Acoustic comfort in large railway stations

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Abstract: Large railway stations attract a wide range of passengers and citizens, and these buildings are likely to have a complex acoustic environment. Previous studies have focused on reducing people's exposure to excessive sound levels caused by transportation, but more research is needed to assess people's preferences and ensure their psychophysical wellbeing. The aim of this study was to explore the complex aspects of the sound environment in large railway stations that contribute to acoustic comfort. On-site measurements and an acoustic comfort survey were performed at a case study site in Harbin, China. The results showed a significant positive correlation between the subjective comfort evaluations and objective measurements of the sound pressure level and reverberation time. Differences in dominant sound sources in different spaces lead to different evaluations of acoustic comfort. People prefer broadcast sound, but its intelligibility needs to be improved. When the density of people increases, the preference for speech sounds and activity sounds decline rapidly. With regard to demographic and social factors, older people and people with higher incomes and education levels are more tolerant of the environment.

34

1. Introduction

36   Railway stations have traditionally been associated with waiting and transit spaces. In the past,
37 this association was because the stations hosted a relatively limited number of functions [1].
38 Currently, however, large railway stations worldwide are being built to accommodate increasingly
39 complicated functions and crowds, which has introduced more stringent requirements for the
40 sound environment. Acoustic comfort, which is the most important index for evaluating soundscape
41 [2], has also been widely studied in public spaces, including offices [3], large dining rooms [4],
42 public libraries [5], commercial spaces [6] quiet and restorative areas [7,8.] In these studies,
43 transportation noise sources are generally mentioned as the primary or secondary noise sources.
44 Researchers have found that different types of vehicles have a specific impacts on the surrounding
45 environment, for instance, noise from road traffic [9], trains [10], aircraft [11] and vessels [12].
46 These noises have been demonstrated to make diffuse people and disturb them in [13] residential
47 areas [14], commercial areas [15], school areas [16], quiet natural areas [17] and port areas [18].
48 Several adverse effects have been associated with exposure to traffic noise [19]. Beyond its
49 effects on the auditory system, noise causes annoyance [20], disturbs sleep [21] and impairs
50 cognitive performance [22]. Furthermore, epidemiologic studies have demonstrated that
51 environmental noise is associated with increased arterial hypertension, myocardial infarction, and
52 stroke [23]. Moreover, aircraft and road traffic noise exposure have been associated with
53 psychological symptoms [24]. In children, chronic aircraft noise exposure impairs reading
54 comprehension and long-term memory and may be associated with increased blood pressure [25].
55 Generally, it has been found that continuous exposure to traffic noise causes people to suffer from
56 various types of discomfort and appreciably reduces measures of well-being. However, little
57 attention has been paid to people's levels of acoustic comfort inside transit spaces. People's
58 comfort and psychophysical well-being are important in transit spaces and should be significant
59 considerations during the designs of such spaces; however, further details concerning the
60 phenomena and theory are still required.

61   In China's railway stations, the entrance hall, ticket office, integrated waiting hall and auxiliary
62 space are all concentrated within a single large space [26]. As the number of functions increases,
63 the types of sound sources also increase. The resulting complex acoustic environment leads to
64 various adverse effects on user comfort and causes a series of acoustic problems, such as high
65 environmental noise and poor language articulation [27]. Conversations between people are a
66 primary behavioral factor influencing the sound environment and acoustic perceptions in railway
67 stations. Studies have found that noise emissions from activities involving crowds of people can
68 also affect the sound environments of public spaces [28]. Nie and Kang [29] proposed a crowd
69 acoustic model and found a relationship between the crowd, sound pressure level, total population
70 and number of people conversing. Wu and Kang [30] using the results of interviews and
71 questionnaires, showed that conversational speech intelligibility is poor and that crowd noise is
72 considered a main factor that affects broadcast clarity. Traffic sounds are another main sound
73 source in railway stations. Bandyopadhyay et al. [31] measured the sound pressure level (SPL) on
74 platforms and found that the SPL affects users' health. Broadcasts are an important aspect of the
75 sound in railway stations. Liu et al. [32] used acoustic measurements and simulations to study the
76 reverberation time (RT) and the speech transmission index of public broadcasting systems.

77　Excessive noise exposure caused by the enormous ventilation systems in large spaces also has
78　serious impacts. Tao et al. [33] evaluated the noise annoyance levels in a metro depot and the
79　noise influence of its ventilation system on adjacent residential buildings. However, simply reducing
80　the overall 'sound level' does not always result in the desired quality of life improvements. Many
81　sound sources have been studied to evaluate their influences on the sound environment and
82　acoustic comfort, but due to their increasing functions, the acoustic comfort levels in large railway
83　stations have not been studied systematically.

84　　Therefore, the goal of this paper is to study the effects of various sound sources on the sound
85　environment and acoustic comfort in extra-large spaces using a soundscape approach. A typical
86　large railway station in China was chosen as a case study. The overall comfort level and sound
87　environment in the station's different functional zones were studied using both objective
88　measurements and a questionnaire survey. First, the sonic composition and appropriateness were
89　analyzed. Then, the effects of different types of sound sources in different zones on loudness,
90　intelligibility, sound level, preference degree and acoustic comfort were analyzed.

2. Methodology

2.1 Survey site

93　　The size of the station determines whether it has sufficient capacity to carry customer flow. The
94　indexes for measuring its size include the number of platforms, number of trains per day, and the
95　number of dispatched passengers yearly [34]. Table 1 shows the sizes of the busiest top 20
96　railway stations in China. For this study, a large railway station with a length of 310 m, a width of
97　190 m, and a volume of 1.2×10^6 m^3 was chosen as the case study site. The selected station is
98　representative: it is neither the largest nor the smallest among China's large railway stations, it has
99　18 platforms, and the number of passengers dispatched yearly is 110 million.

Table 1 The scale of railway stations in China (The busiest top 20) [34]

Name	Number of platforms	Number of trains/day	Number of passengers dispatched yearly (millions)
Shanghai Hongqiao Railway Station	30	520	678
Guangzhou South Railway Station	28	653	470
Xian North Railway Station	34	186	111
Zhengzhou East Railway Station	30	352	135
Kunming South Railway Station	30	118	54.6
Nanjing South Railway Station	28	508	236
Hangzhou East Railway Station	28	243	51.8
Chengdu East Railway Station	26	593	293
Beijing South Railway Station	24	406	320
Changsha South Railway Station	24	399	168
Nanning East Railway Station	24	204	115
Shenzhen North Railway Station	20	258	98.2
Tianjin West Railway Station	18	236	217
Lanzhou West Railway Station	18	186	60.8
Shenyang South Railway Station	18	296	237
Harbin West Railway Station	18	225	110
Jinan East Railway Station	18	259	146
Dalian North Railway Station	18	214	43.8
Taiyuan South Railway Station	18	209	48.6

Beijing West Railway Station	18	188	50.3

101   Case studies of passenger activities are common in China and most Asian countries and even in
102   some European countries [35-37]. The mixed functions inside the selected case site are
103   representative, commonly found in urban transit spaces [38,39], and include cafés, bars,
104   restaurants, shops, security checks, ticket checks, information boards, pharmacies, and
105   bathrooms. Almost all these functions are concentrated in one large space, and because the
106   station is the main city transportation hub, the daily flow of people is very large, which indicates that
107   the building is likely to have a complex acoustic environment [40].

108   To facilitate a high pedestrian movement rate throughout the station, a total of 18 escalators and
109   10 elevators provide full stairs-free access to all areas. In total, there are 570 seats within the
110   station, and 20,000 people use the station every day.

