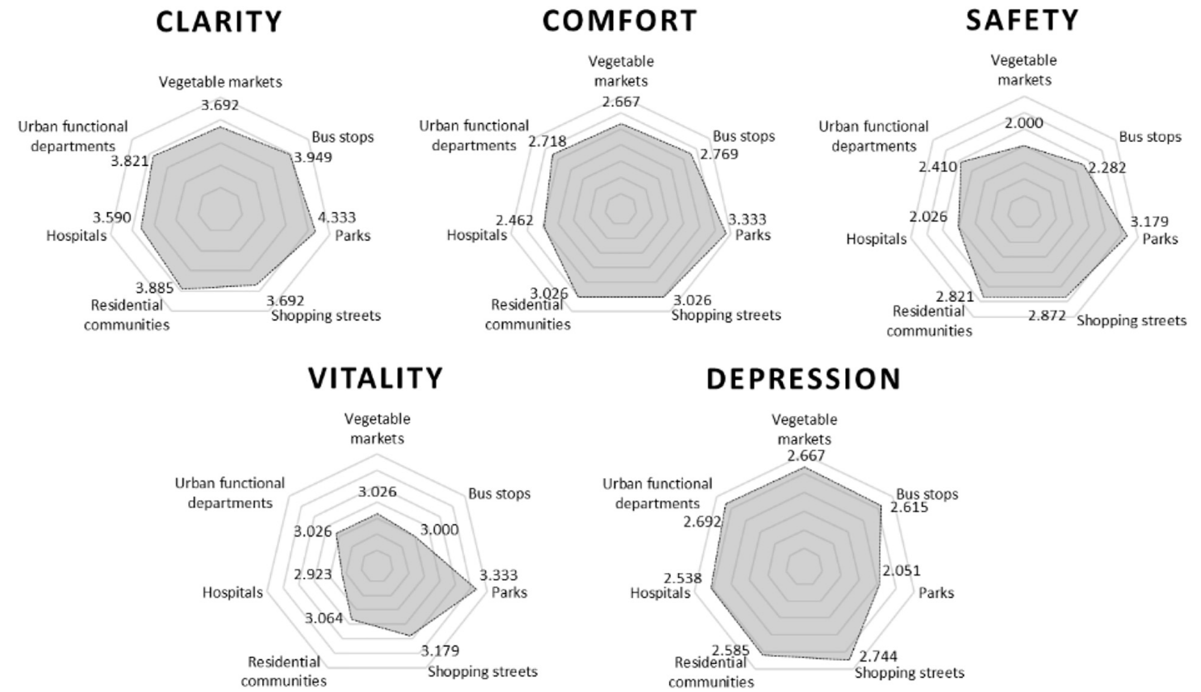

FIGURE 4 | Evaluation results of each evaluation dimension.

space types were analyzed through independent sample non-parametric tests and the significance of differences in the results of each evaluation dimension were detected.

Independent Sample Non-parametric Test

The 24 scenes were divided into two groups, and an independent sample non-parametric test was performed on each group. Group A took the urban space type as a variable, and Group B took the equivalent sound pressure level as a variable. First, the test results of Group A showed that there was no significant difference in the evaluation results of vitality and depression. This means that, under these two dimensions, there is no significant difference in the impact of the seven types of spaces on the psychological perceptions of the visually impaired. The results of the other three dimensions tested are shown in **Table 3**.

In the results of the comfort analysis, it was evident that the evaluation results of the park space was significantly different from the evaluation results of vegetable markets, bus stations, hospitals, and urban departments. The evaluation results of vegetable markets were significantly different from those of shopping streets and residential areas; there were also significant differences between the evaluation results of shopping streets and those of hospitals. Combined with the experimental statistics, parks, shopping streets, and residential areas scored the highest regarding comfort, which positively impacted the psychology of visually impaired people. In the results of the clarity analysis, the evaluation results of parks was significantly different from other types of urban spaces. The evaluation results of bus stations and hospitals were also significantly different. Regarding safety, the evaluation results of parks, shopping streets, and residential areas were significantly different from those of the other four types of urban spaces. Thus, the park had the best evaluation regarding clarity. Regarding safety and comfort, parks, residential communities, and shopping streets were rated the best. Therefore, parks, shopping streets, and residential areas had a positive effect on the psychology of visually impaired people. Comparatively, the other four types of spaces had negative influences.

Second, Group B was tested. According to on-site statistics, the equivalent sound pressure levels of the 24 scenes was in the range of 40–80 dB. The experiment used 5 dB as the division scale and divided scenes into seven groups. The three scenes in the park were in the range of 41–45 dB; the various scenes in the shopping streets, hospitals, and urban departments were in the range of 50–70 dB; the three scenes in the market were in the range of 60–65 dB; the three scenes in the bus stop were in the range of 60–75 dB, and the scenes in the residential community were in the range of 50–80 dB. The non-parametric test results were similar to those of Group A, showing that there was no significant difference in the evaluation results of vitality and depression. This means that, under these two dimensions, there is no difference in the effect of different levels of equivalent sound pressure levels on the psychological perception of people with a visual impairment. The results of the other three dimensions tested are shown in **Table 4**.

Regarding comfort, the 41–45 dB evaluation results were significantly different from the equivalent sound pressure levels of the other six groups. Regarding clarity, when the equivalent

TABLE 3 | Pairwise comparisons of space types.

Comfort	1	2	3	4	5	6	7
Vegetable markets(1)	–	1.00	0.00**	0.01**	0.00**	1.00	1.00
Bus stops(2)	1.00	–	0.00**	0.73	0.20	0.41	1.00
Parks(3)	0.00**	0.00**	–	0.10	0.04	0.00**	0.00**
Shopping streets(4)	0.01**	0.73	0.10	–	1.00	0.00**	0.12
Residential communities(5)	0.00**	0.20	0.04	1.00	–	0.00**	0.02*
Hospitals(6)	1.00	0.41	0.00**	0.00**	0.00**	–	1.00
Urban departments(7)	1.00	1.00	0.00**	0.12	0.02*	1.00	–
Clarity							
Vegetable markets(1)	–	0.15	0.00**	1.00	1.00	1.00	1.00
Bus stops(2)	0.15	–	0.02*	0.08	1.00	0.01**	1.00
Parks(3)	0.00**	0.02*	–	0.00**	0.00**	0.00**	0.00**
Shopping streets(4)	1.00	0.08	0.00**	–	0.70	1.00	1.00
Residential communities(5)	1.00	1.00	0.00**	0.70	–	0.07	1.00
Hospitals(6)	1.00	0.01**	0.00**	1.00	0.07	–	1.00
Urban departments(7)	1.00	1.00	0.00**	1.00	1.00	1.00	–
Safety							
Vegetable markets(1)	–	0.22	0.00**	0.00**	0.00**	1.00	0.03*
Bus stops(2)	0.22	–	0.00**	0.00**	0.00**	0.50	1.00
Parks(3)	0.00**	0.00**	–	1.00	0.11	0.00**	0.00**
Shopping streets(4)	0.00**	0.00**	1.00	–	1.00	0.00**	0.01**
Residential communities(5)	0.00**	0.00**	0.11	1.00	–	0.00**	0.01**
Hospitals(6)	1.00	0.50	0.00**	0.00**	0.00**	–	0.07
Urban departments(7)	0.03*	1.00	0.00**	0.01**	0.01**	0.07	–

$^{**}P \le 0.01$, $^{*}P \le 0.05$. Bold values indicate significant differences between the two data.

sound pressure level was in the range of 66–70 dB, the evaluation results were significantly different from those of the other groups.

TABLE 4 | Pairwise comparisons of equivalent sound pressure levels.

Comfort	1	2	3	4	5	6	7
41–45 dB(1)	–	0.15	0.01**	0.00**	0.00**	0.00**	0.00**
51–55 dB(2)	0.15	–	1.00	0.03*	0.00**	0.12	0.32
56–60 dB(3)	0.01**	1.00	–	0.49	0.01**	0.85	1.00
61–65 dB(4)	0.00**	0.03*	0.49	–	1.00	1.00	1.00
66–70 dB(5)	0.00**	0.00**	0.01**	1.00	–	1.00	1.00
71–75 dB(6)	0.00**	0.12	0.85	1.00	1.00	–	1.00
76–80 dB(7)	0.00**	0.32	1.00	1.00	1.00	1.00	–
Clarity							
41–45 dB(1)	–	0.03	0.01**	0.00**	0.00**	0.23	0.06
51–55 dB(2)	0.03	–	1.00	1.00	0.02**	1.00	1.00
56–60 dB(3)	0.01**	1.00	–	1.00	0.04*	1.00	1.00
61–65 dB(4)	0.00**	1.00	1.00	–	0.00**	1.00	1.00
66–70 dB(5)	0.00**	0.02**	0.04**	0.00**	–	0.01**	1.00
71–75 dB(6)	0.23	1.00	1.00	1.00	0.01**	–	
76–80 dB(7)	0.06	1.00	1.00	1.00	1.00	1.00	–
Safety							
41–45 dB(1)	–	0.39	0.01**	0.00**	0.00**	0.00**	0.00**
51–55 dB(2)	0.39	–	1.00	0.00**	0.08	0.26	0.40
56–60 dB(3)	0.01**	1.00	–	0.01**	1.00	1.00	1.00
61–65 dB(4)	0.00**	0.00**	0.01**	–	1.00	1.00	1.00
66–70 dB(5)	0.00**	0.08	1.00	1.00	–	1.00	1.00
71–75 dB(6)	0.00**	0.26	1.00	1.00	1.00	–	1.00
76–80 dB(7)	0.00**	0.40	1.00	1.00	1.00	1.00	–

$^{**}P \le 0.01$, $^{*}P \le 0.05$. Bold values indicate significant differences between the two data.

Safety analysis results were the same as the results of the comfort analysis. Moreover, 41–45 dB was significantly different compared to the other groups. When the equivalent sound pressure level of the sound environment was between 41 and 44 dB, various scenes in parks made visually impaired people feel comfortable and safe. Comparatively, when the equivalent sound pressure level of urban spaces exceeded 65 dB, such as bus stops, vegetable markets, and urban departments, they felt uncomfortable and unsafe. When the equivalent sound pressure level was 66–70 dB, visually impaired people had the highest ability to distinguish various sound sources in the environment.

Based on the results of the non-parametric test, the attribute elements of each type of space were analyzed, as shown in **Table 5**. Parks, residential communities, and shopping streets belonged to the types of spaces that positively impacted people with a visual impairment; this was reflected in safety, comfort, and clarity.

These space types had some common characteristics. First, regarding sound characteristics, the equivalent sound pressure level was low, with some scenes (residential communities) being slightly high, generally in the range of 50–60 dB, which is positive for the psychological perception of people with a visual impairment. Second, regarding sound elements, there were a small number of hawker and manhole cover sounds, most of which were dominated by chat and hawker sounds; these were non-transportation sounds that are generally favorable to visually impaired individuals. Third, regarding space characteristics, the three types of urban spaces (parks, residential communities, and shopping streets) were all far away from urban roads or had low traffic road levels. Therefore, there were few cars in the space and the speed of cars is not fast. There were also relatively

TABLE 5 | Statistics of attribute elements of each type of space.

	Space type	Evaluation	Leq (dB)	Sound type	Space characteristics
	Park	Safety, comfort, clarity	41–64	Traffic sounds, chat sounds, walking sounds	Away from traffic roads, few people, few buildings
Positive	Residential	Safety, comfort	54–79	Traffic sounds, horn sounds, manhole cover sounds, construction sounds	Narrow traffic road, slow vehicles speeds, few people,
	Shopping street	Safety, comfort	57–67	Chat sounds, hawker sounds	Narrow traffic road, slow vehicle speeds, shops along the street, blind roads
	Bus stop	No safety, discomfort	64–73	Traffic sounds, horn sounds, hawker sounds, construction sounds	Close to the traffic road, many vehicles with fast speeds, many people
	Vegetable market	No safety, discomfort	60–65	Traffic sounds, manhole cover sounds, hawker sounds	Close to the traffic road, many people, many parking spaces
Negative	Hospital	No safety, lack of clarity, discomfort	59–66	Traffic sounds, horn sound, hawker sounds, construction sounds	Close to the traffic road, many people
	Urban department	No safety, discomfort	57–69	Traffic sounds, horn sound, chat sounds, hawker sounds, construction sounds	Close to the traffic road, many vehicles with fast speeds, many people, blind roads

few people in the space. Moreover, shopping streets spaces also have blind roads.

Bus stops, markets, hospitals, and urban departments had a negative psychological impact on people with a visual impairment, reflected in non-safety, discomfort, and lack of clarity. First, regarding sound characteristics, the equivalent sound pressure level of each scene in these four types of spaces was high, mostly in the range of 60–70 dB. Second, regarding sound elements, these scenes included several horn sounds, manhole cover sounds, and building construction sounds, which are unfavorable to people with a visual impairment. Third, regarding space characteristics, these scenes were generally adjacent to traffic roads, with several manhole covers and many people. Thus, the volume of vehicles was large and the speed of traffic was fast. Some scenes also had many parking spaces. In these negative influence spaces, there were also some common features, such as sudden high-decibel sounds. In particular, bus stops were more prominent and belonged to the convergence point of various transportation vehicles in the city.

DISCUSSION

The analysis results showed that the sound pressure level indicators and traffic sounds had a significant effect on the psychological feelings of visually impaired people. They would show a relatively positive attitude when the scene was far from the traffic, or when there was little interference from traffic sounds and the sound pressure level indicator was kept within 60 dB. By comparing positive and negative scenes, people with a visual impairment preferred urban scenes that are quiet, away from traffic roads, and have moderate crowd density. Moreover, they were very sensitive to horn, construction, and manhole cover sounds, which can cause anxiety. Thus, when they are in an urban space with such characteristics, they may not be able to travel properly or make proper judgments. Therefore, when the city starts construction and plans the layout of barrier-free facilities in the future, the main places for visually impaired people to travel daily can be combined with parks, residential areas, and commercial streets and can be kept as far as away possible from busy urban roads. This will help enhance their city experience and reduce negative psychological feelings.

Compared with previous studies, this study further explores the relationship between the psychological feelings of people with visual impairment and sound environment, urban space, reflecting a certain research depth. At the same time, in terms of research methods, the research chain of "visual impaired people—urban space" is constructed through sound environment evaluation, which can provide reference for relevant research.

This study has some limitations. Due to the particularity of the visually impaired participants, only 24 volunteers were recruited during the research phase, and it was difficult to recruit more volunteers in a short period of time. Therefore, such a sample size may have impacted the research conclusions. Secondly, due to the limitations of the experimental site conditions and the participants' own requirements, the single point sound source playback mode was used to let the participants participate concurrently to reduce the total time of the experiment. This may have caused a loss of some sound signals, such as the spatial position information of a sound source, which may have impacted the research conclusions. Therefore, future research should increase the number of volunteers for visually impaired people and improve the experimental location and equipment conditions. Moreover, comparative experiments with people who are not visually impaired should be conducted to explore the evaluation characteristics of urban spaces by different groups of people; thus, enriching the overall research conclusions.

CONCLUSION

In this study, the visually impaired population underwent a five-dimensional psychological perception evaluation of seven types of urban space sound environments in Tianjin City. The results of the non-parametric test showed that there were significant differences in the evaluations of three dimensions: comfort, safety, and clarity. Among them, the overall evaluation of parks, residential areas, and shopping streets was positive, while the evaluation of bus stops, hospitals, markets, and urban departments was negative.

In the results of the analysis, the types of spaces with a positive impact had the following characteristics: lower equivalent sound pressure levels, with decibel levels between 40 and 60 dB, and the types of sound were mainly lower traffic, chat, and hawker sounds. These scenes were far from traffic roads or had low traffic road levels, a small number of vehicles and people, and were mainly living, leisure, and commercial urban spaces belonging to life-type urban spaces. The types of spaces with a negative impact were characterized by high equivalent sound levels, with decibel levels between 60 and 70 dB. The main types of sounds included horn, manhole cover, construction, and higher traffic sounds. These scenes were adjacent to urban roads, characterized by many people and vehicles, had traffic, and belonged to complex-type urban spaces.

Thus, visually impaired people feel anxious and fearful due to traffic, horn, and construction sounds. They are prone to feel helpless when crowded with mixed function spaces or close to main urban roads. This suggests that visually impaired people want a quieter and purer urban space, which is helpful for them to make accurate judgments about the external environment. The characteristics of this type of space should be far away from the main roads with a large flow of people, composed of street spaces dominated by living and leisure functions, and include a moderate density of people. Therefore, when designing travel places, barrier-free facilities and travel routes for visually impaired people should be included in urban construction and planning. This will enable visually impaired people to conduct daily activities more smoothly and, ultimately, achieve the overall goal of smart and fair urban development. Overall, this study compensated for a lack of research in related fields in China. Moreover, it also enriched the basic database of visually impaired individuals in China and provided references for the design of urban spaces, activity centers, and barrier-free systems for visually impaired individuals.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Tianjin Disabled Persons' Federation and Tianjin Association of the Blind. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

SZ, KZ, MZ, and XL: conceptualization and methodology. KZ and MZ: software. XL: validation, data curation, writing—review, and editing. KZ, MZ, and XL: formal analysis. SZ, KZ, and MZ: investigation and writing—original draft preparation. SZ and XL: supervision. SZ: funding acquisition. All authors contributed to the article and approved the submitted version.

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Experimental Study on the Effect of Urban Road Traffic Noise on Heart Rate Variability of Noise-Sensitive People

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Epidemiological studies have confirmed that long-term exposure to road traffic noise can cause cardiovascular diseases (CDs), and when noise exposure reaches a certain level, the risk of related CDs significantly increases. Currently, a large number of Chinese residents are exposed to high noise exposure, which could greatly increase the risk of cardiovascular disease. On the other hand, relevant studies have found that people with high noise sensitivity are more susceptible to noise. And it is necessary to pay more attention to the high noise-sensitive people. This study investigated the acute physiological effect of different noise-sensitive groups by indoor-level noise stimulus experiments under laboratory conditions, by observing heart rate variability (HRV) indicators, including standard deviation of NN intervals (SDNN), low frequency/high frequency (LF/HF), and heart rate (HR). The results showed that (a) there was no significant difference in HRV between the high-sensitive group and the low-sensitive group at the physiological baseline and the different stimulating noise levels. (b) Then, based on the theory of cumulative effect of noise proposed by WHO Regional Office for Europe, non-significant but observable differences between groups were further discussed. By analyzing differences of the variation trends and the within-group significant changes of SDNN and HR between the two groups, the results tended to show that the high-sensitive group is more affected by road traffic noise. In addition, the values of SDNN and HR showed observable between-group differences at 55 dB (A) and 65 dB (A) which corresponding to the SPL associated with a significantly increased risk of cardiovascular disease concerned by epidemiological studies. According to the cumulative effect theory (WHO), these differences in HRV caused by short-term noise stimulation may have the potential to produce physiological response and lead to between-groups differences in prevalence after long-term recurrent effect, and deserve attention and further research.

Keywords: road traffic noise, noise sensitivity, indoor-level noise, heart rate variability, acute physiological effect

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INTRODUCTION

Road traffic noise is one of the causative factors for cardiovascular diseases (CDs) confirmed by numerous studies (Babisch, 2011; Basner et al., 2014). According to the previous research conclusions of noise exposure limits, a considerable number of residents in Chinese cities are exposed to high risk noise environment, facing the greater risks of CDs (Hu et al., 2019). Meanwhile, because high-noise sensitive people are more susceptible to noise, showing a higher level of psychological and physiological influence than others (Persson et al., 2007), the physiological effects of noise related to CDs in this population should be concerned and studied.

Nowadays, the exposure of urban road traffic noise in China is relatively severe (Yang, 2020), which has reached or exceeded the noise control recommendations proposed by relevant studies. According to the China Environmental Noise Prevention and Control Annual Report of the Ministry of Ecology and Environment of the People's Republic of China (2019), from 2015 to 2019, the L_d[1] of road traffic noise in cities nationwide was 66.8 dB (A) to 67.1 dB (A), and the L_d in first-tier cities was higher, reaching at 68.5 dB (A) to 68.9 dB (A). For another, previous epidemiological studies have preliminarily confirmed that long-term exposure to road traffic noise mainly causes CDs (Sørensen et al., 2013; Basner and McGuire, 2018), especially the daytime noise exposure (WHO Regional Office for Europe, 2018b). And some conclusions have shown that the risk of CDs significantly increases when L_{den} is higher than 55 dB (A) or 60 dB (A) (Bluhm and Eriksson, 2011). For the sake of protecting human health, World Health Organization (WHO) proposed the noise limit (L_{den}) of 53 dB (A) in 2018. However, due to the lack of relevant researches in China, especially in the face of the poor road traffic noise environment, more attention should be paid to the impact of road traffic noise on Chinese people.

Different noise-sensitive people are affected differently by noise. As an independent personality trait and a potential variable of individual, noise sensitivity plays a key role in studies on noise annoyance and noise-induced health deterioration (Smith, 2003), and has been gradually paid attention to in studies of the noise impact on the public as an observing factor (van Kamp and Davies, 2013). Previous epidemiological and physiology-psychology studies have found that compared with low-noise sensitive people, high-noise sensitive people have higher subjective annoyance (Jong and Jin, 2011), higher perceived stress (Fyhri and Aasvang, 2010), while worse sleep quality (Halonen et al., 2012) and lower cognitive level (Wright et al., 2014). And physiologically, high-noise sensitive people are at higher risk of CDs (Babisch et al., 2009; Berry and Flindell, 2009; Ndrepepa and Twardella, 2011). These studies indicate that physiological effects of noise are related to noise sensitivity, and more attention should be paid to high-noise sensitive people.

Besides, the relevant research methods of acute effect is available to explore the physiological effects of noise, which is conducive to the observation of indicator variation trend and sensitivity differences in short period (Buccelletti et al., 2009; Lee et al., 2010). For example, numerous researchers have found physiological trends in CDs [through heart rate variability (HRV) indicators] with noise exposure in short-term strong noise stimulation studies (Lusk et al., 2004; Björ et al., 2007; Haralabidis et al., 2008; Dirk et al., 2010). Meanwhile, HRV is often used as a physiological indicator reflecting cardiovascular disease in the noise evaluation of physiological effects, which is an effective indicator to judge and predict cardiovascular diseases in medicine and is reliable physiological parameters to measure the physiological stress state of the human body under noise environment (Lan, 2010). Overall, HRV, as a physiological indicator suitable for observing short-term noise stimulation, is available for this study.

Thus this study focused on the cardiovascular effects of road traffic noise induced in noise-sensitive people through short-term noise stimulation experiment in laboratory, and compared and discussed the physiological effect of noise between high-sensitive groups and low-sensitive groups.

MATERIALS AND METHODS

The noise stimuli experiments were carried out in a semi-anechoic laboratory, with the HRV index measures as the experimental physiological indicators. According to WHO Regional Office for Europe (2018a), chronic CDs are primarily associated with sustained daytime noise exposure, this study explored the influence of noise on subjects in the daytime awake state. The reading state was taken as the test state, and neutral and calm current events were selected as reading materials, in order to minimize the influence of non-experimental factors on the study. A repeated-measures ANOVA was used to analyze the data of the indicators to determine the physiological effect of road traffic noise on people with different noise sensitivities.

Experimental Factor and Levels

The experimental factor was the sound pressure level (SPL), using L_{Aeq} as the corresponding evaluating indicator. Due to the majority of road traffic noise complaints occurred inside buildings according to the China Environmental Noise Prevention and Control Annual Report, this study focused on the physiological effect of noise under the indoor environment. The exposure SPL levels in this study were set to match the following L_{Aeq} values: 35 dB (A), 45 dB (A), 55 dB (A), 65 dB (A), based on the field measured data of indoor SPL [$L_{d,max}$ = 62.4 dB (A) and $L_{d,min}$ = 33.7 dB (A)] and the laboratory background SPL [15.7 dB (A), set as the physiological resting state SPL level]. The experimental noise signals were live audio recordings, and played by Adobe Audition CC2019, JTS-PA150 audio power amplifier, JTSY-omnidirectional sound source which is passive speaker (Beijing J.T Technology Co., Ltd.), and the audio interface is bayonet nut connector (BNC).

Noise signal recording and indoor SPL testing were performed in a typical frontage residential unit with the window opened. The test site is located at an urban expressway in Tianjin, China, which have eight-lane in both directions, with an average daily traffic flow of 86,940 vehicles, including 15,395 heavy vehicles.

[1]Only L_d is available in the China Environmental Noise Prevention and Control Annual Report.

The noise signals were recorded by Roland R44 with Rode NTG-3 microphone (1 channel, 24 bit rate, 96 kHz sampling frequency), then through the distortion degree analysis, the signals with distortion degree less than 3% were selected (Xie, 2006). After modulating the SPL by spectraLAB, the final experimental noise signals were made (89.14% low-frequency energy, non-stationary noise). Due to the focus on the physiological effects of SPL factors, noise spectrum and other characteristics were not considered in this study.

Experimental Observation Indicators

Heart rate variability, as a reliable physiological parameters to measure the physiological stress state of human body under noise environment, were selected as the experimental observation indicators in this study, included time domain parameter [Standard Deviation of NN intervals (SDNN)], frequency domain parameter [Low Frequency/High Frequency (LF/HF)], and Heart Rate (HR). Among them, the SDNN is stable and has a good correlation in the repeat evaluation (HRV Co-operation Study Group, 2000). LF/HF is a valid evaluation index of increased sympathetic activity and decreased parasympathetic activity, and has been widely used in related studies.

This research adopted the ErgoLAB Man-Machine-Environment Testing Cloud Platform V3.0 (Kingfar International Inc., Beijing, China) to record the physiological indicators. And that includes the design module of ErgoLAB V3.0, ECG sensors from the wearable physiological recording system, and analysis modules for HRV, which is used to process data.

Experimental Subjects and Noise Sensitivity Grouping

College students were selected for this study who are convenient for experimental observation as the experimental subjects, because they are relatively healthy and have no cardiovascular diseases compared with other age groups in the adult population. A total of 30 college students were randomly selected as the experimental subjects (mean age of 23.1 ± 1.41 years; 17 male and 13 female). No subjects had past medical history of CDs and all subjects had normal basic hearing. Before the experiment, noise sensitivity of all subjects were collected by the Weinstein Noise Sensitivity scale (Zhong et al., 2018; Moghadam et al., 2021), noise sensitivity grouping was performed according to the scale score. And cluster analysis revealed a noise sensitivity grouping value of 69 points ($p = 0.000$). Fifteen subjects with scores $\geq$69 were classified as the high-sensitivity group, and fifteen subjects with scores $\leq$68 were classified as the low-sensitivity group.

Experimental Process Control

To reduce the experimental error as much as possible, the following measures were taken to control the experimental procedure.

Experimental Steps and Duration

The main steps of the formal experiment were as follows (**Figure 1**):

(1) On the day of the experiment, participants arrived early at the laboratory to make relevant preparations before the experiment, including wearing physiological sensor, gradually adapting to the environment, and stabilizing their emotions. This process lasted for 30 min.
(2) Without playing any experimental noise signal, the physiological data of the subjects in the resting state were recorded for 10 min.
(3) In the formal noise exposure experiment, physiological data of the stress state were collected and recorded during exposure to experimental noise signals of different SPL levels that were randomly played one by one. The noise exposure lasted for 10 min, and the interval between two stimuli was 5 min. The relevant time length was set according to the following bases:

- The basis for setting the duration of a single noise exposure.

A report published by the WHO Regional Office for Europe (WHO Regional Office for Europe, 2018a) showed that acute physiological effects can occur within seconds or minutes from

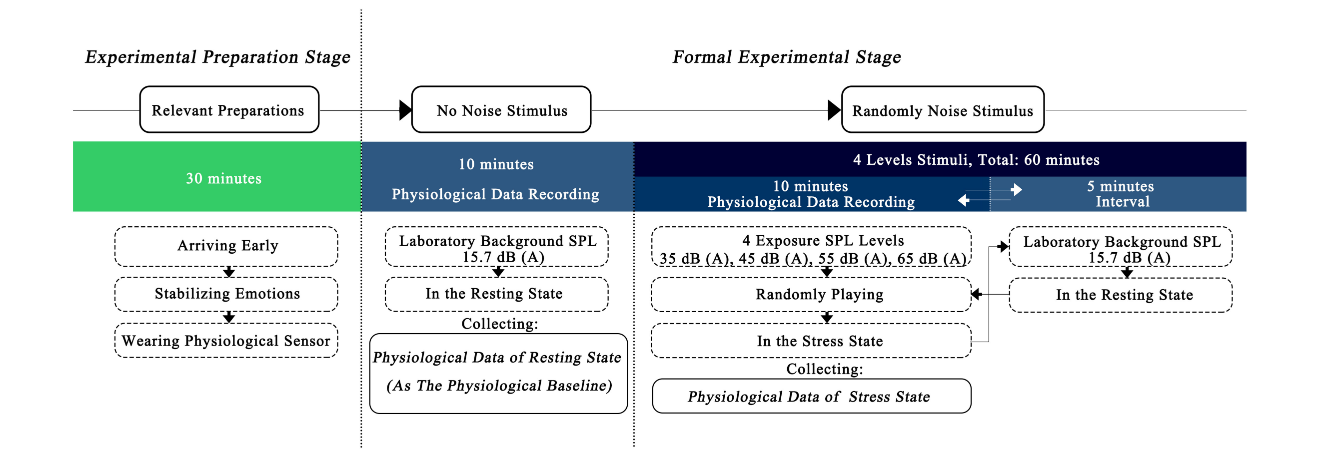

FIGURE 1 | Flow chart of experimental steps.

the initiation of a noise stimulus. In addition, in the relevant research of acute effect, lower SPL levels have been studied with noise exposure duration of mostly 10–20 min (Walker et al., 2016), while higher noise exposure duration was mostly 5–10 min (Kraus et al., 2013; El Aarbaoui et al., 2017). Therefore, the duration of a single noise exposure was set to 10 min.

- The basis for setting the duration of the interval between two noise stimuli.

The pre-experiment found that the HRV indicators, gradually stabilized between 3 and 5 min after exposure to noise. Therefore, the interval between two noise stimuli was set to 5 min.

Experimental Environment Control

The experimental environment control included the following three main aspects:

(1) The noise exposure experiments were completed in a semi-anechoic laboratory, which can meet the demand for playback of low SPL level noise signals.

(2) The light and thermal environment of the laboratory were strictly controlled to ensure that the relevant environmental parameters were maintained at comfort psychological and physiological levels. The horizontal illumination of the desktop on which to complete reading tasks was set at 735 Lux, the air temperature was around 25°C, and the relative humidity of the air was 50–60%.

(3) The experiment-related equipment was placed outside the laboratory to avoid disturbance to the subjects by the sound of operating the equipment and experimenter activity. The physiological data were collected through wearable sensors and wirelessly transmitted to the recording (**Figure 2**).

Experimental Subject Control

The following measures were also taken to avoid unnecessary psychological fluctuations:

(1) One week before the formal experiment, subjects familiarized themselves with the laboratory environment, and explanations about the experimental process were provided.

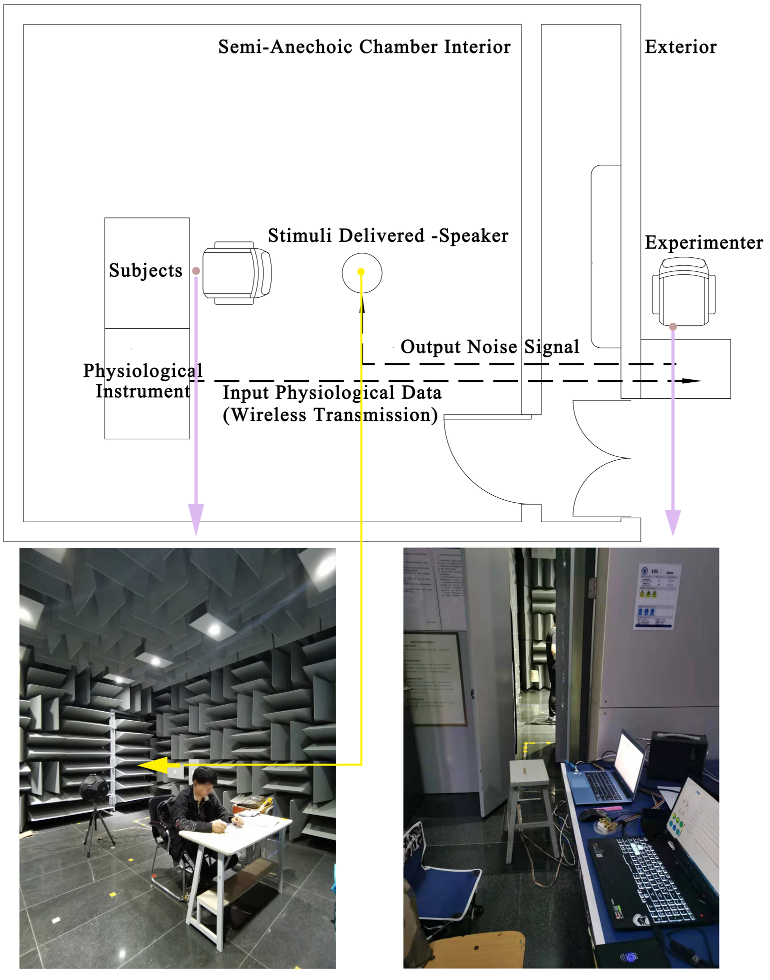

FIGURE 2 | Schematic diagram of the experimental environment control.