2.2 SPL and RT measurements

112   Previous studies have suggested that different sound sources and behavioral patterns influence
113   the sound environment and the acoustic perceptions of users in open and indoor spaces and that
114   the sound environment can, in turn, influence peoples' acoustic perceptions. The most important
115   indexes that affect the sound environment are SPL and RT [13], which were measured by the
116   following methods. The measurement points are shown in Fig. 2. The selected test points covered
117   six different functional spaces, including the seating area, security check, ticket lobby, ticket check,
118   restaurants, and shops. The ticket lobby is located on both sides of the entrance and connected by
119   a hallway to form a coupled space. The ticket window is on one side of the lobby; the rest of the
120   lobby is typically full of people waiting to buy tickets. The other five spaces are all located in the
121   waiting hall; the security checkpoint faces the entrance; there are four baggage screening
122   machines; people queue through security to enter the waiting hall; the seating area is behind the
123   security checkpoint; seats are divided into north and south banks, and each bank consists of 56
124   rows; the shops are located near the seating areas in the waiting hall; the outside is enclosed by
125   a 2 m high glass wall into a semiopen space; the ticket check is outside the seating area at the
126   edge of the waiting hall; there is a large population density at check-in time; and the restaurants are
127   small rooms on either side of the waiting hall.

128   Measurements were made during dense traffic periods. For each measurement point, an SPL
129   meter was set to slow mode and A-weighting, and an instantaneous reading was taken every 10
130   s. To avoid sound source variability, each sound pressure level at each measurement point was
131   tested 10 times; each measuring point was tested every hour, and the average value of the 10 sets
132   of data was taken as the result of this measurement point. The measuring period lasted from 8:00
133   to 18:00. The equipment selection and measurement process followed the ISO3382 standard.
134   The sound level meter microphone was positioned 1 m away from walls and other main reflectors
135   and 1.2-1.5 m off the ground [41]. A total of 5 min of data were obtained at each measurement
136   position, and the corresponding A-weighted equivalent SPL (LAeq) was derived. To avoid
137   measurement error, each measurement in each space was taken from at least five random points
138   at least 3 m apart. To avoid the impact of speech on the measurements, no people were talking
139   within 3 m of the sound level meter [42]. The A-weighted SPLs measured at each point were
140   averaged.

141   To understand the characteristics of the sound field in the waiting hall, the reverberation time in
142   6 areas of the waiting hall was measured at night when the trains had stopped. Only survey crews
143   were present in the waiting hall during these measurements. An OS002 12-sided nondirectional
144   sound source was adopted to play white noise [26]. As shown in Fig. 1, S represents a sound
145   source position, and one sound source point was set in each area. R denotes the position of a
146   receiving point. An 801 sound level meter was used to test the reverberation time. Due to the large
147   volume of the waiting hall, the difference in sound pressure level between most measuring point

148 noise and background noise was less than the test range of T30. Therefore, the reverberation time
149 of each area was compared with the T20 value.
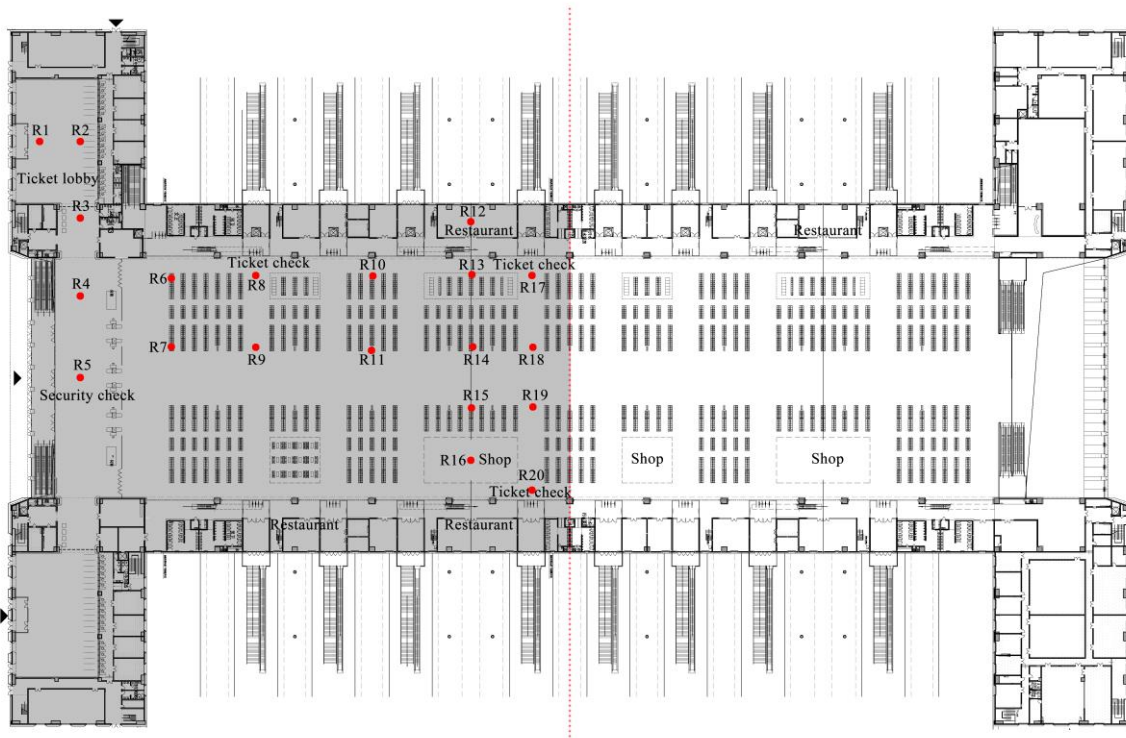
150
151 **Fig. 1**. The survey site and measurement points.

152 **Table 2** Basic information on six typical spaces.

		Seating area	Security check	Ticket check	Ticket lobby	Restaurant	Shop
Space type		Large space	Large space	Large space	Atrium space	Small space	Small space without a ceiling
Volume		11100	180		864	172	288
Geometry (length/width)		162/68	36/5		36/24	21.5/8	24/12
Average customers		592	106	228	194	68	16
Photograph							
Interior materials and sound absorption coefficients	Ceilings	Gypsum $\alpha=0.3$	Gypsum $\alpha=0.3$	Gypsum $\alpha=0.3$	Gypsum $\alpha=0.3$	Gypsum $\alpha=0.3$	Gypsum $\alpha=0.3$
	Walls	Marble $\alpha=0.01$	Marble $\alpha=0.01$	Marble $\alpha=0.01$	Marble $\alpha=0.01$	Glass $\alpha=0.18$	Glass $\alpha=0.18$
	Floors	Marble $\alpha=0.01$	Marble $\alpha=0.01$	Marble $\alpha=0.01$	Marble $\alpha=0.01$	Ceramic $\alpha=0.02$	Marble $\alpha=0.01$
Sound absorber/reflector		Seat	X-ray security Glass partition	Fare gate	Ticket machine/window	Seat Table	Partition wall
Broadcast		With a broadcast	With a broadcast	With a broadcast	With a broadcast	Without a broadcast	With a broadcast
Behavioral patterns		Talking, resting	Talking, security checks	Ticket checks, talking, walking	Talking, ticket machine use, walking	Dining, walking, talking	Talking, walking

153 *2.3 Acoustic comfort survey*

154   Acoustic comfort is a key evaluation index for the soundscapes of indoor spaces [43]. Thus, this
155 study examined the influences of different spaces in the evaluation of passenger acoustic comfort

156 using a questionnaire survey method. In this study, a total of 300 questionnaires were issued, 50
157 in each representative space, among which 289 were valid. The participants were of different ages
158 and a balanced male-to-female ratio was maintained: the participants were between 15 and 80
159 years old, and the male-to-female ratio was set to 1.02:1 (146 males and 143 females) to ensure
160 that the sample sex ratio was balanced.