(2) One day before the formal experiment, subjects were asked not to drink alcohol, tea, coffee, or other caffeinated beverages, and to ensure that they had sufficient sleep the night before the experiment.
(3) Half an hour before the formal experiment, subjects were asked not to perform strenuous exercise and to arrive at the laboratory in advance to prepare and adapt to the environment.

RESULTS

The Differences in Significance of Heart Rate Variability Between Noise-Sensitive Groups

Figure 3 shows the distributions of HRV with the stimulating SPL changing in the high-sensitive group and the low-sensitive group, including the value of maximum, minimum, median, quartile, mean and other information. And the result of one-sample Kolmogorov–Smirnov test (**Table 1**) showed that the distribution of observed physiological data of all experimental samples met the normal distribution. Then the result of the further repeated-measures ANOVA (**Table 2**) showed that the *p*-values of all HRV indicators were greater than 0.05, indicating that there was no significant difference in HRV between the two noise-sensitive groups under short-term noise stimulation. This result has two implications: First, there were no significant differences in physiological baseline[2] of the SDNN, LF/HF, and HR between two groups. Second, there were no significant differences in the SDNN, LF/HF, and HR responses to the same level of noise stimulus between two groups.

The results of non-significant differences between groups were inconsistent with the conclusions of previous relevant studies. And the possible reasons for these results will be analyzed and discussed in the section "Non-significant Difference Between Noise-Sensitive Groups" of this manuscript.

[2]The physiological data measured at resting state (under 15.7 dB) were taken as the physiological baseline.

TABLE 1 | One-sample Kolmogorov–Smirnov test results.

SDNN	15.7 dB	35 dB	45 dB	55 dB	65 dB
Exact sig. (two-tailed)	0.505	0.290	0.429	0.810	0.716
LF/HF	15.7 dB	35 dB	45 dB	55 dB	65 dB
Exact sig. (two-tailed)	0.693	0.312	0.852	0.791	0.842
HR	15.7 dB	35 dB	45 dB	55 dB	65 dB
Exact sig. (two-tailed)	0.916	0.713	0.933	0.984	0.519

TABLE 2 | The repeated-measures ANOVA results.

	SDNN	LF/HF	HR
F	0.056	1.613	0.147
Sig.	0.814	0.214	0.705

p > 0.05, no significant difference.

Variation Trend of Heart Rate Variability in the High-Sensitive Group

Standard Deviation of NN Intervals

The variation trend of SDNN in the high-sensitive group with SPL is shown in **Figure 4**. With the increase of SPL, SDNN generally presented an upward trend. The SDNN increased significantly from 15.7 dB (A) to 45 dB (A), and this upward trend eased off from 45 dB (A) to 65 dB (A), with slight fluctuations. The maximum value of SDNN offset to the baseline appeared at 65 dB (A). The repeated-measures ANOVA result of SDNN for the main effect of SPL was $p = 0.043$, and the corresponding results of pairwise comparison (**Table 3**) revealed that the SDNN only showed a significant difference between 45 dB (A) and 15.7 dB (A) ($p < 0.05$).

Low Frequency/High Frequency

The variation trend of LF/HF in the high-sensitive group (**Figure 4**) showed that LF/HF gentle increase at first and then decreased with the increase of SPL. The LF/HF increased obviously from 35 dB (A) to 55 dB (A), and the maximum value of LF/HF offset to the baseline occurred at 55 dB (A). The Mauchly's test of sphericity of LF/HF ($p = 0.010 < 0.05$) did not obey the

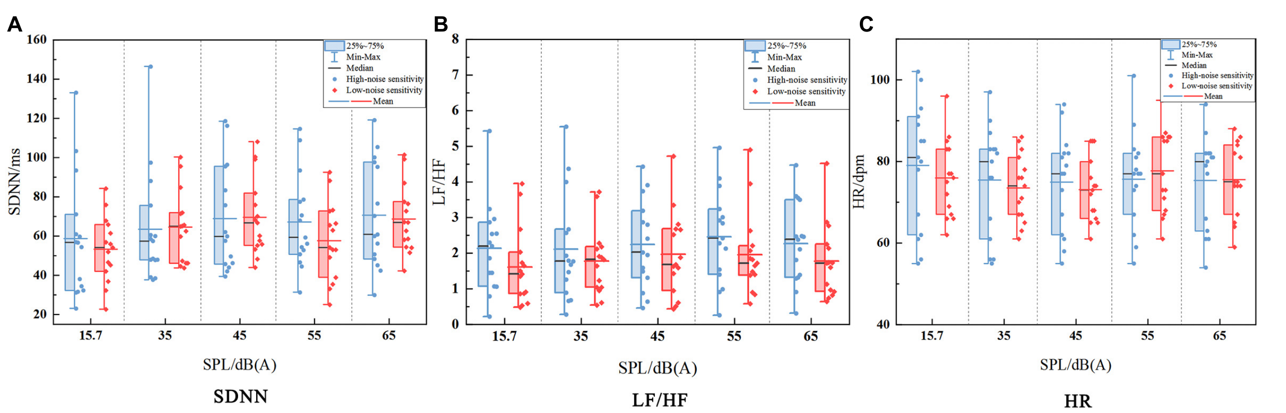

FIGURE 3 | The distribution of HRV indicators of the subjects in different noise-sensitive groups. **(A)** The distribution of SDNN in different noise-sensitive groups. **(B)** The distribution of LF/HF in different noise-sensitive groups. **(C)** The distribution of HR in different noise-sensitive groups.

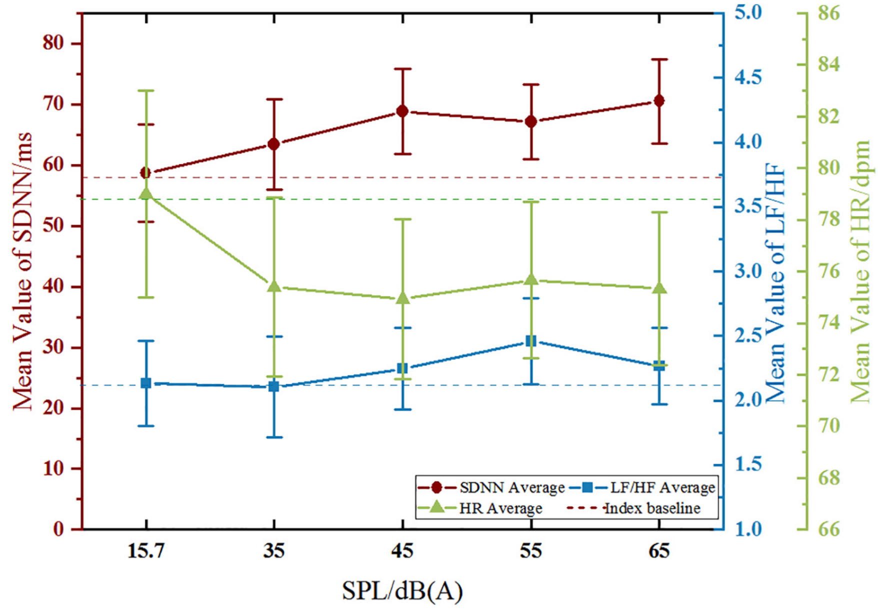

FIGURE 4 | Variation trend of HRV with SPL in the high-sensitive group.

TABLE 3 | High-sensitive group's SDNN/ms pairwise comparisons.

(I) SPL	(J) SPL	Mean difference (I-J)	Std. error	Sig.[b]	95% confidence interval for the difference[b]	
					Lower-bound	Upper-bound
15.7 dB (Resting)	35 dB	−4.731	3.003	0.137	−11.172	1.709
	45 dB	−10.133*	3.547	0.013	−17.741	−2.526
	55 dB	−8.451	4.757	0.097	−18.654	1.752
	65 dB	−11.836	5.646	0.055	−23.945	0.273
35 dB	45 dB	−5.402	4.002	0.199	−13.986	3.182
	55 dB	−3.720	4.503	0.423	−13.377	5.937
	65 dB	−7.105	5.430	0.212	−18.751	4.542
45 dB	55 dB	1.682	4.408	0.709	−7.773	11.137
	65 dB	−1.703	5.484	0.761	−13.465	10.06
55 dB	65 dB	−3.385	3.661	0.371	−11.236	4.467

Mauchly's test of sphericity $p = 0.257 > 0.05$ obeyed the hypothesis of a spherical distribution, and the tests of within-subjects effects was $p = 0.043 < 0.05$.
Based on estimated marginal means.
**The mean difference was significant at the 0.05 level.*
[b]Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

hypothesis of spherical distribution, and the further multivariate test was $p = 0.939$, which indicated that there was no significant difference in LF/HF between the different SPL levels.

Heart Rate

The variation trend of HR in the high-sensitive group (**Figure 4**) showed a general downward trend with the increase of SPL, whereby HR decreased significantly from 15.7 dB (A) to 35 dB (A), and this downward trend began to plateau from 35 dB (A) to 65 dB (A), with slight fluctuations. The maximum value of HR offset to the baseline appeared at 45 dB (A). The repeated-measures ANOVA result of HR for the main effect of SPL was $p = 0.050$, and the corresponding results of pairwise comparison (**Table 4**) revealed that HR showed significant differences between 35 dB (A), 45 dB (A), and 15.7 dB (A) ($p < 0.05$).

Variation Trend of Heart Rate Variability in the Low-Sensitive Group

Standard Deviation of NN Intervals

The variation trend of the SDNN in the low-sensitive group with SPL is shown in **Figure 5**. With the increase of SPL, the SDNN generally showed an upward trend. The SDNN increased significantly from 15.7 dB (A) to 45 dB (A), and this upward trend eased off from 45 dB (A) to 65 dB (A), with a more obvious decline at 55 dB (A). The maximum value of the SDNN offset to the baseline appeared at 45 dB (A). The

TABLE 4 | High-sensitive group's HR/bpm pairwise comparisons.

(I) SPL	(J) SPL	Mean difference (I-J)	Std. error	Sig.[b]	95% confidence interval for the difference[b]	
					Lower-bound	Upper-bound
15.7 dB (Resting)	35 dB	3.600*	1.129	0.007	1.179	6.021
	45 dB	4.067*	1.152	0.003	1.595	6.539
	55 dB	3.333	2.670	0.232	−2.394	9.060
	65 dB	3.667	2.203	0.118	−1.059	8.392
35 dB	45 dB	0.467	0.888	0.608	−1.439	2.372
	55 dB	−0.267	2.159	0.903	−4.897	4.364
	65 dB	0.067	1.551	0.966	−3.259	3.392
45 dB	55 dB	−0.733	2.161	0.739	−5.369	3.902
	65 dB	−0.400	1.650	0.812	−3.939	3.139
55 dB	65 dB	0.333	1.027	0.750	−1.869	2.535

Mauchly's test of sphericity $p = 0.000 < 0.05$ did not obey the hypothesis of spherical distribution, and the multivariate test results was $p = 0.050$.
Based on estimated marginal means.
**The mean difference was significant at the 0.05 level.*
[b]Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

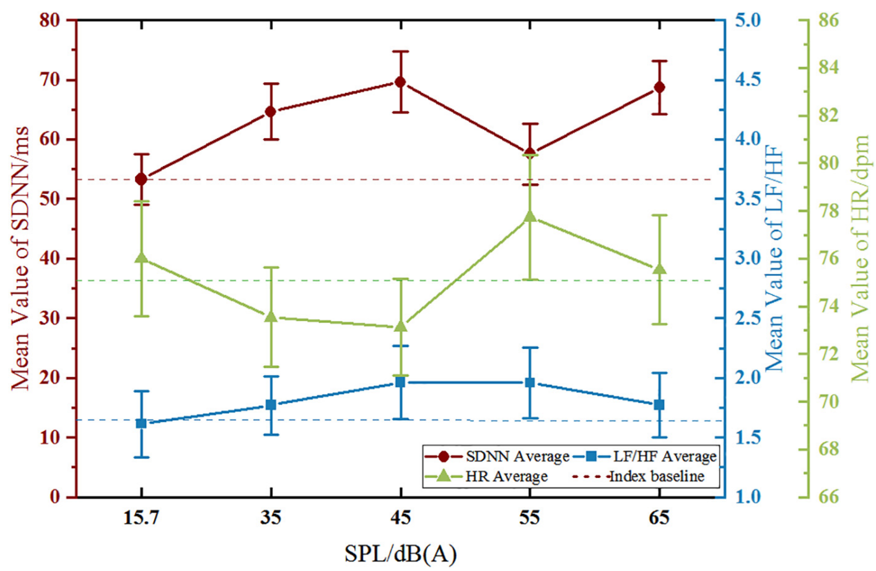

FIGURE 5 | Variation trend of HRV with SPL in the low-sensitive group.

repeated-measures ANOVA result of SDNN for the main effect of SPL was $p = 0.004$, and the corresponding results of pairwise comparison (**Table 5**) revealed that significant differences in the SDNN were found between 35 dB (A), 45 dB (A), 65 dB (A), and 15.7 dB (A) ($p < 0.01$), as well as between 45 dB (A), 65 dB (A), and 35 dB (A) ($p < 0.05$), between 55 dB (A) and 45 dB (A) ($p < 0.05$), and between 65 dB (A) and 55 dB (A) ($p < 0.05$).

Low Frequency/High Frequency

The variation trend of LF/HF in the low-sensitive group (**Figure 5**) revealed that LF/HF increased at first and then decreased with the increase of SPL. The LF/HF increased obviously from 15.7 dB (A) to 45 dB (A), and the LF/HF values of 45 dB (A) and 55 dB (A) were similar, reaching a maximum offset to the baseline. The Mauchly's test of sphericity of LF/HF ($p = 0.010 < 0.05$) did not obey the hypothesis of spherical distribution, and the further multivariate test was $p = 0.412$, which indicates that there was no significant difference in LF/HF between the different SPL levels.

Heart Rate

The variation trend of HR in the low-sensitive group (**Figure 5**) revealed a general decrease at first and then an increase with the increase of SPL, whereby HR decreased obviously from 15.7 dB (A) to 45 dB (A), and significantly fluctuated from 45 dB (A) to 65 dB (A). The maximum value of HR offset to the baseline appeared at 45 dB (A). The repeated-measures ANOVA result of HR for the main effect of SPL was $p = 0.050$, and the corresponding results of pairwise comparison (**Table 6**) revealed

TABLE 5 | Low-sensitive group's SDNN/ms pairwise comparisons.

(I) SPL	(J) SPL	Mean difference (I-J)	Std. error	Sig.[b]	95% confidence interval for the difference[b]	
					Lower-bound	Upper-bound
15.7 dB (Resting)	35 dB	−11.341*	3.120	0.003	−18.033	−4.650
	45 dB	−16.343*	3.352	0.000	−23.533	−9.154
	55 dB	−4.248	3.659	0.265	−12.095	3.599
	65 dB	−15.360*	3.424	0.001	−22.704	−8.016
35 dB	45 dB	−5.002*	1.877	0.019	−9.028	−0.976
	55 dB	7.093	5.248	0.198	−4.163	18.350
	65 dB	−4.019	3.651	0.290	−11.849	3.812
45 dB	55 dB	12.095*	4.994	0.030	1.384	22.807
	65 dB	0.983	3.620	0.790	−6.782	8.748
55 dB	65 dB	−11.112*	2.771	0.001	−17.055	−5.169

Mauchly's test of sphericity p = 0.001 < 0.05, which did not obey the hypothesis of spherical distribution, and the multivariate test result was p = 0.004 < 0.05.
Based on estimated marginal means.
**The mean difference was significant at the 0.05 level.*
[b]*Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).*

TABLE 6 | Low-sensitive group's HR/bpm pairwise comparisons.

(I) SPL	(J) SPL	Mean difference (I-J)	Std. error	Sig.[b]	95% confidence interval for the difference[b]	
					Lower-bound	Lower-bound
15.7 dB (Resting)	35 dB	2.467	1.272	0.073	−0.261	−0.261
	45 dB	2.867	1.737	0.121	−0.859	−0.859
	55 dB	−1.733	2.892	0.559	−7.937	−7.937
	65 dB	0.467	2.065	0.824	−3.963	−3.963
35 dB	45 dB	0.400	1.154	0.734	−2.075	−2.075
	55 dB	−4.200	2.187	0.075	−8.891	−8.891
	65 dB	−2.000	1.298	0.146	−4.785	−4.785
45 dB	55 dB	−4.600*	2.042	0.041	−8.980	−8.980
	65 dB	−2.400*	1.018	0.033	−4.583	−4.583
55 dB	65 dB	2.200	1.455	0.153	−0.920	−0.920

Mauchly's test of sphericity p = 0.001 < 0.05, which did not obey the hypothesis of spherical distribution, and the multivariate test result was p = 0.050.
Based on estimated marginal means.
**The mean difference was significant at the 0.05 level.*
[b]*Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).*

that HR was significantly different between 55 dB (A), 65 dB (A), and 45 dB (A) (all, $p < 0.05$).