161 To ensure the representativeness of the selected spaces, a preliminary survey of six typical
162 spaces in the station was conducted before the formal investigation [30]. The contents of the
163 investigation concerned sound sources, personnel behavior, sound field characteristics and
164 comfort evaluation. The results obtained from the six spaces were typical and obviously diverse.
165 Previous studies have also indicated that an interview duration of more than 5 min may decrease
166 the reliability of the investigation [44]; therefore, the questionnaires in this study were all delivered
167 and completed within 2–3 min. Approximately 10 interviews were conducted at each survey point.
168 Participants were interviewed individually and briefed on the purpose of the study; then, they
169 provided written informed consent to participate in the research. The survey points are marked
170 with solid circles in Fig. 1, and Table 3 shows the questions, which included four social factors (Nos.
171 1–6) and a subjective evaluation (Nos. 7–14). Previous studies have shown that social factors may
172 cause different evaluation results [45], and therefore, Nos. 1–4 provide a survey of the social
173 background. When people arrive at the waiting hall at different time periods, they may give
174 different evaluations of the comfort level of the acoustic environment. In addition, the time people
175 spend in the space may also make a difference in their evaluation of environmental comfort. Nos.
176 5–6 are intended to address the above questions. Nos. 7–10 provide a subjective evaluation of the
177 total sound environment and Nos. 11–15 provide a subjective evaluation of each sound source. No.
178 7 is an overall sound environment evaluation, No. 8 provides an evaluation of the comfort level, No.
179 9 asks the participant to evaluate the language intelligibility in the overall sound environment and
180 thereby indirectly evaluate the level of background noise, and No. 10 provides a subjective
181 evaluation of the reverberation time. The existing research showed that the acoustic comfort of
182 sound sources is related to sound characteristics such as loudness, intelligibility, noise level and
183 preference degree, as shown in Table 3, Nos. 12–15. Loudness is a subjective measurement
184 describing the strength of the ear's perception of a sound [46]. Intelligibility is a measure of speech
185 comprehensibility during communication [47]. Sound level refers to various logarithmic
186 measurements of audible vibrations [48], and preference degree is related to a person's degree
187 of preference for one or more sound sources [49].

188 The attitudes of participants were measured using a Likert scale, which has been widely used in
189 survey research of environmental effects on subjective comfort [50, 51]. Regarding acoustic
190 comfort, the interviewees provided answers using the following five-point Likert-type scale: 1, very
191 uncomfortable; 2, uncomfortable; 3, neither comfortable nor uncomfortable; 4, comfortable; and 5,
192 very comfortable [52]. The reliability coefficient of the questionnaire was estimated as 0.82
193 (Cronbach's alpha). The Kaiser-Meyer-Olkin (KMO) values of the subscales were greater than 0.5.
194 For the Bartlett spherical test, $p < 0.01$, with a reliability coefficient of $0.9 > \alpha \geq 0.8$, indicating that
195 the questionnaire satisfied the reliability requirement [53].

196 **Table 3** Questionnaire questions and scales.

No.	Questions	Scale
1.	Gender	1, male; 2, female
2.	Age	1, <20; 2, 20-40; 3, 40-60; 4, >60
3.	Education level	1, primary; 2, secondary; 3, higher education
4.	Income	1, <1000; 2, 1000-2000; 3, 2001-3000; 4, 3001-4000; 5,4001-5000; 6, >6000
5.	Visit time	1, morning (9:00-11:59); 2, midday (12:00-14:59); 3, afternoon (15:00-17:59); 4, evening (18:00-21:00)

6.	Visit duration	1, less than an hour; 2, 1–2 h; 3, more than 2 h
7.	Evaluation of the overall sound environment	scale of 1 to 5, with 1 being very noisy and 5 being very quiet
8	Acoustic comfort of the overall sound environment	scale of 1 to 5, with 1 being very uncomfortable and 5 being very comfortable
9.	Sound volume of communicating with companions	scale of 1 to 5, with 1 being very loud and 5 being very soft
10.	Subjective impression of reverberation	Scale of 1 to 5, with 1 being very long and 5 being very short
11.	Acoustic comfort of various sound sources	scale of 1 to 5, with 1 being very uncomfortable and 5 being very comfortable
12.	Loudness of various sound sources	scale of 1 to 5, with 1 being very low and 5 being very high
13.	Intelligibility of various sound sources	scale of 1 to 5, with 1 being very clear and 5 being very unclear
14.	Noise level of various sound sources	scale of 1 to 5, with 1 being very noisy and 5 being very quiet
15.	Preference degree of various sound sources	scale of 1 to 5, with 1 being highly disliked and 5 being highly liked

2.4 Data statistics and analysis

The results of the subjective and objective measurements were analyzed using SPSS 15.0 software [54]. Pearson's correlation coefficient was used to determine the factors and dominant sound sources that affected people's comfort evaluations of the sound environment, and mean differences (t-tests, two-tailed) were used to investigate the influences of the existence or nonexistence of dominant background sound sources on the participants. Pearson's correlation and regression analysis were used to determine the factors affecting the acoustic comfort of the dominant sound sources from the sound source characteristics. The factors affecting people's acoustic comfort evaluation are discussed from the perspectives of demographic and social factors.

## 3. Results and analysis

Based on the survey and measurement results, this section discusses the following effects: different types of sound sources, dominant sound sources, demographic and social factors on sound level, sound perception, loudness and acoustic comfort.

3.1 Overall comfort level and sound environment

Fig. 2 shows the subjective evaluations of the overall sound environment in the six spaces and includes the mean and standard deviation of each evaluation. The comfort of the sound environment in the railway station was acceptable (mean value of 3.65). However, the comfort evaluations in the seating area and shop were relatively higher (mean values of 3.81 and 3.91, respectively), and the comfort evaluations in the restaurant were slightly lower (mean value of 3.28). Sound level and speech intelligibility were considered the most important influencing factors in the sound environment [55]. The SPL and RT measurement results are shown in Table 4. The seating area, shop area and ticket lobby were quieter, and the areas with high concentrations of people are noisy. RT is related to the size of the space: the larger the space is, the longer the RT is.
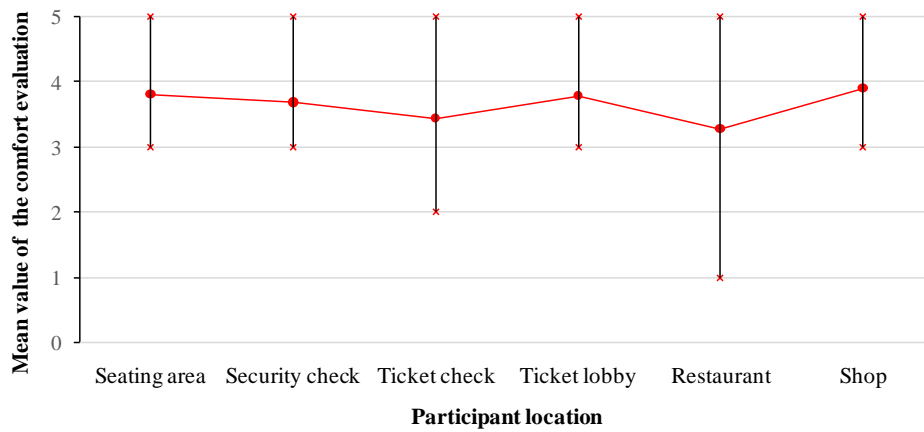
Fig. 2. Means and standard deviations of the comfort evaluations of the overall sound environment

**Table 4** Measurement results for each measurement point in the six areas.

Space	Ticket lobby			Security check		Restaurant	Shop		
Measurement point	R1	R2	R3	R4	R5	R12	R16		
Leq (A) [dB]	68.2	67.7	68.4	69.8	70.8	75.1	58.7		
RT [s]	5.16	4.98	5.39	2.97	3.15	1.58	4.62		
Space	**Ticket check**								
Measurement point	R8	R13	R17	R20					
Leq (A) [dB]	72.8	68.9	73.8	73.2					
RT [s]	3.28	4.16	3.59	3.36					
Space	**Seating area**								
Measurement point	R6	R7	R9	R10	R11	R14	R15	R18	R19
Leq (A) [dB]	64.9	62.1	66.4	65.2	60.8	64.2	62.6	66.0	65.8
RT [s]	8.96	9.64	9.69	9.98	8.63	9.15	9.38	8.79	8.91

Fig. 3 illustrates the individual response ratings regarding the overall environment vs. the SPL measurement at each survey site. The overall trend is that the comfort level and sound volume of communication decrease with increasing SPL. However, it is interesting to note that in addition to the measuring point of the restaurant, the other measuring points also show reduced comfort levels as the sound pressure level increases. The average SPL values in the seating area, ticket lobby and shops were all below 70 dB. The restaurants are the noisiest places, with an average SPL value of 75.1 dB, but the comfort level and the appropriateness rating in the restaurants are higher than those in the ticket check area. According to the Pearson correlation analysis, the correlation coefficient between the subjective comfort evaluation of the sound environment and the objective SPL measurement was 0.513 ($p < 0.01$). In other words, there is a significant positive correlation between the subjective comfort evaluation and the objective measurement of the SPL, namely, the SPL affects the comfort evaluation of the sound environment.

The ratings of the individual responses on the overall environment vs. the RT measurement at each survey site are shown in Fig. 4. It is interesting to see that as the RT increases, the comfort level also increases. When the RT exceeds 4.5 s, participants can feel the reverberation in the space. High RT also increases the communication sound volume because high RT increases the background noise and reduces speech intelligibility [56].
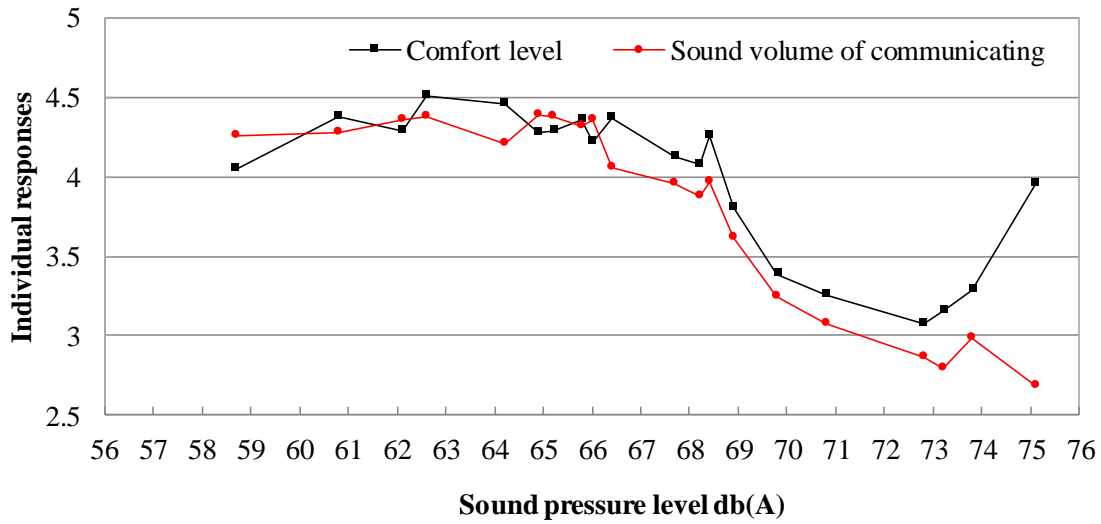
Fig. 3. Ratings of the comfort level and appropriateness with mean values of the SPL measurements.
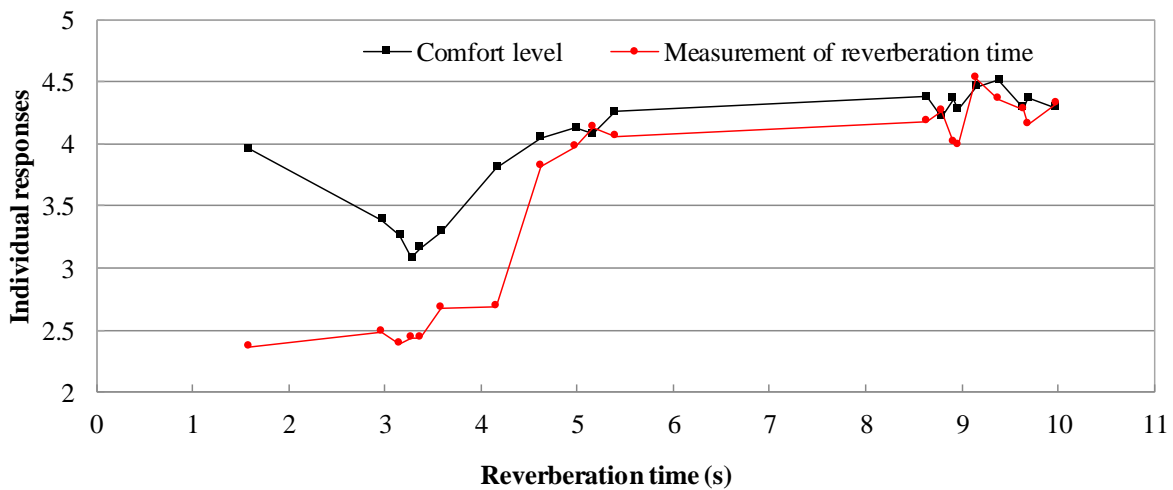
Fig. 4. Ratings of the comfort level and subjective impression of reverberation with the RT measurements

3.2 Sonic composition

Participants were asked to list three sounds that they heard at that moment and provide a comfort scale (scale of 1 to 5, with 1 being very uncomfortable and 5 being very comfortable) to identify various background noise sound sources and determine the types of the sound sources from participants' perspective. Sound sources mentioned fewer than five times were ignored [57]. Finally, the various individual sound sources in railway stations were divided into five types: broadcasts, speech sounds, activity sounds, mechanical noise and luggage noise. The key sounds and comfort scale in each space are shown in Fig. 5. Interestingly, the participants gave lower evaluations of the comfort level at the survey points in spaces with high-density crowds, such as ticket checks and restaurants, and they were significantly influenced by activity sounds and speech sounds. The participants found the spaces around machines to be a generally poor acoustic environment, and it appeared that people were bothered more by mechanical noise and luggage noise. In particular, as a key sound, most participants gave a high appropriateness score for broadcasts, and people interacting and communicating in spaces were not significantly annoyed by broadcasts.

The space name of participant location
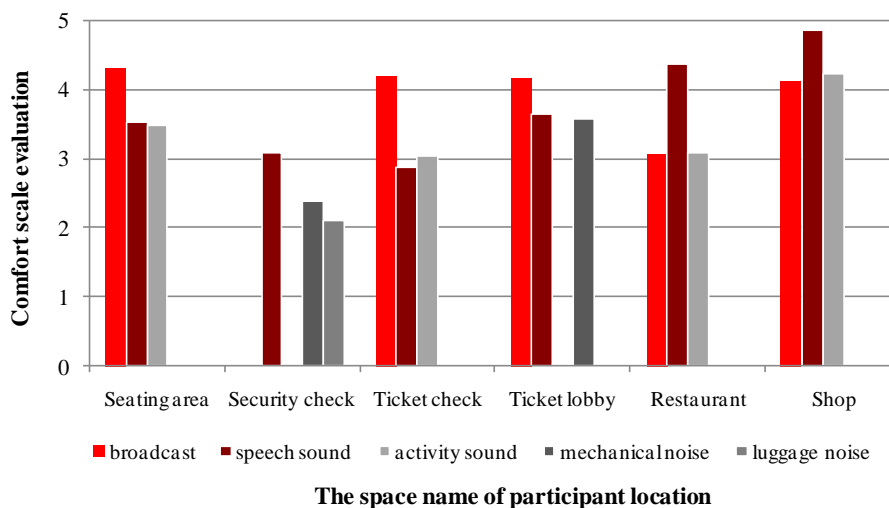
Fig. 5. Key sounds and mean comfort evaluation in different spaces