ANALYSIS AND DISCUSSION

Non-significant Difference Between Noise-Sensitive Groups

According to the results presented in section "The Differences in Significance of Heart Rate Variability Between Noise-Sensitive Groups," the HRV indicators, including SDNN, LF/HF, and HR, did not differ significantly between the high-sensitive group and the low-sensitive group under short-term noise stimulation in this study. And these result are not consistent with the conclusions of previous relevant studies. In the chronic noise-physiological effect studies, cross-sectional studies of long-term exposure to traffic noise (mainly airport noise) (Babisch et al., 2009; Shepherd et al., 2010) confirmed that residents with higher noise sensitivity suffer significantly more CDs and sleep disorders than residents with lower noise sensitivity. And in the acute effect studies, Shepherd et al. (2016) confirmed that HRV of 103 subjects showed significant differences in SDNN and HR between different sensitive groups under stimulation of standard digitized sound samples [70 dB (A)] in laboratory. Compared with these studies, firstly, the level of noise in above studies were higher, while this study focuses on the effects of noise below 65 dB (A). Based on the physiological mechanism for coping with noise (Babisch, 2006; WHO Regional Office for Europe, 2018a), higher SPL stimulation may cause faster physiological feedback. Due to the low SPL [≤65 dB (A)] and short duration of noise stimulation (10 min) in this study, the slow physiological response caused by low SPL noise probably has not reached the adequate degree in a short time, so no significant results were presented. Secondly, compared with Shepherd's study, the state of subjects and duration of noise stimulation during the experiment were similar in this study, but Shepherd chose digital audio samples which are different with the real recorded signals using in this study. And the HRV data testing period in Shepherd's study was several seconds after noise exposure, while it was 10 min while noise stimulating in this study. In summary, the non-significance results in this study may be mainly caused by the lower SPL of stimuli noise followed by the characteristics of stimulating noise signals and HRV data testing period.

Although there were no significant differences in HRV of short-term noise stimulation between groups, this study still showed that there were clear differences in variation trend of the physiological indicators with SPL changing between the two sensitive groups. And according to WHO Regional Office for Europe (2018a) relevant theories, the acute biological effects of cardiovascular autonomic arousal do not adapt over time, and that long-term noise exposure can increase the risk of chronic diseases. Based on this theory, it could be inferred that non-significant differences between the two groups may cause distinction on physiology after long-term accumulating, and the details of HRV trends is worth further exploring.

The Differences of Heart Rate Variability Trends Between Noise-Sensitive Groups

The results (**Figure 6**) show that there were significant variations just in SDNN and HR with the stimulating SPL changing in the both two groups, while LF/HF showed no significant change among different SPL. Therefore, only the characteristics of trends in SDNN and HR are discussed in this part.

Variation Trend of Standard Deviation of NN Intervals

Standard deviation of NN intervals showed an upward trend with the increase of SPL in both groups, which is consistent with relevant research conclusions (Kraus et al., 2013; Walker et al., 2016; El Aarbaoui et al., 2017). It follows that, in this study, under the influence of indoor-level road traffic noise, the higher SPL is, the higher SDNN value is. As we know, higher SPL has a greater impact on human body, confirmed by epidemiological studies on the chronic effects of noise, which shown that prevalence rate of CDs of residents living in high noise exposure environment for a long time was significantly higher than those living in quiet areas (Nassur et al., 2019). So it follows that higher SDNN value is detrimental to human physiological health. From this point of view, SDNN of the high-sensitive group was obviously higher than that of the low-sensitive group under 55 dB (A) and 65 dB (A) SPL, which the numerical difference was 9.595 ms and 1.868 ms, respectively. It can be seen that under the same noise level [55 dB (A) or 65 dB (A)], the high-sensitivity group is more affected.

On the other hand, some scholars suggest that rapid physiological responses of low-sensitive people were manifested as strong adaptability to noise (Stansfeld, 1992), and may give rise to the coping mechanism of humans mentioned by WHO which may indirectly reduce the impact of noise on health. In terms of the significance of changes in SDNN within groups, the high-sensitive group just showed a significant change to the baseline at 45 dB (A), while the low-sensitive group changed significantly almost with every increase of SPL level. It can be seen that the low-noise sensitive group is more responsive to the change of SPL. Meanwhile, in terms of the degree of deviation from the SDNN baseline, a similar status was observed. At 45 dB (A) ($p < 0.05$), there was a increase of 10.133 ms in the high-sensitive group and a increase of 16.343 ms in the low-sensitive group. It can be seen that under the same noise stimulus, the physiological feedback of the high-sensitive group was 6.21 ms slower, and the low-sensitive group also showed stronger response. Based on the analysis of the above two aspects, the low-sensitivity group showed a rapid response in SDNN than the high-sensitivity group. According to the above views of relevant scholars, the high-sensitivity group would be more affected by road traffic noise.

Variation Trend of Heart Rate

Heart rate showed a downward trend at lower SPL, then leveled off and even increased when SPL is higher than 45 dB (A) (only in the low-sensitive group showed an upward trend at higher

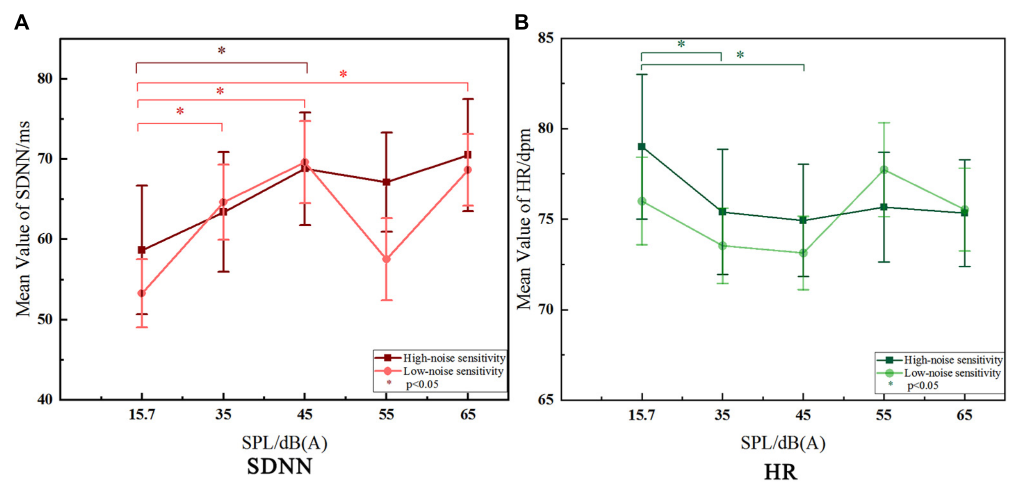

FIGURE 6 | Comparison of the trends of SDNN and HR between noise-sensitive groups.

SPL). According to Park and Lee (2017), under noise stimulation below 60 dB (A), HR decreases in the post-encounter stage due to people's attention being oriented by stimulation (Lang and Bradley, 1997; Boucsein, 2012). After that, when the body reaches the high arousal noise stimulus state, HR presents an upward trend, corresponding to the circa-striker stage. From the above point of view, after significant decrease at 35 dB (A) and 45 dB (A) compared with the baseline, HR then leveled off in the high-sensitive group. However, the HR in the low-sensitive group increased significantly when SPL was higher than 45 dB (A), reaching earlier to the upward trend than the high-sensitive group, which is correspond to the circa-striker stage mentioned above. As other studies have shown, HR of the high-sensitive group seemed to be less responsive to different noise stimuli than that of the low-sensitive group (White et al., 2010), and the ability to adapt to noise was also weaker (Stansfeld, 1992). And this is consistent with the result reflected by SDNN.

In terms of HR value, an epidemiological study of people living with long-term exposure to aircraft noise in west London found that HR value of high-sensitive groups was lower than that of low-sensitive groups (Stansfeld et al., 1985). This study also found a similar trend under the short-term influence of noise, which was lower 2.1 dpm at 55 dB (A) and 0.2 dpm at 65 dB (A) in HR of the high-sensitive group than that of the low-sensitive group. At the same time, the above-mentioned 55 dB (A) and 65 dB (A) (also in the SDNN part) are highly consistent with the SPL findings of epidemiological studies that the prevalence of CDs increasing significantly when the SPL is higher than around 55 dB (A) to 60 dB (A) (Barregard et al., 2009; Bluhm and Eriksson, 2011; Chang et al., 2011). And according to the WHO cumulative effect of noise impact, the differences in HR (and in SDNN) indicators observed in this study caused by short-term noise stimulation may have the potential to produce physiological response and lead to between-groups differences in prevalence after long-term recurrent effect, which is worthy of further research.

CONCLUSION AND PROSPECTS

In this study, there was no significant difference between sensitive groups in the acute physiological effects of indoor-level traffic noise reflected by observing SDNN, LF/HF, and HR. According to the comparative analysis with the previous research, the possible reasons may be related to the low SPL [$\leq$65 dB (A)] of noise concerned in this study, as well as the type of stimulus audio signal and HRV data testing period.

However, according to the theory of cumulative effect of noise proposed by WHO Regional Office for Europe (2018a), we discussed the variation trends and the within-group significant changes of SDNN and HR indicators with SPL, and the results showed that the high-sensitivity group was more affected by road traffic noise. In addition, there are also observable numerical differences in SDNN and HR between the two sensitive groups at the SPL that can significantly increase the prevalence of CDs concerned by epidemiological studies. According to the cumulative effect theory, these non-significant but observable differences in HRV are likely to lead to differences in morbidity between groups, and deserve attention and further research.

In the follow-up study, it is necessary to focus on the residents living on the street for a long time, and the relationship between the acute and chronic noise effects needs to be further discussed by observing the differences between exposed groups and non-exposed groups. For another, the subjects of this study were only college students. Because of the prevalence of CDs would increase with age, middle-aged and elderly population should be paid attention to in subsequent studies. In addition, in order to further improve the experiment, the acquisition and playing process of noise signals should be optimized.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the School of Architecture, Tianjin Chengjian University, Tianjin, China. The patients/participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

CC and YW conceptualized and supervised the project. YNX managed the project and did data analysis and graphs. CC, YNX, and QKW designed the experiments. YNX and QKW carried out the experiments. CC and YNX conceptualized and wrote the first draft of the manuscript. LL made substantial contributions in searching for references. All authors participated in reviewing the manuscript.

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Religious Belief-Related Factors Enhance the Impact of Soundscapes in Han Chinese Buddhist Temples on Mental Health

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In contemporary society, mental health issues have received increasing attention. Moreover, how people perceive the acoustic environment affects mental health. In religious places, the unique religious soundscape, composed of the acoustic environment and sounds, has an obvious effect on mental health. In China, Han Chinese Buddhism has a long history and is currently the religion with the largest number of believers. The soundscape of temples has always been an important component of creating a Buddhist atmosphere. For this study, questionnaires were distributed to believers and tourists inside and outside several well-known Han Chinese Buddhist temples in China to analyse the relationship between evaluations of temple soundscapes (including the overall acoustic environment and preferences for typical sounds) and mental health and the role of religious belief-related factors in this relationship. The results indicated that for the respondents, the overall acoustic environment of Buddhist temples was significantly correlated with mental health and that a preference for three sounds in Buddhist temples, i.e., bells, wind chimes and chanting sounds, was significantly correlated with mental health. Among religious belief-related factors, attitudes toward Buddhist thought, frequency of temple visitation and purpose for visiting temples can affect the correlation between personal evaluations of temple soundscapes and mental health. For people who partially believe in Buddhist thought, people who visit Buddhist temples twice or less per year, or people who visit temples for tourism purposes, the correlations between evaluations of the overall acoustic environment and mental health are higher than for people without these religious characteristics. For people who fully believe in Buddhist thought or who visit temples neither to worship Buddha nor for tourism purposes, the correlations between the preferences for bells and wind chimes and mental health are higher than for people without these religious characteristics. For people who partially believe in Buddhist thought, the correlation between the preference for chanting and mental health is higher than for people with other attitudes toward Buddhist thought.

Keywords: Han Chinese Buddhist temple, soundscape, evaluation, mental health, religious belief-related factors

INTRODUCTION

The concept of soundscapes was first proposed by the Finnish geographer Granö in 1929. In the 1960s and 1970s, the Canadian composer Schafer conducted research by treating soundscapes as an artistic concept. The ISO 12913-1 standard defines the term soundscape as "an acoustic environment as perceived or experienced and/or understood by a person or people, in context" (ISO, 2014). The study of soundscapes has become a widely researched topic in academia, and related interdisciplinary research has continuously emerged (Kang et al., 2016; Jahani et al., 2021).

Human mental health is an important component of health. The World Health Organization (WHO) proposes that health is not only the absence of disease or frailty but also a state of physical, psychological, and social integrity. However, many people in modern society have mental health issues. According to the WHO, the average life expectancy of people with mental disorders is approximately 20 years shorter than that of people with normal mental health. In 2017, 264 million people worldwide experienced anxiety. Based on data released by the Bureau of Disease Control and Prevention of the National Health Commission of China, the proportion of people with mental disorders in the Chinese population is as high as 17.5% (Www.cir.cn, 2019). Therefore, there is an urgent social need to explore ways to prevent and treat mental health problems. Scholars have conducted many studies on mental health, some of which have focused on the relationship between mental health and soundscapes or acoustic environments. These results showed that the quiet rural soundscape might benefit the general mental health of the population through its potential for psychological restoration (De Coensel and Botteldooren, 2006). The experience of quietness supports health, resulting in a lower degree of annoyance and contributing to physiological and psychological well-being (Öhrström et al., 2006). The experience of pleasant soundscapes facilitates faster recovery from stress (Medvedev et al., 2015). Noise exposure or excessive reverberation affects the well-being of children at school in their early childhood (Astolfi et al., 2019). Positive experiences of natural sound help subjects recovering from stress-related mental disorders (Cerwén et al., 2016). Better health conditions are associated with greater satisfaction with everyday soundscape experience (Booi and Van den Berg, 2012). The association between the physiological responses and the well-founded psychological components of the soundscape has also been explored (Erfanian et al., 2019). A systematic review was performed using three major scientific databases, and the findings revealed that regardless of the scale, statistically significant associations existed between positive soundscape perceptual constructs and health benefits (Aletta et al., 2018). For the relationship between noise and mental health, a narrative review documented the role of noise in clinical environments and its deleterious effects with a particular focus on mental health care (Brown et al., 2015). The association between mental well-being and the physical environment, such as neighbour noise, has been confirmed (Guite et al., 2006), and research (from 2003 to 2008) on the mental health effects of noise in adults and children has been summarised (Van Kamp and Davies, 2008). The results from international surveys suggested that long-term noise exposure was associated with mental health problems such as anxiety and depression (Stansfeld et al., 2000; Stansfeld and Matheson, 2003).

Previous studies have shown that individual characteristics could affect the relationship between the acoustic environment and mental health. For example, the correlation between the score on the mental health scale and the sound environment was affected by the respondent characteristics, such as gender, age, education, and noise sensitivity (Van Kempen et al., 2011); neighbourhood noise had different effects on the mental health of children, adults, and older people (Niemann et al., 2006). A report in a Turkish suggested that among students over 14 years old, men showed a higher annoyance in noise pollution (Anilan, 2014).

Soundscapes in religious places have been one of the important research objects in academia in recent years, including ancient English church music and soundscape maps (Burgess and Wathey, 2000), the effect of church bells on the soundscapes of early modern European towns (Garrioch, 2003), soundscapes in Islamic mosques in the Netherlands (Arab, 2017), and soundscapes in Han Chinese Buddhist temples (Zhang et al., 2016). Regarding the relationship between mental health and religious soundscapes or music, research has shown that the pleasantness of soundscapes in the two religious precincts in Korea significantly affects the perception of tranquillity, and the evaluation of tranquillity includes the degree of stress and restlessness (Jeon et al., 2014). Religious songs are an important form of religious expression important to the mental health of older African Americans (Hamilton et al., 2013). The frequency of listening to religious music among older Americans is associated with a decrease in death anxiety and increases in life satisfaction, self-esteem, and a sense of control (Bradshaw et al., 2015). Quran recitation could be introduced as an effective treatment for physical and mental diseases (Jafari et al., 2016). In terms of the relationship between religious beliefs and mental health, although some studies have demonstrated that the two are correlated (Koenig et al., 2001; Mueller et al., 2001; Maselko and Buka, 2008), there are relatively few studies on the relationship between Han Chinese Buddhism and mental health.