Participants were also asked to list five sound sources that they heard in each space and provide their evaluation of the acoustic comfort. Table 5 (Column A) shows the means and standard deviations of the participants' acoustic comfort evaluation of various background noise sound sources in the spaces. As a key sound, broadcasts were fundamental in most spaces. This sound did not garner much attention in the security check, but participants listed broadcasts as a key sound source in the other spaces, and the acoustic comfort evaluation of broadcasts tended to be given a comfortable score. The speech sound sources consisted of the sounds of participants (the speech sounds of companions and other participants, shouting, crying and phone calls of people moving around) and the speech sounds of staff. Speech sounds were mentioned as key sounds in every space, and the participants tended to provide a better evaluation of the comfort level of speech sounds in commercial spaces, including restaurants and shops. The comfort level of speech sound was the lowest in the ticket check area and was evaluated as uncomfortable. A comparison of the measurement results of the SPL found that the SPLs of the test points R8, R17 and R20 near the ticket check all exceeded 70 dB, indicating that when an SPL is above a certain level enhances the annoyance degree of speech sound, resulting in low comfort-level evaluations in this area. Activity sound sources were caused by user activities in these spaces, including impact sounds from footsteps, scratching sounds from clothes, the sounds of food preparation by staff, and the sounds of people choosing goods from store shelves. Participants listed activity sounds as dominant in the seating and ticket check areas and in restaurants and shops. The general evaluation of its comfort level showed more comfort in shops. Mechanical noise sources include the sounds of a ticket machine, the sounds of a security check machine, the sounds of a ticket check machine, and the sounds of ventilators and elevators. In the security check area, mechanical noise was evaluated as an uncomfortable sound source; however, in the ticket lobby, the mechanical noise was considered acceptable. Luggage noise sources included the sounds of dragging luggage and placing luggage in the security scan machine. Luggage noise was listed as a key sound only in the security check area and was evaluated as an uncomfortable sound source.

Table 5 provides a statistical analysis using the Pearson correlation of the acoustic comfort evaluations of various individual sound sources and the comfort evaluation of the overall sound environment in each space (p < 0.01). The results showed that positive correlations among the following: acoustic comfort evaluations of broadcast sounds, the speech sounds of other participants, and shouting in the seating area; the speech sounds of the staff, the security check machine and the sound of placing luggage in the security scan machine in security check area; broadcast sounds, conversational sounds from other participants and the sound of the ticket machine in the ticket lobby; the speech sounds of staff and the food preparation by staff in the restaurant; and the broadcast and the chatting sounds of other participants in the shops. The

301 correlation coefficients ranged from 0.25–0.5. To determine the influences of these sound sources
302 on the overall comfort of the sound environment, an independent samples t-test was conducted in
303 both the presence and absence of the sound sources. The results (Table 4, Column C) showed
304 that the comfort evaluations of the overall sound environment in the presence or absence of
305 shouting in the seating area, luggage noise in the security check, the speech sounds of staff at the
306 ticket check and shouting in the ticket lobby all displayed marked differences. The comfort
307 evaluation (mean of 2.96) of the overall sound environment in the seating area in the presence of
308 shouting was significantly lower than that (mean of 3.42) in the absence of shouting; the comfort
309 evaluation (mean value of 2.11) of the overall sound environment in the security check in the
310 presence of luggage noise was lower than that (mean of 2.69) in the absence of luggage noise; the
311 comfort evaluation (mean of 2.49) of the overall sound environment in the ticket check in the
312 presence of the speech sounds of staff was lower than that (mean of 2.92) in the absence of the
313 speech sounds of staff; and the comfort evaluation (mean of 3.01) of the overall sound environment
314 in the ticket lobby in the presence of shouting was lower than that (mean of 3.42) in the absence
315 of shouting. The presence or absence of broadcast and chatting sounds of other participants in the
316 seating area; the speech sounds of staff and security check machines in the security check; the
317 broadcast and chatting sounds of other participants in the ticket check; the broadcast and ticket
318 machine noise in the ticket lobby; the speech sounds of staff and food preparation by staff in
319 restaurants; and the broadcast and chatting sounds of other participants in shops showed no
320 significant effect on the comfort evaluation of the overall sound environment.

321 **Table 5.** Correlation analysis between the acoustic comfort of various sound sources and the overall sound
322 environment comfort evaluation. Note: Significant (at 0.05) is in bold.

Name of space	Type of sound source (Only include key sound sources)		A	B	C
Seating area	Broadcast	Broadcast information	**4.31/0.68**	**0.293/0.000(**)**	P=0.072＞0.05
	Speech sounds	Speech sounds of companions	4.02/0.81	0.223/0.021	/
		Chatting sounds of other people	**3.97/1.05**	**0.492/0.000(**)**	P=0.075＞0.05
		Shouting	**2.96/0.80**	**0.228/0.000(**)**	**P=0.035＜0.05**
		Crying	3.08/0.89	0.245/0.037	/
Security check	Speech sounds	Speech sounds of companions	3.56/0.86	0.198/0.026	/
		Chatting sounds of other people	3.01/0.88	0.312/0.053	/
		Speech sounds of staff	**2.86/0.89**	**0.332/0.000(**)**	P=0.081＞0.05
	Mechanical noise	Security check machines	**2.39/0.93**	**0.255/0.000(**)**	P=0.093＞0.05
	Luggage noise	Placement of luggage	**2.11/0.69**	**0.366/0.000(**)**	**P=0.035＜0.05**
Ticket check	Broadcast	Broadcast information	**4.18/1.02**	**0.258/0.000(**)**	P=0.065＞0.05
	Speech sounds	Speech sounds of companions	3.29/0.87	0.218/0.041	/
		Chatting sounds of other people	**2.98/0.82**	**0.308/0.000(**)**	P=0.072＞0.05
		Speech sounds of staff	**2.49/0.79**	**0.281/0.000(**)**	**P=0.035＜0.05**
		Shouting	2.36/0.83	0.186/0.044	/
Ticket lobby	Broadcast	Broadcast information	**4.16/0.92**	**0.292/0.000(**)**	P=0.064＞0.05
	Speech sounds	Speech sounds of companions	3.87/0.83	0.124/0.128	/
		Chatting sounds of other people	3.49/0.69	0.146/0.013	/
		Shouting	**3.01/0.78**	**0.322/0.000(**)**	**P=0.035＜0.05**
	Mechanical noise	Ticket machines	**3.56/0.96**	**0.251/0.000(**)**	P=0.082＞0.05
Restaurant	Broadcast	Broadcast information	3.08/0.85	0.243/0.029	/
	Speech sounds	Speech sounds of companions	4.47/0.92	0.242/0.086	/
		Chatting sounds of other people	4.27/1.01	0.262/0.069	/
		Speech sounds of staff	**4.36/1.14**	**0.265/0.000(**)**	P=0.095＞0.05

	Activity sounds	Food preparation by staff	**3.08/0.96**	**0.278/0.000(**)**	P=0.068＞0.05
Shop	Broadcast	Broadcast information	**4.12/0.98**	**0.226/0.000(**)**	P=0.089＞0.05
	Speech sounds	Speech sounds of companions	4.95/0.82	0.206/0.028	/
		Chatting sounds of other people	**4.78/0.99**	**0.288/0.000(**)**	P=0.091＞0.05
		Speech sounds of staff	4.82/0.83	0.186/0.058	/
	Activity sounds	Choosing goods from store shelves	4.22/0.79	0.229/0.083	/

323   A. Mean and standard deviation of the acoustic comfort evaluations of the sound sources
324   B. Correlation coefficient and significance level of acoustic comfort evaluation of various sound sources and the overall sound environment comfort
325   evaluation
326   C. P-value of independent samples t-test