In summary, soundscapes and acoustic environments can affect mental health. In Western society, the relationship between the soundscapes or acoustic environments of religious sites and mental health has received attention. In China, the world's most populous country, Han Buddhism has the largest number of religious believers, but there is nonetheless a lack of research on the relationship between the soundscapes of Han Chinese Buddhist temples and mental health and whether the relationship is influenced by religious belief-related factors. Recently, an increasing amount of attention has been given to the mental health of Chinese people; therefore, it is necessary to conduct research on this topic. As an important concept in statistics, moderation refers to whether the influence of variable X on variable Y can be moderated by variable Z. This paper aims to analyse the relationship between people's evaluations of the soundscape in Han Chinese Buddhist temples and their mental health, as well as the moderator effects of religious belief-related factors on this relationship. First, questionnaires regarding temple soundscapes were distributed inside and outside Han Chinese Buddhist temples. The Kessler Psychological Distress Scale 10-item (K10) was used in the questionnaire to investigate respondents' mental health. Based on the questionnaire results and the relationship between evaluations of Han Chinese Buddhist temple soundscapes and mental health, the influence of religious belief-related factors on the correlation between evaluations of the overall acoustic environment of Buddhist temples and mental health and the correlation between respondents' sound preferences in Buddhist temples and mental health were analysed.

MATERIALS AND METHODS

Questionnaire Design

This study used a questionnaire survey composed of four parts. The first part obtained basic demographic information from respondents, including gender, age, education level and occupation. The second part included items related to Buddhist beliefs, including attitudes toward Buddhist thought, the annual frequency of attending religious activities or visiting Buddhist temples and the purpose of visiting Buddhist temples. The third part was used to evaluate Buddhist temple soundscapes, including the importance of the acoustic environment of temples; respondents' evaluations of the quietness, comfort and harmony of the overall acoustic environment of temples; and respondents' preferences regarding six typical sounds in Han Chinese Buddhist temples (Buddhist instruments, chanting, bells, drums, background electronic Buddhist music and wind chimes). According to a previous questionnaire, among the sounds that can be heard in temples, respondents considered these six sounds to occur frequently and to be characteristic of religious places.

In the fourth part of the questionnaire, respondents' mental health was assessed with the K10 scale, which contains 10-items divided among four factors: nervousness, restlessness, fatigue, and negative affect (see **Table 1**). Among them, nervousness, restlessness, and fatigue were assessed with two items each, while negative affect was assessed with four items, separately targeting the occurrence frequency of non-specific mental health-related symptoms, such as anxiety and stress, experienced by the respondents in the past 4 weeks. The occurrence frequency of each item was divided into the following five levels, each of which was scored from 1 to 5 points: all of the time, most of the time, some of the time, a little of the time and none of the time (Zhou et al., 2008). The scores for the 10-items (total possible score of 50 points) were summed, and the individual's mental health status was divided into four levels based on the score: 10–30 points (very poor mental health), 31–38 points (poor mental health), 39–44 points (good mental health), and 45–50 points (very good mental health) (Kessler et al., 2002).

TABLE 1 | Corresponding evaluation content of Kessler Psychological Distress Scale 10-item.

Evaluation content	Corresponding item
Nervousness	Did you feel nervous?
	Did you feel so nervous that nothing could calm you down?
Restlessness	Did you feel restless or fidgety?
	Did you feel so restless that you could not sit still?
Fatigue	Did you feel tired out for no good reason?
	Did you feel that everything was an effort?
Negative affect	Did you feel hopeless?
	Did you feel depressed?
	Did you feel so sad that nothing could cheer you up?
	Did you feel worthless?

Determination of the Number of Questionnaires

The number of questionnaires in this study was determined based on previous studies (Zhang et al., 2018). First, 136 pilot questionnaires were tested before the formal questionnaires were distributed. The statistical results of these pilot questionnaires showed that the maximum standard deviation (SD) of the items for the acoustic environment and sounds was 1.135.

The maximum number of total questionnaires required was based on the empirical formula below (Du, 2010).

$$n = \left(\frac{u_{a/2}S}{d}\right)^2$$

where n is the maximum sample size, ua/2 is a constant based on the confidence level, S is the estimate of the standard deviation, and d is the absolute limit of error.

In this study, the absolute limit of error "d" was set to 0.1, and the confidence level was set to 95%. Then, ua/2 = 1.96 and S was 1.135 in the test questionnaires, and the maximum sample size "n" was 495.

For this study, a final total of 521 questionnaires were distributed to and collected from tourists and believers in several well-known Han Chinese Buddhist temples. All respondents were clearly informed in advance about the purpose of the questionnaire survey and agreed to participate. After 22 invalid questionnaires were excluded, 499 valid questionnaires were eventually analysed. The maximum SD of the items in the formal questionnaire was 1.124 (less than 1.135 for the pilot questionnaire), indicating that the number of questionnaires distributed in this study met the requirements.

Questionnaire Reliability and Validity

Reliability and validity analyses of questionnaires are a necessary step before data analysis. This study used SPSS software (version 25.0) for reliability and validity analyses of the results for the evaluations of overall acoustic environment and sound preferences (not including personal information and the K10 scale, which has been verified by numerous studies). The Cronbach coefficient for the evaluations of the overall acoustic environment was 0.803, indicating acceptable reliability of the data (Wu, 2010). Then, factor analysis was used to verify the construct validity of the questionnaire, that is, to test the extent to which the results of the questionnaire correctly verified the ideal assumption in the questionnaire design. Factor analysis was conducted on the results of the acoustic environment evaluation, and the results showed that the Kaiser-Meyer-Olkin (KMO) value was 0.735 and that the significance value for Bartlett's test of sphericity was 0.000 (less than 0.05). These findings indicated that the data can be subjected to factor analysis (Du, 2010). Based on a characteristic root > 1, one principal component was obtained, and the cumulative contribution to all variables was 55.566% (>50%); therefore, the factor analysis results were acceptable (Wu, 2010). The reliability analysis of the results for sound preferences indicated that the Cronbach coefficient was 0.883. The factor analysis showed that the KMO value was 0.879 and that the significance value for Bartlett's test of sphericity was 0.000 (less than 0.05), indicating that the data were suitable for factor analysis. Based on a characteristic root > 1, six principal components were obtained, the calculated results of the Cronbach coefficients for the six principal components were 0.857, 0.848, 0.849, 0.813, 0.832, and 0.851, respectively, and the cumulative contribution to all variables was 56.920% (>50%); therefore, the factor analysis results were acceptable (Wu, 2010), and the structural validity requirements were required.

Determination of Calculation Methods

In this study, different calculation methods and indicators were selected based on the types of variables (see **Table 2**).

Respondents' Personal Characteristics

The basic demographic characteristics of the respondents in 499 questionnaires were collected and statistically analysed. Men and women accounted for 39.08% (195) and 60.92% (304) of the total respondents, respectively. The subjects were divided into three groups based on age: 29 years of age and younger, 30–44 years of age, and 45 years of age and older. These groups accounted for 35.47% (177), 38.28% (191), and 26.25% (131) of the respondents, respectively. In terms of education level, 11.42% (57) of the respondents had a junior high school education or below, 16.03% (80) had attended technical secondary school or high school, 53.71% (268) had attended vocational school or college, and 18.84% (94) had a master's degree or above. In terms of occupation, survey respondents were divided as follows: students 18.04% (90) of the respondents, teachers 15.63% (78), technicians 11.82% (59), service personnel 7.62% (38), management personnel 7.41% (37), workers 7.01% (35), and other occupations 32.46% (162).

In terms of their attitudes toward Buddhist thought, 12.22% (61) of the respondents fully believed in Buddhist thought, 74.95% (374) partially believed in Buddhist thought, and 12.83% (64) had little or no faith in Buddhist thought. In terms of temple visiting frequency, 47.09% (235) of respondents visited the temple twice or less per year, 42.89% (214) visited the temple three to five times per year, and 10.02% (50) visited the temple more than five times per year. In terms of the purpose of visiting Buddhist temples, tourism accounted for 55.11% (275), worship accounted for 27.05% (135), and other purposes accounted for 17.84% (89).

RESULTS

The temple soundscape results from the questionnaire, including respondents' evaluations of the overall acoustic environment of temples and their sound preferences, were analysed. Then, the mental health scores for the respondents were calculated, and correlation analysis was conducted for the temple soundscapes and mental health scores.

Results of the Questionnaire Survey

The results of the formal questionnaire survey showed that among the four factors that exert an impact on respondents' perception of Buddhist temples, i.e., the auditory environment, the visual environment, temperature, and humidity. As shown in **Figure 1A**, 269 people (53.91%) chose the auditory environment as the first influencing factor, 188 people (37.68%) chose the visual environment as the first influencing factor, and fewer than 50 people chose temperature or humidity as the first influencing factor, indicating that within the physical environment of temples, people paid more attention to the acoustic and visual environments.

In terms of respondents' evaluation of the quietness of the temple acoustic environment, **Figure 1B** shows that 129 people (25.85%) chose "quiet," 227 (45.49%) chose "somewhat quiet," 97 (19.44%) chose "neither quiet nor noisy," and 46 (9.22%) chose "somewhat noisy" or "noisy." In terms of the comfort of the acoustic environment of temples, 127 people (25.45%) chose "comfortable," 255 (51.10%) chose "somewhat comfortable," 76 (15.23%) chose "no specific feeling," and 41 (8.22%) chose "somewhat uncomfortable" or "uncomfortable." In terms of the harmony of the acoustic environment, 132 people (26.45%) chose "harmonious" (i.e., they thought that the acoustic environment of temples was in harmony with the temple atmosphere), 233

TABLE 2 | The calculation method of independent and dependent variables.

Independent and dependent variables	Variable type	SPSS calculation approach	Index
Gender vs. mental health scores, attitude toward Buddhist thought, frequency of temple visitation, purpose	Dichotomous (nominal) variable/Continuous variable (Ordinal variable)	Independent-samples *t*-test	Mean difference
Purpose, occupation vs. mental health scores	Nominal variable/Continuous variable	Crosstabs	Phi and Cramer's V
Age, education level, attitude toward Buddhist thought, frequency of temple visitation, evaluation of quietness (comfort and harmony), preferences for sounds vs. mental health scores	Ordinal variable/Continuous variable	Bivariate correlation	Spearman
Age, education level vs. attitude toward Buddhist thought, frequency of temple visitation	Ordinal variable/Ordinal variable	Crosstabs	Gamma

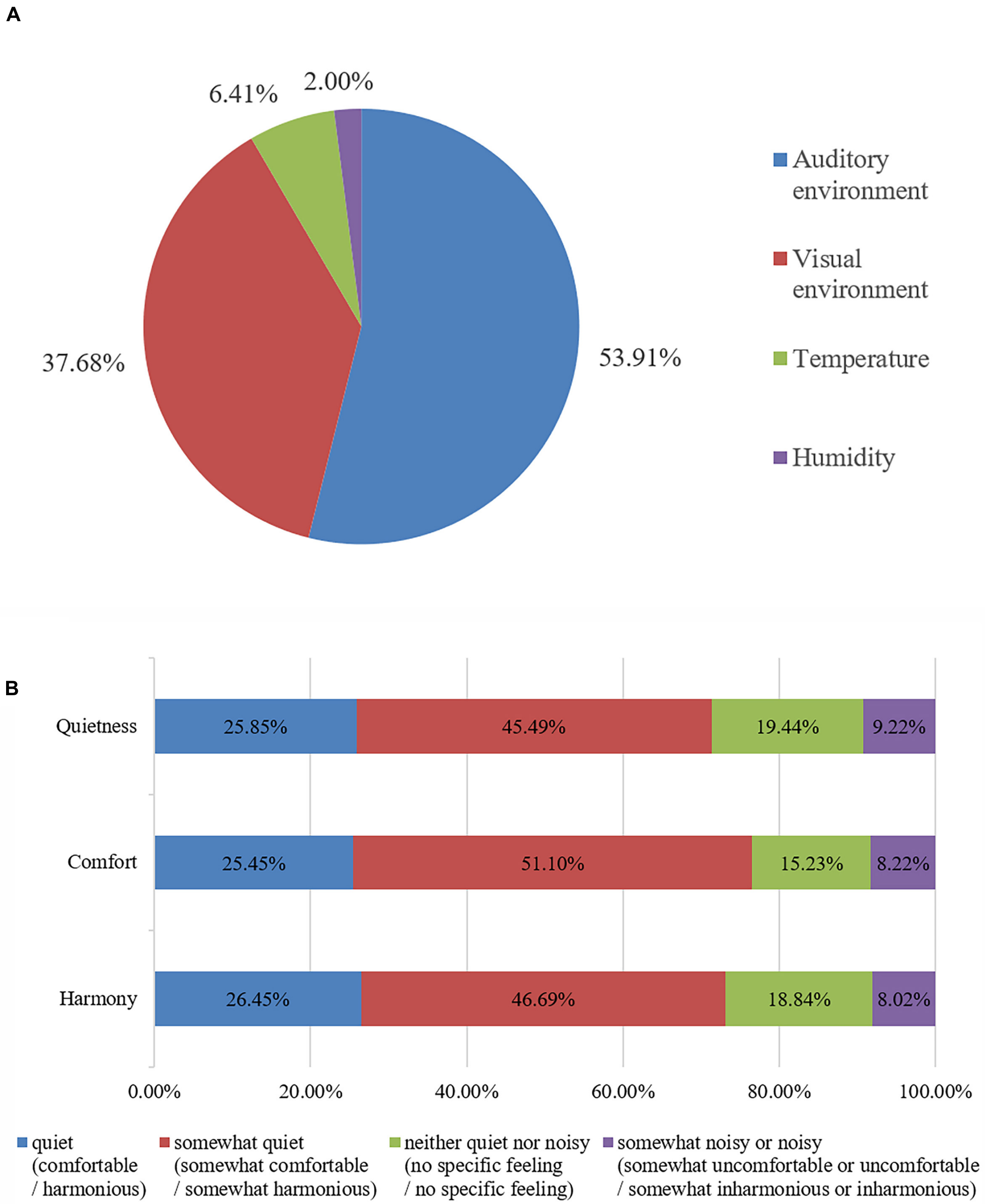

FIGURE 1 | Distribution of the respondents' environmental evaluations of the temple. **(A)** The first influencing factor; **(B)** Evaluation of the acoustic environment.

(46.69%) chose "somewhat harmonious," 94 (18.84%) chose "no specific feeling," and 40 (8.02%) chose "somewhat inharmonious" or "inharmonious."

The respondents' preferences for the six selected typical sounds in the temples are shown in **Figure 2**. Among all kinds of sounds, the proportion of respondents who liked bells was the highest (40.48%), followed by wind chimes (37.47%) and chanting (31.86%). Background electronic Buddhist music (9.62%), followed by drums (5.01%) and chanting (3.81%), were the sounds that respondents most disliked.

The average mental health score of all respondents was 36.69, which indicates a poor level in general. Among the four mental health factors, the overall average score for nervousness was 7.12 (total score was 10), the overall average score for restlessness was 7.53, the overall average score for fatigue was 6.90, and the overall average score for negative affect was 15.13 (the total score was 20, and the equivalent score was 7.57 due to the differing number of items). Fatigue was the lowest scoring of the four factors, indicating that people are facing great stress in current society and that the

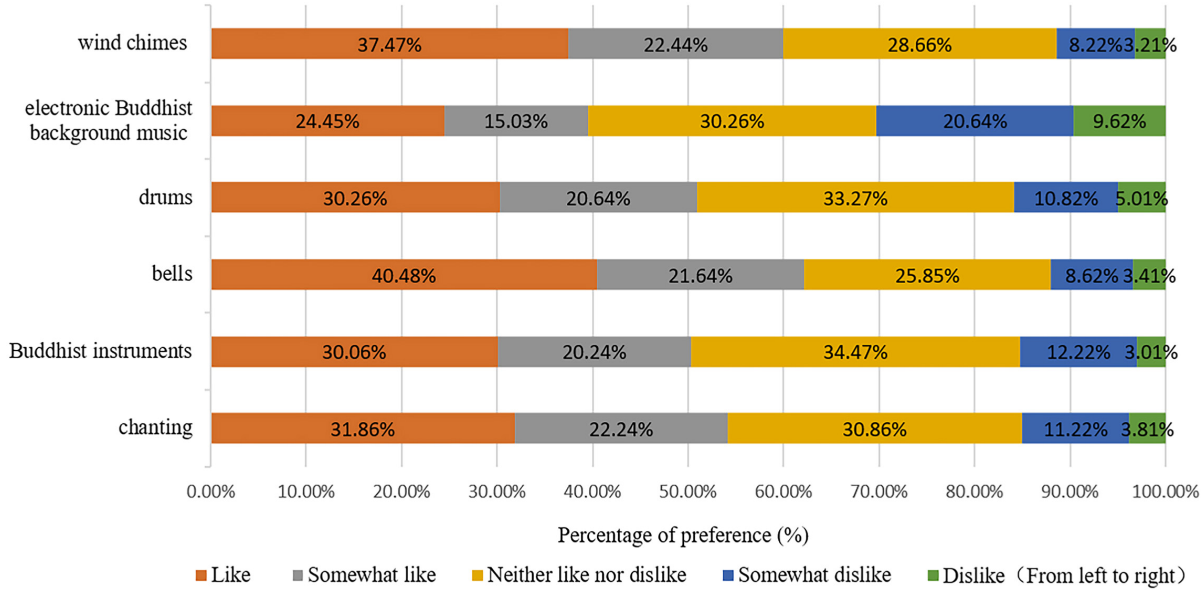

FIGURE 2 | Preferences for the six selected typical sounds in the temples.

resulting fatigue has become the most prominent problem affecting mental health.

In terms of gender, the mental health score for men was 35.03 and that for women was 37.75. The mean difference in mental health scores between men and women was 2.72, and both scores could be considered to indicate a poor mental health state. An independent-samples t-test was performed and indicated a significant difference in mental health between men and women. **Figure 3A** shows that the proportions of male respondents with "very good," "good," and "poor" mental health states were slightly lower than those of female respondents, while the proportion of male respondents with a "very poor" mental health state was 30.3%, almost twice that of female respondents (15.5%). The proportion of male respondents with "poor" and "very poor" mental health states accounted for nearly 60% of the total male respondents, indicating that more female respondents were in good mental states than male respondents. In conclusion, although the mean difference of mental health scores for men and women is not too large, the differences between them are mainly reflected in the proportion of various states.

In terms of age, the mental health score for adolescents (29 years of age and younger) was 36.10, that for middle-aged people (30–44 years of age) was 36.39 and that for middle-aged and elderly people (45 years of age and older) was 37.92. The correlation analysis between respondents' age and mental health score indicated a significant positive correlation between age and mental health, with a correlation coefficient of 0.099*. This value indicates that the degree of interaction between the two variables is not high, but there is a significant correlation between them (In this paper, * indicates that the correlation between the two variables is significant, that is, $p < 0.05$; ** indicates that the correlation is highly significant, that is, $p < 0.01$). **Figure 3B** shows that with increasing age, the proportion of people with a "very good" mental health state gradually increases and that the proportion of people with a "very poor" mental health state gradually decreases. This may be because people aged 60 and older face less stress in life or work than adolescents and middle-aged people and thus exhibit better mental health.

Among respondents with different education levels, those with a junior high school education or below and those with a master's degree or above had high mental health scores, i.e., 37.68 and 37.65, respectively, while those with a college degree had the lowest scores, i.e., 35.90. There was no correlation between mental health score and education level. Among respondents with different occupations, the mental health score was 37.14 for teachers, 36.37 for students, 35.85 for technicians, 35.82 for service personnel, 34.66 for workers and 34.30 for management personnel. Occupation and mental health were significantly correlated (correlation coefficient of 0.284*), mainly manifesting in two factors, nervousness (0.184*) and restlessness (0.182*); the other two factors showed no correlations.

Regarding attitudes toward Buddhist thought, the mental health score was 34.77 for respondents who fully believe in Buddhist thought, 37.66 for those who partially believe in Buddhist thought and 32.88 for those who have little or no faith in Buddhist thought. Regarding the annual number of visits to Buddhist temples, the mental health score was 33.30 for respondents who visited Buddhist temples twice or less per year, 38.76 for those who visited three to five times per year and 43.76 for those who visited more than five times per year. The attitudes toward Buddhist thought and the number of visits to Buddhist temples were significantly correlated with the mental health score, with correlation coefficients of 0.106* and 0.465**, respectively. There was no correlation between the respondents' purpose for visiting Buddhist temples and mental health scores. The mental health score was 36.80 for respondents who were only

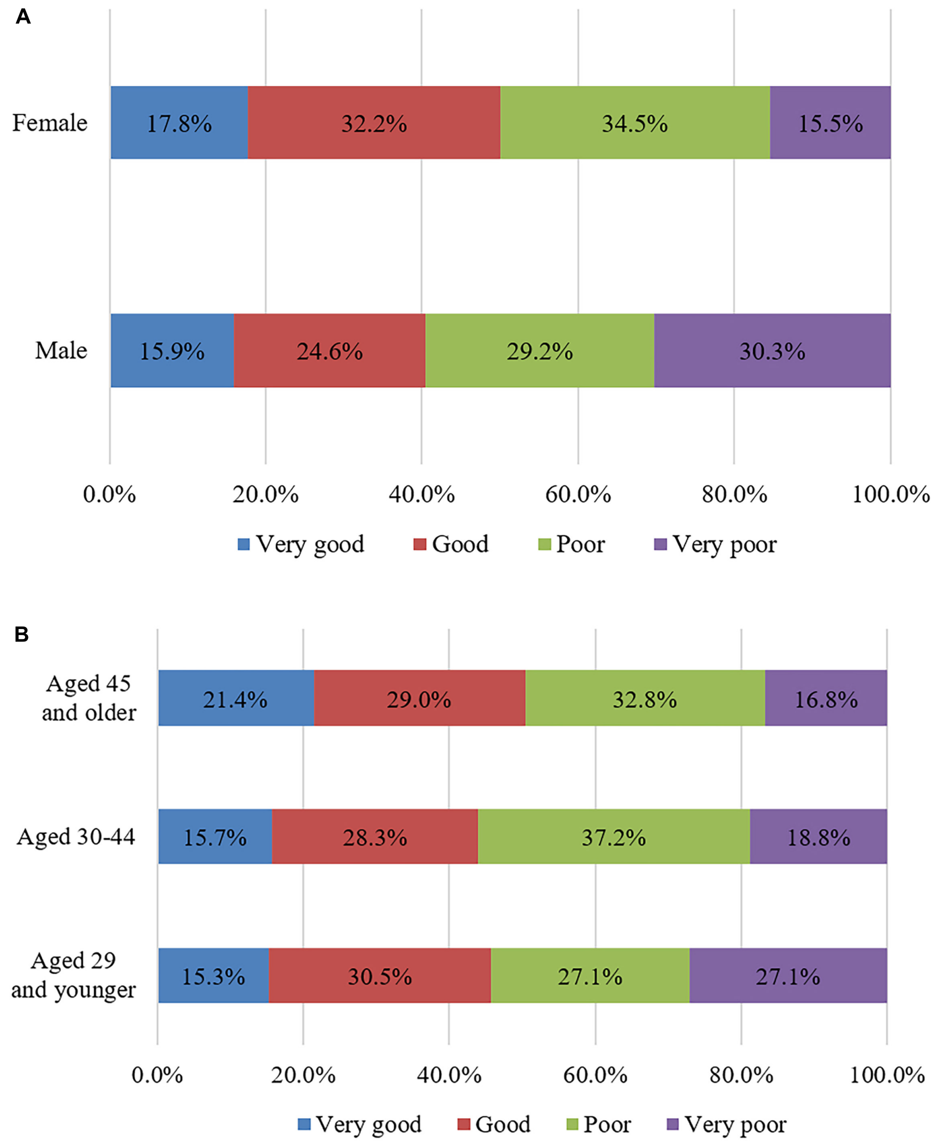

FIGURE 3 | The proportions of respondents' various mental health states by gender and age. **(A)** Gender; **(B)** Age.

tourists, 36.36 for those who worship Buddha, and 36.85 for those who visited temples neither to worship Buddha nor as tourists.

We used ANOVA to examine the relationship between mental health score and various religious factors (including the frequency of visiting temples, purpose for visiting temples and attitudes toward Buddhist thought). The test for homogeneity of variance showed that the frequency of visiting temples and purpose for visiting temples were suitable for ANOVA. However, the variance of attitudes toward Buddhist thought was heterogeneous, so ANOVA could not be used. The ANOVA results show that there is a significant difference between the mental health scores of each visit frequency (the *p*-values of single factor analysis and multiple analysis are all less than 0.001); however, there is no significant difference between the mental health scores of various visit purposes (the *p*-values of single factor analysis and multiple analysis are all greater than 0.600).

The Relationship Between Han Buddhist Temple Soundscapes and Mental Health

Previous studies have shown that the acoustic environment of religious sites may exert an impact on mental health. In our questionnaire, the overall acoustic environment of temples was evaluated by respondents based on the three aspects of quietness, comfort and harmony; respondents' mental health scores based on their evaluations of the acoustic environment are shown in **Table 3**. The results showed that the respondents who assessed the temple as quiet or somewhat quiet (comfortable or somewhat comfortable, harmonious or somewhat harmonious) had a

TABLE 3 | The mental health scores based on their evaluations of the acoustic environment.

Type	Mental health scores			
	Quiet (comfortable/ harmonious)	Somewhat quiet (somewhat comfortable/somewhat harmonious)	Neither quiet nor noisy (no specific feeling/no specific feeling)	Somewhat noisy or noisy (somewhat uncomfortable or uncomfortable/somewhat inharmonious or inharmonious)
Quietness	37.03	37.16	36.64	33.50
Comfort	36.42	38.34	34.47	31.37
Harmony	37.95	37.95	34.91	29.35

significantly better mental health status than those who assessed the temple as noisy or somewhat noisy (somewhat uncomfortable or uncomfortable, somewhat inharmonious or inharmonious).

Respondents' evaluations of these three acoustic environmental factors were all significantly correlated with the mental health score; the correlation coefficients for quietness, comfort and harmony were 0.102*, 0.113*, and 0.213**, respectively. Respondents' evaluation of the harmony of the acoustic environment had the highest correlation with mental health and was significantly correlated with the four mental health factors (nervousness, restlessness, fatigue, and negative affect). Quietness was only significantly correlated with nervousness and fatigue, while comfort was significantly correlated with restlessness, fatigue, and negative affect.

Among the six sounds typical in a Han Chinese Buddhist temple, preferences for three sounds were correlated with respondents' mental health: wind chimes (0.127**), bells (0.120**), and chanting (0.094*). The three non-correlated sound preferences were Buddhist instruments, drums and electronic Buddhist background music. Among the sound preferences that were correlated with mental health, the correlation between the preference for wind chimes and mental health was the highest, and the preference for wind chimes was significantly correlated with four mental health factors (nervousness, restlessness, fatigue, and negative affect). Preferences for bells and for chanting were significantly correlated only with fatigue and negative affect.

Effect of Religious Belief-Related Factors on the Relationship Between Respondents' Evaluations of the Overall Acoustic Environment of Han Chinese Buddhist Temples and Their Mental Health

Moderating Effect of Religious Belief-Related Factors

The impact of respondents' belief-related factors on the correlation among respondents' evaluations of three acoustic environmental factors and their mental health was analysed. **Figure 4** shows the relationships between the evaluations of the overall acoustic environment and mental health by level of belief in Buddhist thought (Note: In **Figures 4–9** in this paper, only when the correlations were significant were the lines connected to the means added). For those who fully or partially believe in Buddhist thought (those with partial beliefs accounted for the largest proportion of the respondents), there was an approximately linear negative association between mental health and evaluations of the overall acoustic environment of temples. However, for people who have little or no belief in Buddhist thought, there was no such linear association between mental health and the evaluations of the overall acoustic environment of temples. In general, as shown in **Figures 4A–C**, for those respondents who evaluated the temple as quiet (comfortable, harmonious) or somewhat quiet (somewhat comfortable, somewhat harmonious), the order of mental health scores, ranked from high to low, was relatively regular, i.e., partial belief > complete belief > little or no belief. In contrast, for respondents who indicated no feelings or chose somewhat noisy or noisy (somewhat uncomfortable or uncomfortable, somewhat inharmonious or inharmonious), there was no such pattern. These results may indicate that a good acoustic environment in a temple can regularly and positively affect mental health and that if the acoustic environment in a temple prompts negative or no feelings, the impact on people's mental health is not obvious or is irregular. Overall, these findings indicate the important role of a good acoustic environment for people who visit temples. Correlation analysis showed that for people who partially believe in Buddhist thought, as shown in **Figures 4A–C**, respondent evaluations of the three acoustic environmental factors were all correlated with mental health; the correlation coefficients for quietness, comfort and harmony were 0.125*, 0.130*, and 0.226**, respectively. In addition, for those who fully believe in Buddhist thought, as shown in **Figure 4C**, only the evaluation of the harmony of the acoustic environment in the temple was significantly correlated with mental health, with a correlation coefficient of 0.360**. These findings indicate that, compared with evaluations of quietness or comfort, evaluations of harmony were correlated with mental health in respondents with more varied levels of belief in Buddhist thought (including those who fully believe in Buddhist thought). Moreover, the correlation coefficient was larger, and the degree of correlation was more significant (from $p < 0.05$ to $p < 0.01$). As shown in **Figures 4A–C**, there was no correlation between respondents' evaluations of the acoustic environment of temples and mental health among those who had little or no belief in Buddhist thought.

Regarding the annual frequency of Buddhist temple visitation, the relationships between evaluations of the acoustic environment and mental health under different frequencies are shown in **Figure 5**. The respondents who visited Buddhist temples more than five times per year and indicated no specific feelings regarding the quietness, comfort and harmony of the acoustic environment of temples had the highest mental

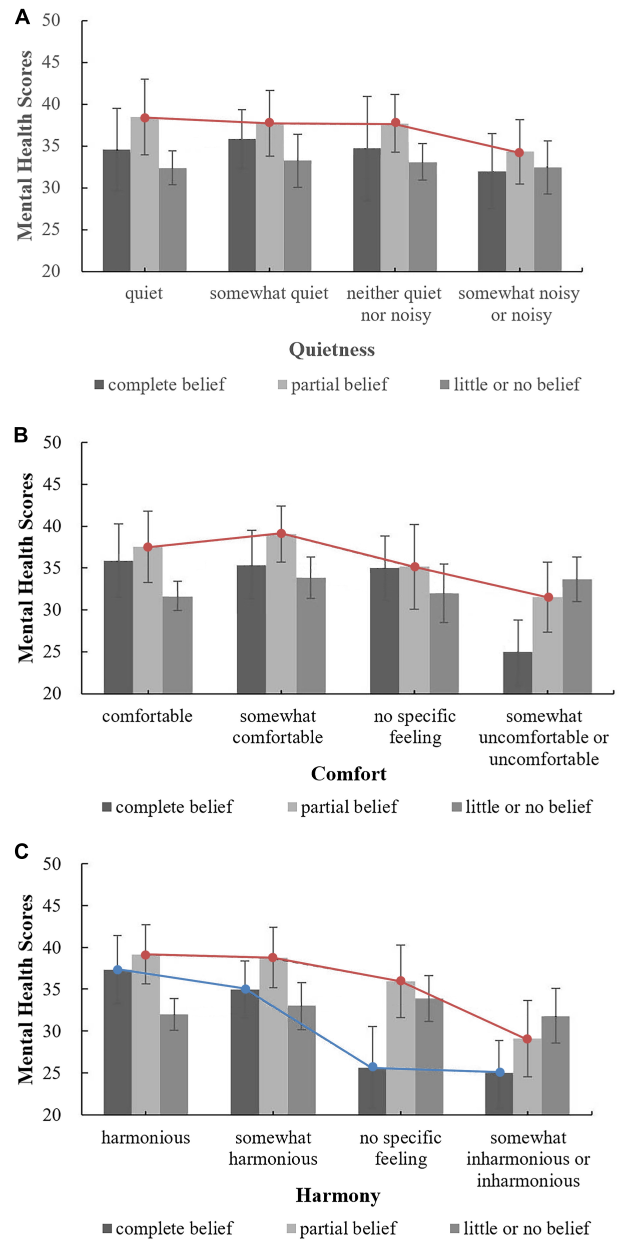

FIGURE 4 | The relationships between the evaluations of the overall acoustic environment and mental health by level of belief in Buddhist thought. **(A)** Quietness; **(B)** Comfort; **(C)** Harmony.