3.3 Sound characteristics of dominant individual sound sources

328   In this section, the subjective evaluations of the loudness, intelligibility, noise level and
329   preference degree based on the questionnaire survey are analyzed. Fig. 6 summarizes the sound
330   source characteristics by averaging the scores of four factors for different sound sources.
331   Broadcasts, which drew people's attention, exhibited the lowest sound level, resulting in a high
332   preference degree (with a mean value of 4.21), although the loudness and intelligibility were high.
333   However, there were variations in the luggage noise and mechanical noise; they had a high sound
334   level and loudness but a low preference degree, meaning that these two sound sources resulted
335   in a high annoyance degree (discomfort) of people (means of 2.65 and 2.54, respectively). The
336   four sound characteristics of speech and activity sounds were moderate, with mean values of 3-4.
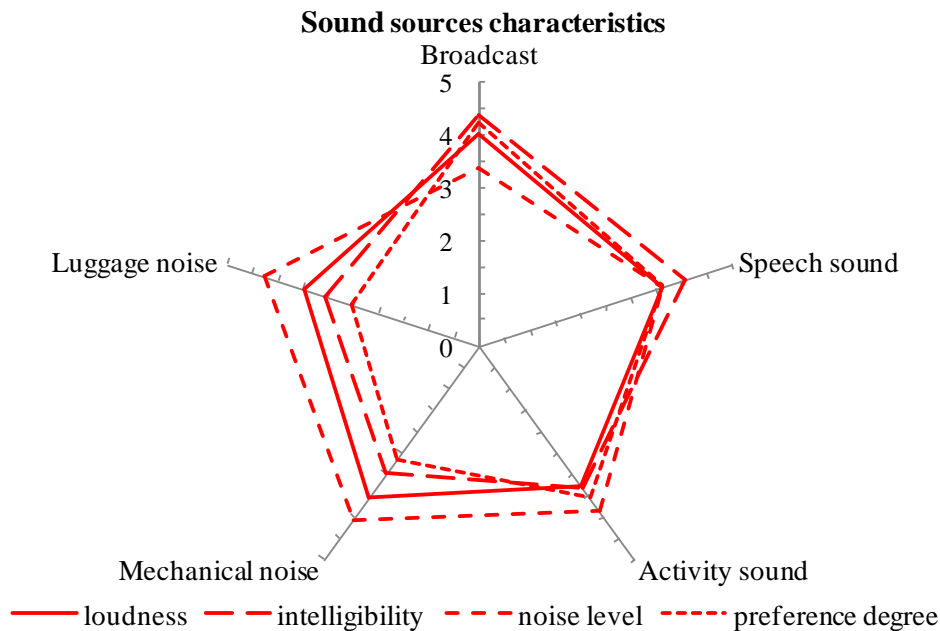

Fig. 6. Sound source characteristics for each sound source.

339   Because the evaluation of the sound characteristics of the dominant sound sources may have
340   different influences on the SPL and acoustic comfort, the SPLs and acoustic comfort of different
341   sound source characteristics from different dominant sound sources were also compared.
342   Mechanical noise and luggage noise are not analyzed in this section due to a lack of examples. The
343   relationships between the measured LAeq and sound source characteristics as well as acoustic
344   comfort and sound source characteristics with different sound sources are shown in Figs. 7–8,
345   where the linear regressions and the coefficients of determination (R^2) are also presented. There
346   is a general correlation between the measured sound level and loudness and intelligibility as well
347   as with the sound level for some of the sound sources (p < 0.001).
348   As the measured overall sound level increases, the sound level of speech also increased; the R^2

349 value was 0.515. Other sound sources showed only weak correlations. A possible reason for this
350 difference is that broadcasts and activity sounds were not always present, but speech sounds
351 were always present as background noise, and noise from speech was the most important factor
352 affecting the sound environment. It is interesting to note that as the measured sound level
353 increased, the intelligibility of both the broadcast and speech sound also decreased; the R^2 values
354 were 0.511 (broadcast) and 0.532 (speech sound). A possible reason is that the increase in the
355 SPL is mainly caused by these two sounds; they interfere with each other such that one voice
356 obscures the other, decreasing the intelligibility of both. It is also interesting to note that as the
357 measured sound level increased, the loudness of three sound sources decreased; sound masking
358 among these sound sources may have led to this result. There was a significant correlation ($R^2 =$
359 0.791) between acoustic comfort and the speech sound level, indicating that noise from speech
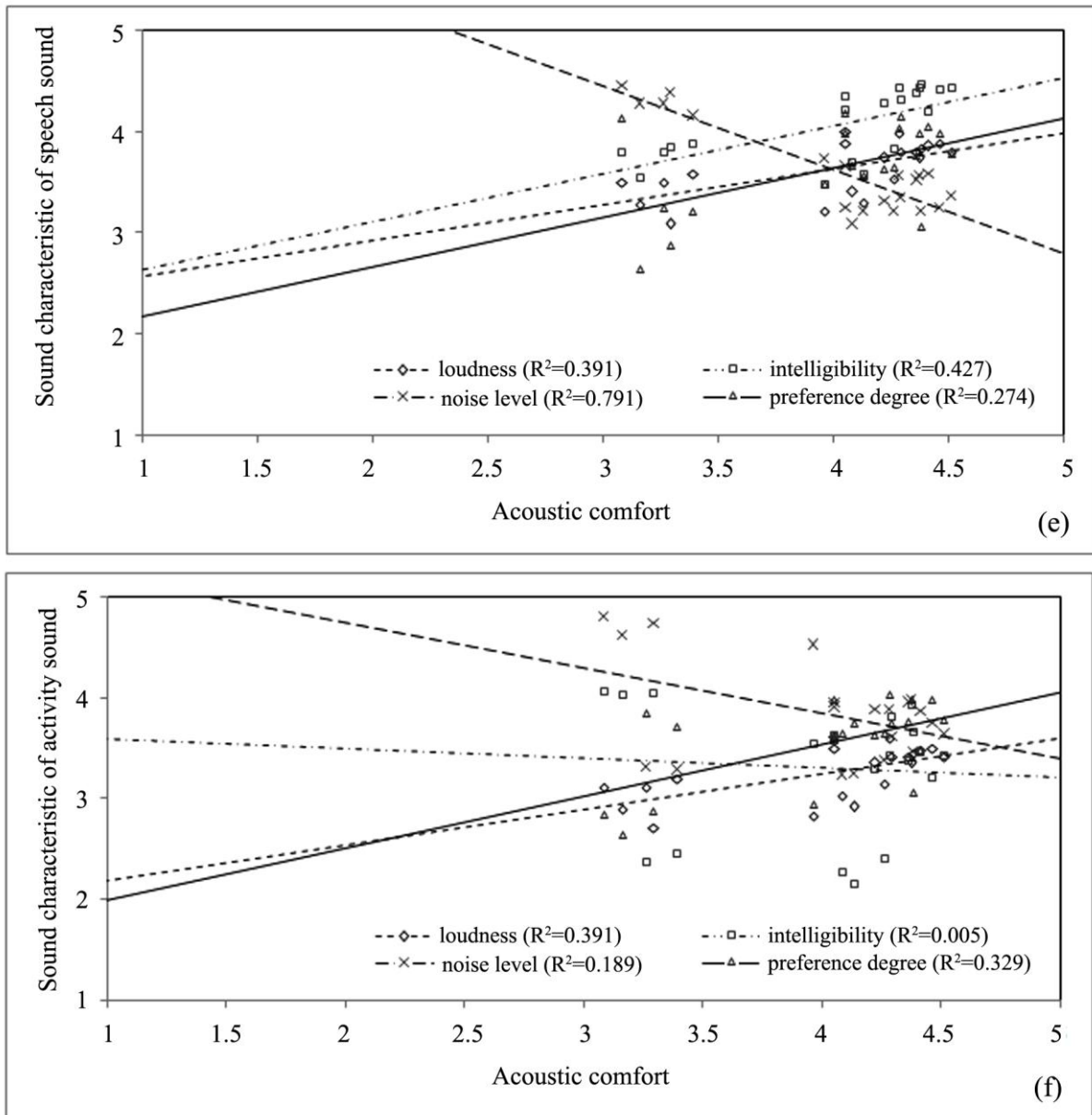360 sounds is not generally liked.