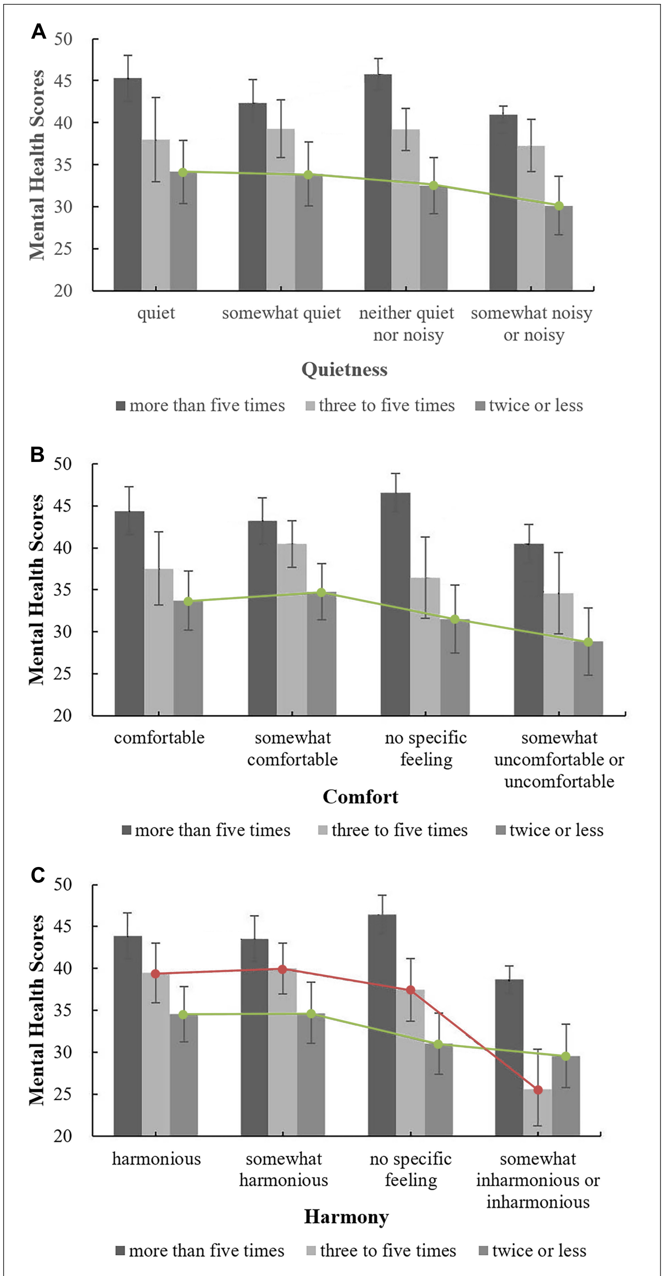

FIGURE 5 | The relationships between the evaluations of the overall acoustic environment and mental health under different frequencies. **(A)** Quietness; **(B)** Comfort; **(C)** Harmony.

health scores, which indicates that people who visited temples frequently (who may be Buddhist believers) may not have special requirements for the acoustic environment of temples and that their mental health state is high and not affected by the acoustic environment (i.e., they might already be accustomed to the acoustic environment of temples). However, for those who visit temples twice or less per year, one possible way to improve their mental health is to increase the number of visits to the temple by improving the overall acoustic environment of temples. Correlation analysis showed that for people who visited Buddhist temples twice or less per year, as shown in **Figures 5A–C**, respondent evaluations of the three acoustic environmental factors were all correlated with mental health; the correlation coefficients for quietness, comfort and harmony were 0.155*, 0.166*, and 0.223**, respectively. In addition, as shown in **Figure 5C**, for people who visit Buddhist temples three to five times per year, respondents' evaluation of the harmony of the acoustic environment was significantly correlated with mental health, with a correlation coefficient of 0.177**. For other conditions, there was no correlation. These findings indicate that,

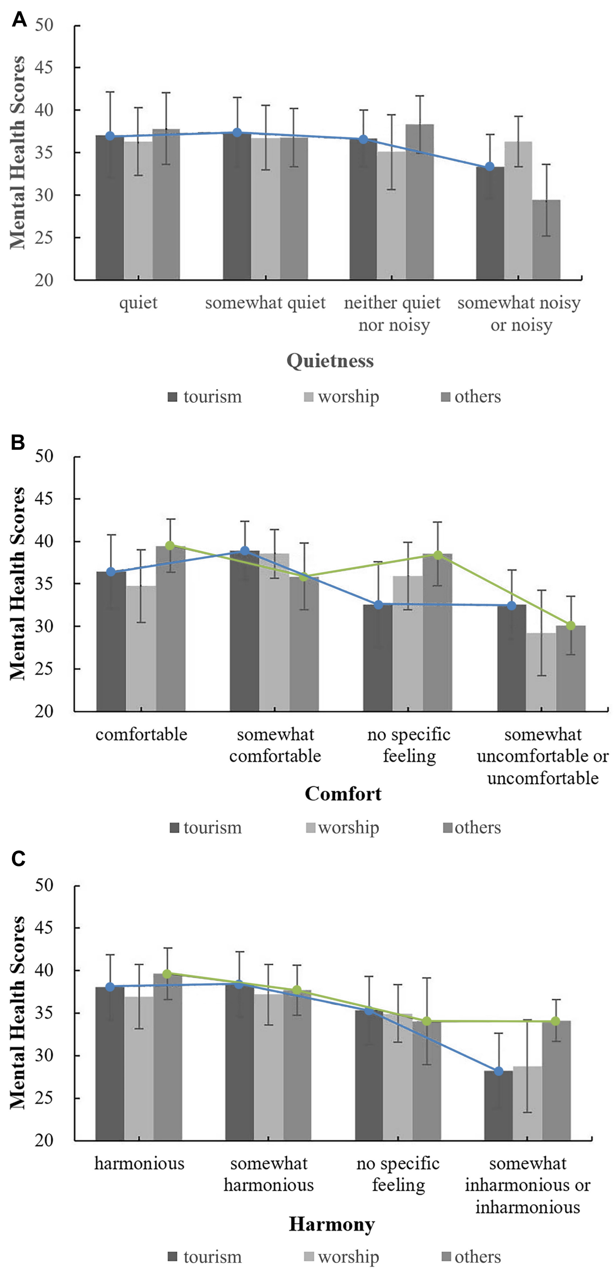

FIGURE 6 | The relationships between the evaluations of the overall acoustic environment and mental health by purpose of visiting. **(A)** Quietness; **(B)** Comfort; **(C)** Harmony.

compared with evaluations of quietness or comfort, evaluations of harmony were correlated with mental health in respondents with more varied frequencies of visitation (including those who visit Buddhist temples three to five times per year).

Regarding the purpose of temple visitation, **Figure 6** shows the relationships between respondents' evaluations of the overall acoustic environment and mental health by purpose of visiting. These results indicated that, as shown in **Figures 6A,C**, for people who are only tourists, when the acoustic environment of temples changes from quiet (harmonious) to noisy (inharmonious), the mental health score decreases approximately linearly. However, this trend was not observed for those who worship Buddha or those who visit for purposes other than worship or tourism. For people with different purposes for visiting, when the acoustic environment of temples was evaluated as quiet or somewhat quiet (harmonious or somewhat harmonious), the mental health scores were very close, but when the acoustic environment of temples was evaluated as somewhat noisy or noisy (somewhat inharmonious or inharmonious), the mental health scores differed greatly, indicating that the design of the acoustic environment of temples should consider the various purposes for temple visitation to improve people's mental health. Correlation analysis showed that for tourists, respondents' evaluations of all three acoustic environmental factors were correlated with mental health; the correlation coefficients for quietness, comfort and harmony were 0.138*, 0.168**, and 0.247**, respectively. For those who worship Buddha, as shown in **Figures 6A–C**, respondents' evaluations of all three acoustic environmental factors were not correlated with mental health, which may indicate that, compared with tourists, people who worship Buddha are more adaptable to the acoustic environment of temples or are not affected by the acoustic environment. For people who visit for purposes other than worship or tourism, as shown in **Figures 6B,C**, respondents' evaluations of the comfort and harmony of the acoustic environment in the temple were correlated with mental health; the correlation coefficients were 0.211* and 0.274**, respectively. Among the three acoustic environmental factors, for various groups of people, evaluations reflecting harmony had the highest correlation with mental health.

In summary, the results of this study showed that for respondents with a partial belief in Buddhist thought, respondents who visited temples twice or less per year or those who visited temples only for tourism purposes, the influence of religious belief-related factors on the correlation between respondents' evaluations of the overall acoustic environment of temples and mental health was more significant.

Influence of Demographic Factors

Respondents' demographic factors also affected the correlation between their evaluations of the overall acoustic environment of temples and their mental health. For gender, the analysis showed an approximately linear, downward trend for women's mental health scores when evaluations of the acoustic environment of temples changed from quiet (harmonious) to noisy (inharmonious); no such trend was observed for men. Correlation analysis showed that for women, evaluations of the three acoustic environmental factors were all significantly correlated with mental health, but for men, there were no such correlations. Regarding age, for adolescents (below 29 years of age), evaluations indicating comfort and harmony were correlated with mental health; for middle-aged people (30–44 years of age), evaluations indicating quietness and harmony were correlated with mental health; and for middle-aged and elderly people (older than 45 years of age), there were no correlations between evaluations of the three acoustic environmental factors and mental health. Regarding education level, for people with a junior high school education or below, evaluations indicating comfort and harmony were correlated with mental health, and for people with a college degree, evaluations indicating harmony were correlated with mental health. In terms of occupations, for service personnel, evaluations indicating comfort and harmony were correlated with mental health, and for students and teachers, evaluations indicating harmony were correlated with mental health; there were no correlations for other occupations. Previous studies have similarly shown that gender, age, education, and other factors can affect the correlation between the acoustic environment and human mental health (Niemann et al., 2006; Van Kempen et al., 2011; Anilan, 2014), indicating that the relationship between the acoustic environment of both Eastern and Western religious sites and mental health may be affected by factors such as gender, age, and education.

Influence of Demographic Factors on the Moderating Effect of Religious Belief-Related Factors

One of the research aims of this paper is to determine the influence of religious belief-related factors on the correlation between respondents' evaluations of the acoustic environment of temples and their mental health. However, can demographic factors, such as gender, age, and education level, affect this moderation? The relationships between human demographic factors and religious belief-related factors were analysed. The results showed that gender and religious belief-related factors were not correlated and that gender did not affect the moderating effect of religious belief-related factors. Regarding the attitudes toward Buddhist thought, frequency of temple visitation and purpose for visiting, the correlation coefficients for age were 0.146**, 0.151**, and 0.137**, respectively; those for education level were −0.133**, −0.022/0.620, and 0.165**, respectively; and those for occupation were 0.186/0.124, 0.156/0.552, and 0.224**, respectively. These coefficients indicted that the overall correlation was not high. Additionally, the population 30–44 years of age, the population with a college degree and the student population (collectively accounting for the highest proportion of respondents) were analysed. The results showed that the moderating effect of religious belief-related factors in these populations was not significantly different from that for the whole population; therefore, human demographic factors did not significantly affect the moderating effect of religious belief-related factors on the correlation between respondents' evaluations of the temple acoustic environment and their mental health.

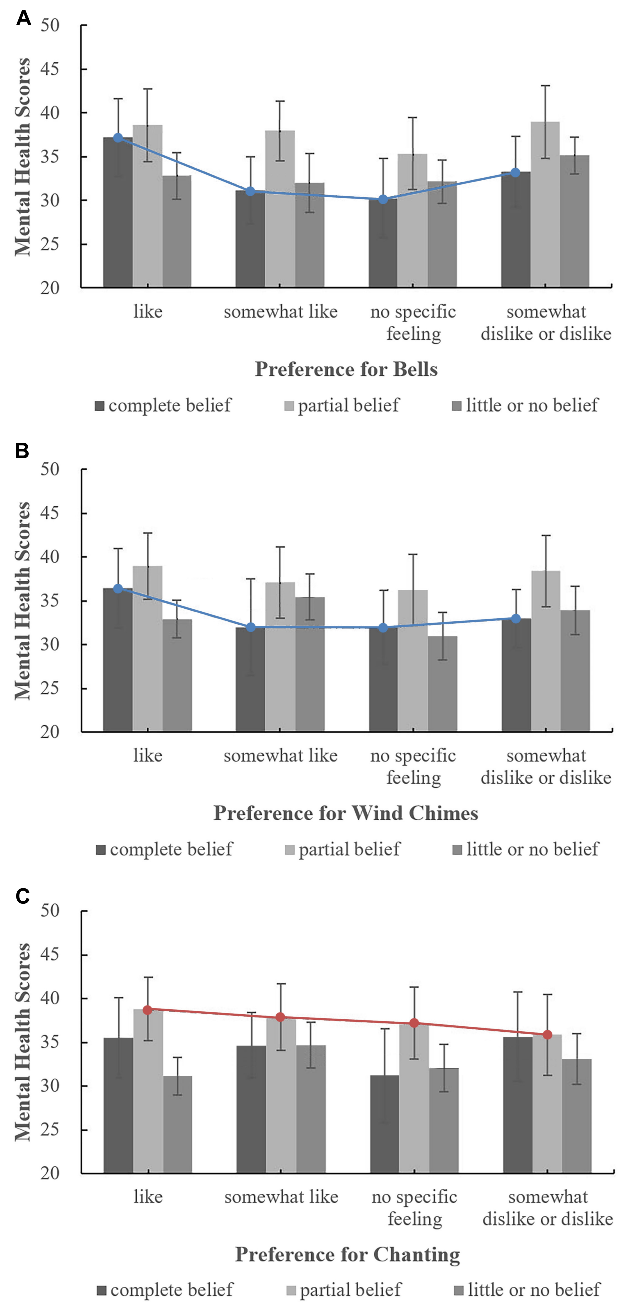

FIGURE 7 | The relationships between sound preferences and mental health by level of belief in Buddhist thought. **(A)** Bells; **(B)** Wind chimes; **(C)** Chanting.

Effect of Religious Belief-Related Factors on the Relationship Between Preference for Sounds in Han Chinese Buddhist Temples and Mental Health

Moderating Effect of Religious Belief-Related Factors

The moderating effect of respondents' belief-related factors on the correlation between three sound preferences (bells, wind chimes, and chanting) and mental health was analysed, and the influence of attitudes toward Buddhist thought on the relationships between sound preferences (bells, wind chimes, and chanting) and mental health was investigated, as shown in **Figure 7**. Among respondents who enjoyed the three sounds, the mental health scores corresponding to different attitudes toward Buddhist thought were ordered as follows: partial belief > complete belief > little or no belief. However, among respondents who did not indicate that they liked the three sounds, the mental health scores associated with different attitudes toward Buddhist thought did not exhibit the same pattern, a finding similar to the relationship between respondents' evaluations of the overall acoustic environment and mental health analysed in the previous section. These results suggest that the sounds in temples that people enjoy may regularly affect their mental health, whereas sounds that people dislike or about which they have no feelings are unlikely to regularly affect their mental health. Correlation analysis showed that, as shown in **Figures 7A,B**, for people who fully believe in Buddhist thought, preferences for bells and wind chimes were both correlated with mental health; the correlation coefficients were 0.366** and 0.297*, respectively. As shown in **Figure 7C**, for those who partially believe in Buddhist thought, the preference for chanting was correlated with mental health; the correlation coefficient was 0.104*. There were no correlations for other attitudes toward Buddhist thought. Overall, for people who fully believe in Buddhist thought, the correlation between the preference for bells and mental health was highest, a finding that is consistent with the results of one of our previous studies, i.e., the sound of bells is generally considered to be the most representative sound in Han Chinese Buddhist temples (Zhang et al., 2018).

The effect of annual visit frequency on the relationship between preferences for the sounds of bells, wind chimes and chanting and mental health was analysed; the results are shown in **Figures 8A–C**. For people with different visit frequencies, there was no correlation between the preferences for various temple sounds and mental health, indicating that visit frequency did not have a moderating effect on the relationship between sound preference and mental health. Thus, to improve the mental health of people who visit temples, it may not be necessary to group people based on visit frequency, i.e., people with different visit frequencies can be treated as a whole population.

The effect of the purpose of visiting Buddhist temples on the relationship between mental health and preferences for bells, wind chimes and chanting was analysed; the results are shown in **Figure 9**. For people with purposes other than worshipping Buddha and tourism, as shown in **Figures 9A,B**, when their preferences for bells and wind chimes changed from "like" to "no specific feelings," the mental health score linearly declined, an association that was not reflected in the preferences for chanting, as shown in **Figure 9C**. For those with purposes other than worshipping Buddha or tourism, the influence of sound preferences on mental health was irregular. Therefore, when designing and choosing sounds in temples, people's auditory preferences should be comprehensively considered independent of their purpose for visiting. Correlation analysis showed, per **Figures 9A,B**, that for people whose purpose for visiting was neither worship nor tourism, there was a correlation between preferences for bells and wind chimes and mental health; the correlation coefficients were 0.260** and 0.255*, respectively. There were no correlations between sound preferences and mental health under other conditions.

In summary, for people who fully believe in Buddhist thought or whose purpose for visiting temples is neither for worship nor for tourism, their religious belief-related factors exert a more significant impact on the correlation between sound preferences in temples and mental health than for people without these religious characteristics.

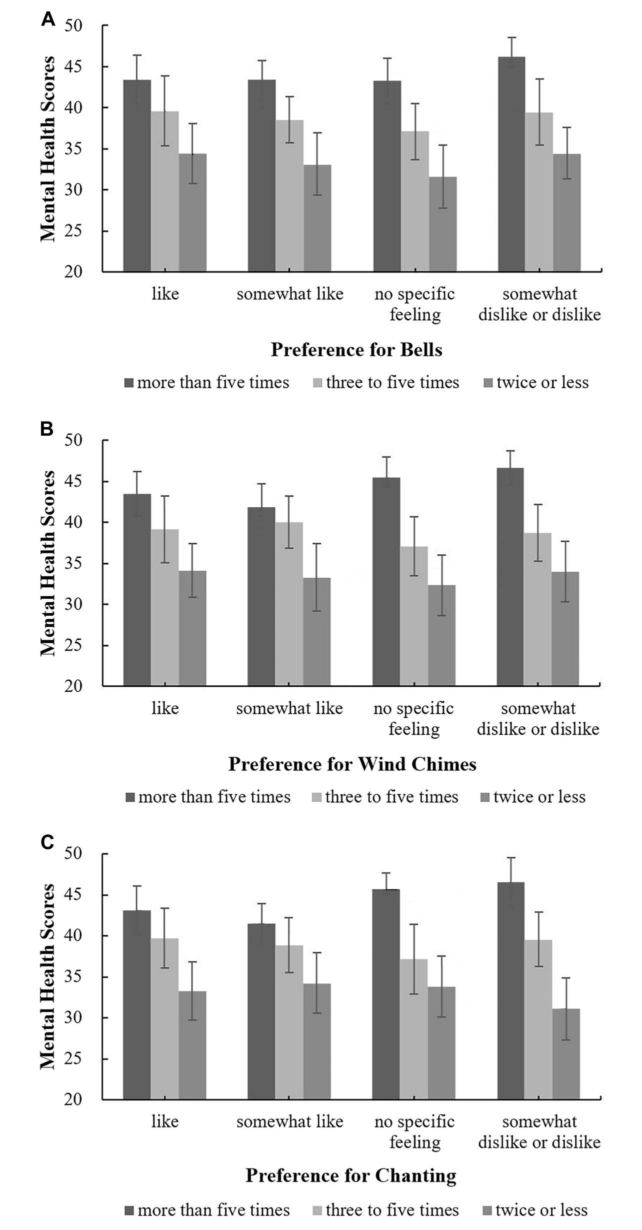

FIGURE 8 | The relationships between sound preferences and mental health under different frequencies. **(A)** Bells; **(B)** Wind chimes; **(C)** Chanting.

Influence of Demographic Factors

For women, preferences for the three sounds were correlated with mental health, but no such correlation was observed for men. The effect of age on the relationship between mental health and preferences for bells, wind chimes and chanting was analysed. When evaluating the preferences for bells and chanting, the mental health scores corresponding to each preference among adolescents were the same as those among middle-aged people but were substantially different from those among people aged 45 and older. Among the people who selected "somewhat dislike" or "dislike" for the three sounds of bells, wind chimes and chanting, those aged 45 and older had the

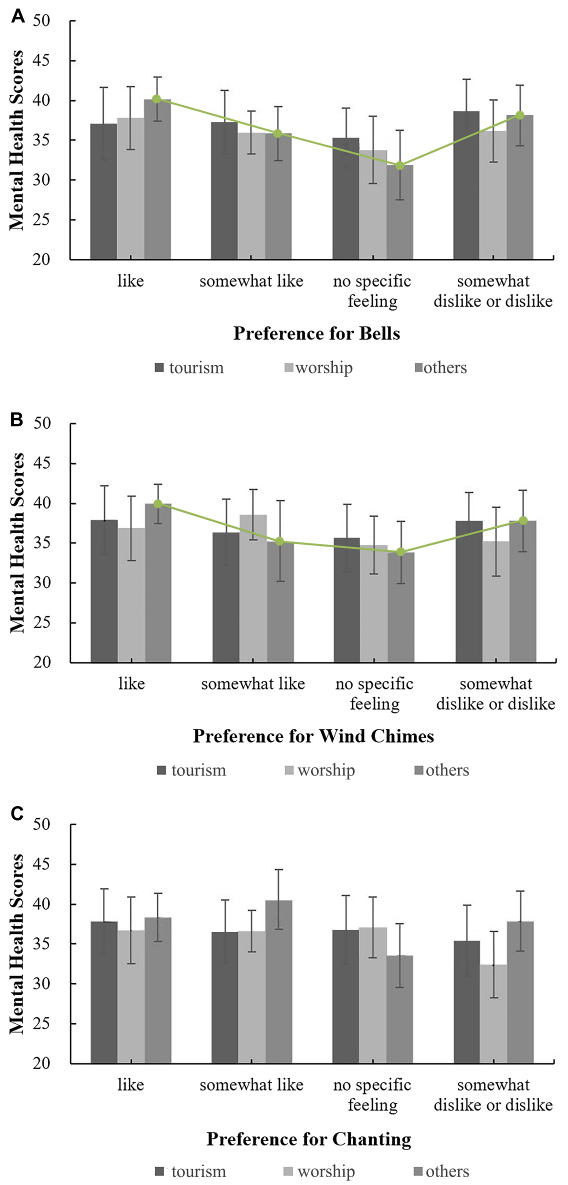

FIGURE 9 | The relationships between sound preferences and mental health by purpose for visiting. **(A)** Bells; **(B)** Wind chimes; **(C)** Chanting.

best mental health. This finding may indicate that people over 45 years of age have a higher tolerance of various sounds in temples and that their mental health is unaffected by sounds that they dislike. Correlation analysis showed that adolescents' preferences for bells and wind chimes were correlated with mental health; the correlation coefficients were 0.217** and 0.163*, respectively. Middle-aged people's preference for bells was correlated with mental health, with a correlation coefficient of 0.147*. The preferences of respondents aged 45 and older for the three sounds were not correlated with mental health. In terms of education level, for the respondents with a college degree, there were correlations between preferences for bells and wind chimes and mental health; the correlation coefficients were 0.178** and 0.169**, respectively. There were no correlations between sound preferences and mental health among people with other education levels. Regarding occupations, only workers' preference for chanting and students' preference for bells were correlated with mental health; there were no correlations for other occupations. In summary, the gender, age, education, and occupation of the respondents affected the correlation between the preferences of sounds in temples and mental health to a certain extent.

Influence of Demographic Factors on the Moderating Effect of Religious Belief-Related Factors

In section "Effect of Religious Belief-Related Factors on the Relationship Between Respondents' Evaluations of the Overall Acoustic Environment of Han Chinese Buddhist Temples and Their Mental Health," the results showed that there is no correlation between gender and religious belief-related factors, and the correlations between belief-related factors and age, education and occupation were not high. Additionally, this study analysed the population aged 30–44, the population with a college degree and the student population (collectively accounting for the highest proportion of respondents), with the results showing that the moderating effect of religious belief-related factors on sound preferences in temples and mental health in these populations was basically consistent with that for the population as a whole. Therefore, respondents' demographic factors did not significantly affect the moderating effect of religious belief-related factors on the correlation between sound preferences in temples and mental health.

DISCUSSION

Comparison of Respondents' Evaluations of the Overall Acoustic Environment and Sound Preferences

The moderating effect of belief-related factors on the correlation between respondents' evaluations of the overall acoustic environment and their mental health was compared with the effect of belief-related factors on the correlation between sound preferences and mental health, illustrating that, in terms of the attitudes toward Buddhist thought, people who partially believe in Buddhist thought accounted for the highest proportion of respondents. For these respondents, their evaluations of the three acoustic environmental factors were correlated with mental health; however, only a preference for chanting was correlated with mental health, with a correlation coefficient less than that for any of the evaluations of acoustic environmental factors, indicating that the impact of the evaluations of the overall acoustic environment on mental health is more important than a single sound. In terms of the frequency of Buddhist temple visits, the population with two or fewer annual visits to Buddhist temples accounted for the highest proportion of respondents, and their evaluations of the three acoustic environmental factors were correlated with their mental health. However, there was no correlation between sound preferences and mental health among people with different visit frequencies. Regarding the purpose of visiting Buddhist temples, tourists accounted for the highest proportion of respondents, and their evaluations of acoustic environmental factors were correlated with their mental health, while there was no correlation between sound preferences and mental health for this group of people. These results indicate that the influence of religious belief-related factors on the correlation between the evaluations of the overall acoustic environment and mental health is significantly stronger than the influence of religious belief-related factors on the correlation between sound preferences and mental health.

Comparison With Related Studies

Religions in China mainly include Buddhism, Taoism, and Islam. There are few studies on the relationship between the acoustic environment or soundscape in Chinese religious places and mental health. We compare the results of this research with similar studies in other countries on the relationship between Islamic or Christian soundscapes and mental health. According to several studies on Islamic religious music, the positive impact of religious music on mental health is undeniable, and in Islamic countries, the voice of the holy Quran is used to heal patients (Heidari and Shahbazi, 2013; Babaii et al., 2015; Jafari et al., 2016).

Compared with the soundscapes or sound environment in mosques, the soundscapes in Han Chinese Buddhist temples do not seem to have such a strong impact on human mental health, which is reflected in the low correlation coefficient. This may also be related to the Chinese religious conception of Han Chinese Buddhism. It is generally believed that most Chinese people recognise Buddhist thought, but their beliefs are not very pious. Interestingly, the results of this paper are similar to the results of a study on the relationship between American Christian music and the mental health of elderly individuals, which showed that the correlations between the frequency of listening to religious music in late life and several different aspects of mental health (death anxiety, life satisfaction, self-esteem, and sense of control) were salutary and statistically significant but relatively weak, and the correlations ranged from 0.076 to 0.171 in magnitude (Bradshaw et al., 2015).

Application of the Results

The value of this study is mainly reflected in three aspects. First, the results of this study show that a good acoustic environment and pleasant sounds in temples can regularly and positively affect the mental health of people who visit temples, indicating the important role of the acoustic environment of temples in human mental health. Related studies have also shown that good soundscapes could help Chinese people enjoy positive environmental experiences and relieve stress (Zhang et al., 2017). Therefore, when designing temples, it is necessary to fully consider the incorporation of Buddhism-related sounds and the creation of a religious atmosphere in the acoustic environment. Considering all kinds of soundscape evaluation conditions, the mental health of people who visit Buddhist temples more often is better than that of people who visit the temple less often. Therefore, if we can create a good acoustic environment to attract people to visit the temple more often, it may achieve the purpose of improving people's mental health. Second, various religious belief-related factors affect the relationship between respondents' evaluations of the acoustic environment of or sound preferences in temples and their mental health to varying degrees; therefore, when designing the sound environment of temples, belief-related factors should be considered. Reasonable zoning should be implemented based on the characteristics of different populations so that a suitable acoustic environment or pleasant sounds can be created for people with different religious characteristics. Even for people who are not sensitive to religious acoustic environments, their mental health can improve by hearing sounds they enjoy. In addition, the results of this research show that the psychological feelings and tolerance of the temple soundscape between elderly individuals and the young or middle-aged are not the same, and mental health of elderly individuals is not related to his evaluation of the acoustic environment or preference for various sounds in the temples. Therefore, the acoustic environment could be designed according to the age characteristics of the visitors in the temple; for example, more consideration can be given to the auditory needs of young or middle-aged people. Third, this study provides some specific measures for the design of the acoustic environment of temples. For example, the results show that among temple sounds, bells, and wind chimes are most closely related to the mental health of people with various religious beliefs. Therefore, special attention should be devoted to the distribution of these two sounds in the acoustic environment of temples. The results of this study also show that harmony, one aspect of the acoustic environment in temples, has the highest correlation with the mental health of various groups of people and that harmony is correlated with all four mental health factors explored in this study. Therefore, in the design of the acoustic environment of temples, the most important consideration is whether the sound environment is harmonious with the religious atmosphere of the temple. In addition, the results of this study can also provide a reference for the acoustic environmental design of other similar religious sites.

Research Limitations

The method used in this study was a questionnaire survey. Therefore, the results regarding the relationship between mental health and personal evaluations of soundscapes need to be verified by other methods. The study subjects were tourists and believers in Han Chinese Buddhism; Buddhist monks were not included. Therefore, the types of research subjects need to be expanded in future studies. This study focused on Han Chinese Buddhism, and no research or comparative analysis was conducted for other religions in China (such as Taoism and Tibetan Buddhism). The correlations between mental health and soundscapes in other religious places may have similarities to and differences from those revealed in this study. Whether these similarities are related to the national characteristics of Chinese people and whether the differences are related to various religious doctrines and rituals require further analysis.

In addition, this research did not include the acoustic parameters of soundscapes in Buddhist temples. In our previous research on soundscapes in Han Chinese Buddhist temples, we analysed acoustic parameters such as sound pressure level, loudness, and sharpness. The results showed that the acoustic parameters of soundscapes in Han Chinese Buddhist temples could affect the feelings of respondents (Zhang et al., 2016, 2018). In future research, we plan to combine acoustic parameters with subjective health evaluations, which are believed to provide better guidance for the soundscape design of temples.

CONCLUSION

As the religion with the highest number of believers in the world's most populous country, Han Chinese Buddhism has played an important role in the development of Chinese society and the lives of Chinese people. Soundscapes are important means of creating a religious atmosphere in Han Chinese Buddhist temples. However, the influence of soundscapes on Chinese people's mental health has not received due attention from scholars. This study used a questionnaire survey to analyse the correlation between Chinese people's evaluations of Buddhist temple soundscapes (including the overall acoustic environment of the temple and sound preferences) and mental health as well as the influence of respondents' religious belief-related factors on this correlation. After 499 valid questionnaires were analysed, the following main conclusions were obtained.

(1) There were significant correlations between the evaluations of the quietness, comfort and harmony of the acoustic environment of Buddhist temples and respondents' mental health scores, with correlation coefficients ranging from 0.10 to 0.22. Among the religion-related sounds in temples, bells, wind chimes and chanting were significantly correlated with respondents' mental health, with correlation coefficients ranging from 0.10 to 0.13. The correlation between the evaluations of the overall acoustic environment in temples and mental health was generally higher than that between sound preferences and mental health, and the correlation between an acoustic environment evaluated as harmonious and mental health was the highest.

(2) Respondents' belief-related factors, including their attitudes toward Buddhist thought, annual number of visits to temples and their purposes for visiting temples, all exerted a significant impact on the relationship between their evaluations of the overall acoustic environment of temples and mental health. For people who fully believe in Buddhist thought or those who visit Buddhist temples three to five times per year, there was a positive correlation between the evaluations of the acoustic environment as harmonious and mental health. For people who partially believe in Buddhist thought, people who visit temples twice or less per year, or people who visit temples as tourists, evaluations of all three acoustic environmental factors were positively correlated with mental health, with correlation coefficients ranging from 0.13 to 0.25. Additionally, some demographic factors somewhat affected the relationship between evaluations of the acoustic environment and mental health, but demographic factors did not significantly affect the moderating effect of religious belief-related factors on the correlation between evaluations of the acoustic environment of temples and mental health.

(3) Among the respondents' belief-related factors, attitudes toward Buddhist thought and purpose for temple visitation exerted a significant impact on the relationship between sound preferences and mental health. For people who partially believe in Buddhist thought, there was a significant correlation between the preference for chanting and mental health, and for people who fully believe in Buddhist thought or those who visit temples neither for worship nor for tourism purposes, there was a significant correlation between the preferences for bells and wind chimes and mental health, with correlation coefficients ranging from 0.26 to 0.37. Some demographic factors affected the relationship between sound preferences and mental health, but the demographic actors did not significantly affect the moderating effect of religious belief-related factors on the correlation between sound preferences in temples and mental health.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

Ethical review and approval was not required for this study in accordance with the local legislation and institutional requirements. Permission for carrying out this work was obtained from the JangHo Architecture College, Northeastern University. The participants were provided written informed consent to participate in the study.

AUTHOR CONTRIBUTIONS

DZ: study conception, questionnaire design, and manuscript writing. CK: research idea, questionnaire survey, and statistical analysis of the data. MZ: interpretation of the results, supervision, and project administration. JK: overall supervision and the structuring of the manuscript. All authors reviewed the results and approved the final version of the manuscript.

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