361

(a)

(b)

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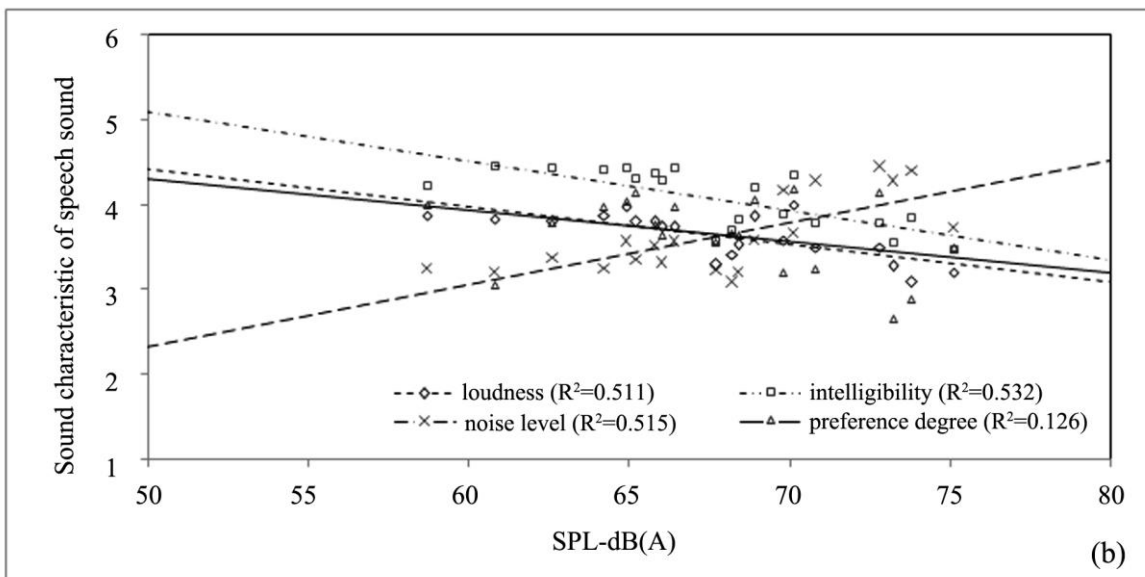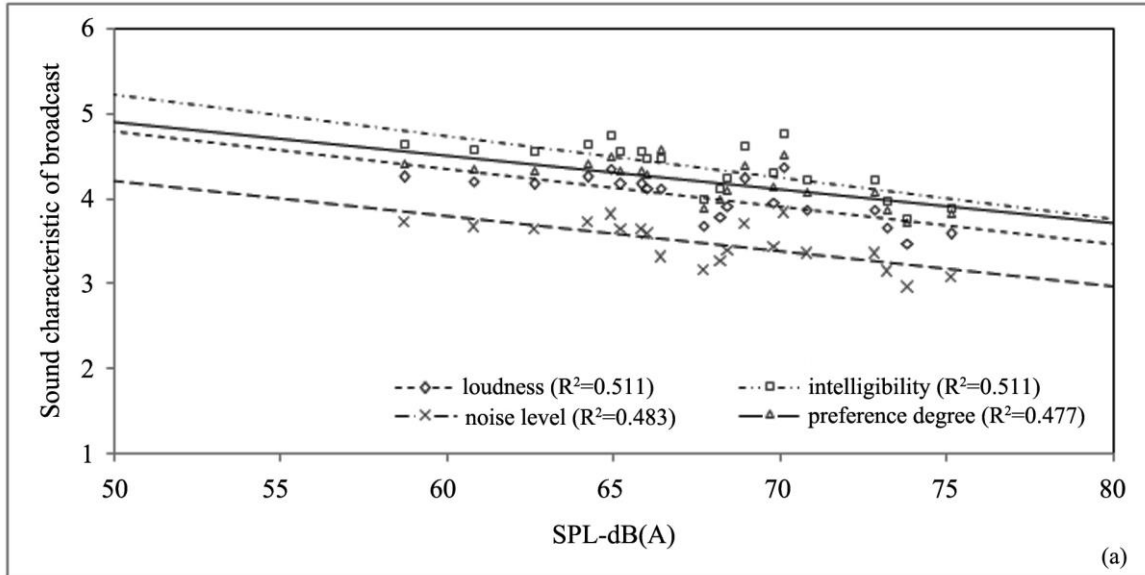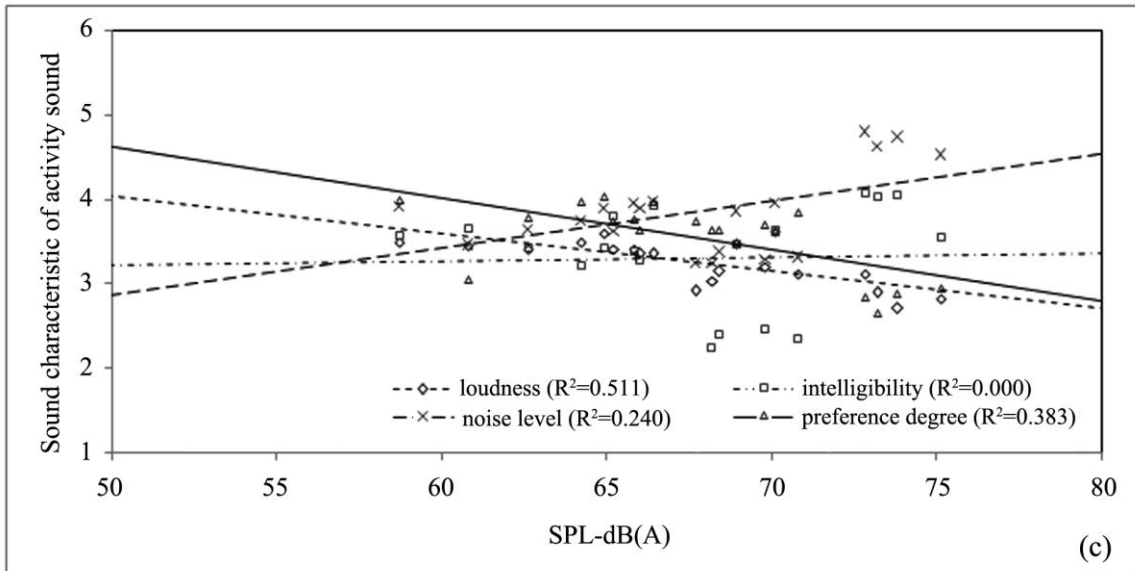
Fig. 7. The relationship between SPL and the sound characteristics of the dominant sound sources.
(a) Relationship between SPL and the sound characteristics of a broadcast;
(b) Relationship between SPL and the sound characteristics of speech sounds;
(c) Relationship between SPL and the sound characteristics of activity sounds.

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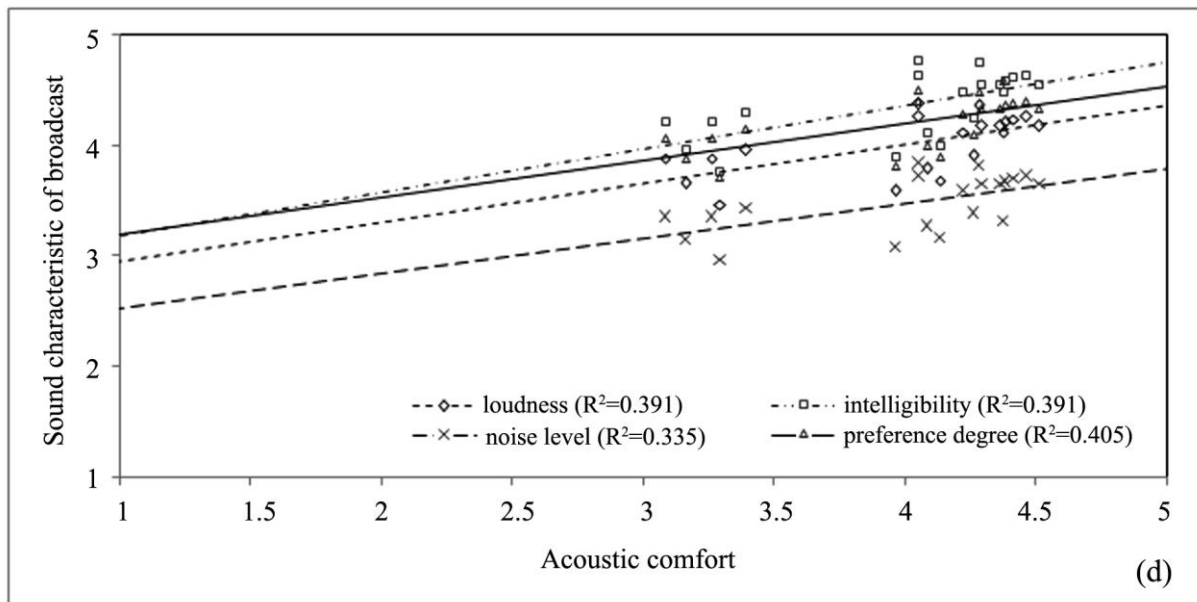
Fig. 8. The relationship between acoustic comfort and the sound characteristics of the dominant sound sources.
(a) Relationship between acoustic comfort and the sound characteristics of a broadcast;
(b) Relationship between acoustic comfort and the sound characteristic of speech sounds;
(c) Relationship between acoustic comfort and the sound characteristics of activity sounds.

3.4 Effects of demographic and social factors

The mean difference between males and females in the evaluation of acoustic comfort was determined in every space. As shown in Table 6, no significant differences ($p < 0.1$) were found between males and females. These results were consistent with those of previous studies, which suggested that the effect of gender on sound annoyance evaluation is generally insignificant (Meng and Kang, 2016). However, age difference was significant ($p < 0.01$ or $p < 0.05$); the correlation coefficients ranged from 0.16 to 0.28 in most spaces. Acoustic comfort was higher for older people, and our results are consistent with those of a previous study in Europe [1], which showed that cultural aspects were not the main factor influencing older people's noise perceptions. The same conclusion has been drawn for other types of buildings [58]. Education level and income difference were also significant factors ($p < 0.01$ or $p < 0.05$) in people's acoustic comfort; the correlation coefficients ranged from 0.13 to 0.22 for education level and 0.15 to 0.22 for income

390 for the tested spaces. It is interesting to note that acoustic comfort increased with higher education
391 level and income in quiet places (where the measurement results of SPL were below 70 dB), while
392 it usually decreased with higher education level and income in noisy places (where the
393 measurement results of SPL exceeded 70 dB). This result indicates that people with different
394 income levels have different tolerances for different SPLs. Differences in visit frequency were
395 associated with a significant difference in the comfort evaluation of the sound environment in six
396 spaces (p < 0.05): people who visited the station frequently (mean = 3.46) gave a more critical
397 evaluation than people who did not (mean = 3.12). It was also found that the visit duration in space
398 was significantly correlated (p < 0.01) with acoustic comfort, and under a high SPL, visit duration
399 and acoustic comfort had a significant negative correlation. This indicates that people tend to be
400 more annoyed when they spend more time in a high-SPL environment.

401 **Table 6**. The relationship between acoustic comfort and participant demographic information.

Social factors	Seating area	Security check	Ticket check	Ticket lobby	Restaurant	Shop
Sex	0.03	0.03	0.01	0.04	0.01	0.02
Age	**0.28****	**0.16***	**0.18***	**0.20****	**−0.15***	0.08
Education level	**0.18***	**−0.16***	**-0.22****	**0.15***	**-0.13***	**0.21****
Income	**0.22****	**-0.19****	**-0.25****	**0.15***	0.06	**0.24****
Visit time	**−0.18***	**−0.21****	**-0.26****	**0.20****	**0.15***	**−0.29****
Visit duration	**0.15****	**−0.28****	**-0.31****	**0.16****	**0.11****	**−0.16****

402 Significant correlations are marked in bold; ** denotes p＜0.01 and * denotes p＜0.05.

403 4 Conclusions

404 Based on measurements and the results of a questionnaire survey conducted at a railway
405 station, the effects of various sound sources on the sound environment and the corresponding
406 subjective evaluations of acoustic comfort were studied.

407 With regard to the overall sound environment and comfort level, according to the measurement
408 and survey results, the SPLs were concentrated between 60–70 dB(A). There was a significant
409 positive correlation between the subjective comfort evaluation and sound level measurement: the
410 correlation coefficient was 0.513 (p < 0.01). The comfort level and appropriateness were
411 moderately negatively correlated with the SPL at the station. It is interesting to see that people's
412 comfort level increases with increasing RT, which is contrary to popular belief. This result occurs
413 because the test points with lower SPL values have longer RT, and the comfort level is more highly
414 affected by SPL, leading to a higher comfort rating. The RT was difficult for people to sense; when
415 it exceeded 4.5 s, the participants could feel the reverberation in the space. High RT also increases
416 the sound volume during communication.

417 The sonic composition of sound sources in the railway station included broadcasts, speech
418 sounds, activity sounds, mechanical noise and luggage noise. The dominant sound sources
419 differed in each space. Broadcasts, speech sounds, and activity sounds were the sounds most
420 identified by the participants. The acoustic comfort of broadcasts was the most preferable;
421 speech sounds were preferred in restaurants and shops but considering annoying in security and
422 ticket check areas, and the acoustic comfort of mechanical noise and luggage noise was the least
423 preferable in security check areas. Among the sound sources, the speech sounds of other people
424 in the seating area, the speech sounds of staff, the sounds of placing luggage in the security scan
425 machine in the security check area, the sound of the ticket machine in the ticket lobby, and the
426 speech sounds of staff in the restaurants significantly influenced the participants' acoustic comfort
427 evaluations.

428 With regard to the effects of various sound sources on the comfort level, the sound
429 characteristics of five main sound sources were analyzed. The results show that people have the

highest preference for broadcasts, followed by speech sounds and activity sounds. The intelligibility of broadcasts is low because they are easily obscured by other sound sources, such as speech sounds and activity sounds. However, people want to hear the broadcasts; therefore, the intelligibility of the broadcasts needs to be improved. Although the participants' preferences for speech sound and activity sound were at high levels, as the density of people increases, the preferences for those types of sound decline rapidly. Therefore, those two sound source types need to be controlled, especially in large spaces with high population densities. People dislike luggage and mechanical sounds because of their high sound levels and perceived loudness; these two sound sources received considerable attention and need to be reduced. To improve the acoustic environment, sound sources with both low preferences and high loudness were considered. It is worth investigating the sound environment of large railway stations from a soundscape perspective to determine whether measures might be implemented that would enhance users' acoustic comfort.

With regard to demographic and social factors, age differences resulted in significant differences in comfort evaluations: older people provided higher comfort evaluations. People's education level and income differences also resulted in significant differences ($p < 0.01$ or $p < 0.05$) in acoustic comfort: higher incomes and education levels were associated with high evaluations of acoustic comfort in quiet places but low evaluations in noisy places. Both visit frequency and visit duration were significantly different: people who visited the station frequently gave a more critical evaluation, and visit duration and acoustic comfort had a significantly negative correlation.

While in this study the station spaces are rather large, it is also interesting to consider other spaces types such as long spaces in further studies [59-62].

Acknowledgements

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