Article:
Meng, Q. and Kang, J. (2016) Effect of sound-related activities on human behaviours and acoustic comfort in urban open spaces. Science of The Total Environment, 573. pp. 481-493. ISSN: 0048-9697

https://doi.org/10.1016/j.scitotenv.2016.08.130

Effect of sound-related activities on human behaviours and acoustic comfort in urban open spaces

Qi Meng [a, b] Jian Kang [a, b, c]

[a]School of Architecture, Harbin Institute of Technology, Harbin, 150001, China

[b]Heilongjiang Cold Region Architectural Science Key Laboratory, Harbin, 150001, China.

[c]School of Architecture, University of Sheffield, Western Bank, Sheffield, S10 2TN, UK

*Corresponding author: Email: j.kang@hit.edu.cn

Abstract

Human activities are important to landscape design and urban planning; however, the effect of sound-related activities on human behaviours and acoustic comfort has not been considered. The objective of this study is to explore how human behaviours and acoustic comfort in urban open spaces can be changed by sound-related activities. On-site measurements were performed at a case study site in Harbin, China, and an acoustic comfort survey was simultaneously conducted. In terms of effect of sound activities on human behaviours, music-related activities caused 5.1–21.5% of persons who pass by the area to stand and watch the activity, while there was a little effect on the number of persons who performed excises during the activity. Human activities generally have little effect on the behaviour of pedestrians when only 1 to 3 persons are involved in the activities, while a deep effect on the behaviour of pedestrians is noted when more than 6 persons are involved in the activities. In terms of effect of activities on acoustic comfort, music-related activities can increase the sound level from 10.8 to 16.4 dBA, while human activities such RS and PC can increase the sound level from 9.6 to 12.8 dBA; however, they lead to very different acoustic comfort. The acoustic comfort of persons can differ with activities, for example the acoustic comfort of persons who stand watch can increase by music-related activities, while the acoustic comfort of persons who sit and watch can decrease by human sound-related activities. Some sound-related activities can show opposite trend of acoustic comfort between visitors and citizens. Persons with higher income prefer music sound-related activities, while those with lower income prefer human sound-related activities.

Keywords: Sound-related activities, sound environment, pedestrian behaviour, acoustic comfort, urban open space

Date received:14 June 2016 **Date accepted:** 8 August 2016

Publish online:27 August 2016

1. *Introduction*

With the regeneration of city centres, urban open spaces are reconceptualised with the new 'urbanity' (Thwaites et al. 2005). To create a friendly environment, rethinking the urban landscape from an ecological viewpoint is important (Yu and Kang 2010). Sound quality is considered as a key part of ecological/sustainable development of urban landscape (Zhang et al. 2006). In recent years, the soundscape was usually used as a key method to increase the sound quality in urban open spaces. The concept of the soundscape is a broad one, accommodating the complete sound environment in a location and the human response to it (Brown et al. 2011, Davies et al. 2013). According to ISO, the soundscape is the acoustic environment as perceived or experienced and/or understood by a person or people in context (ISO 2014). For urban planning and landscape design, one key attraction of the soundscape is that it seems to be a better fit than noise level to the many factors influencing human experience in the urban open spaces, since previous studies indicated that human reaction to a sound is not just physical perception but also an aesthetic sensation that one receives from the environment (Raimbault and Dubois 2005). Therefore, a thorough analysis of the function of soundscape or soundscape characteristics such as human behaviours and evaluation of acoustic comfort is very important to landscape researches in urban open spaces.

Human behaviours in urban landscape have been considered in many previous studies in relation to sound and soundscape perception, since it is important for urban landscape design (Carles et al. 1999, Yang and Kang 2005). Kang (2006) indicated that sound quality of an urban area will depend on how long people have been living there. A study by soundwalk shows that positive sound such as bird sounds in urban spaces may affect the behaviours of people (Davies et al. 2013). Meng and Kang (2013) indicated that acoustic comfort is influenced by the reason for visit, frequency of visit, and length of stay with correlation coefficients of 0.10 to 0.30. The users who were waiting for someone were found to have lower acoustic comfort than those who were shopping. The interactions between aural and visual behaviours are also an important research topic in soundscape studies (Southworth 1969; Dubois et al. 2006). A study under laboratory conditions with controlled aural and visual stimuli suggested that the visual parameter was a predominant variable with regard to aural–visual interactions (Viollon and Lavandier 2000). All the visual information had different ways and different efficiencies in affecting the auditory judgement. The more urban the visual settings were, the more contaminated was the auditory judgement (Viollon et al. 2002; Guastavino et al. 2006; Zhang and Kang 2007). The aural–visual interaction was also studied in the field of product sound quality. A study on the sound quality evaluation of construction machines showed that the 48 urban soundscape results obtained by presenting only sound were more unpleasant, more powerful and sharper than those obtained by presenting sound with scenery (Kang 2006,).

Acoustic comfort, which is the most important index to evaluate soundscape, was also widely studied in urban landscape. Among these studies, some have focused on urban landscape index in terms of acoustic comfort (Parsons and Towsey 2012). Some previous studies show that when the landscape shape index of buildings and water areas (LSI_B, LSI_W) and the patch cohesion index of water areas (COHESION_W) were increased, the evaluation of acoustic comfort can also be increased (Liu et al. 2013, 2014a and 2014b). The different sound sources in urban landscape may also lead to different evaluation of acoustic comfort (Guski 1997). Some previous studies have indicated that the evaluation of human sounds, nature sounds and machine sounds by people is different, for instance, a survey study in Japan showed that 45–75% of people favour nature sounds, while 35–55% of them are annoyed by machine noises (Tamura 1998). Moreover, the type of sound in landscape may also influence the categorisation/classification. A study on the relationship between loudness and pleasantness shows that the pleasantness of stimuli at intermediate loudness levels is not influenced by its loudness, but for sound at relatively high loudness levels, there is a good correlation between the two (Hellbrück 2000; Zwicker and Fastl 2013). The different social background or behaviours of people in urban landscape may also lead to the difference in the evaluation of sound sources, for instance, a soundscape survey with a number of foreign residents in Fukuoka showed that there were considerable differences between the sounds they heard in Japan and in their home countries (Iwamiya and Yanagihara 1998). Hopffman (1977) and Yang and Kang (2005) indicated a slight tendency for women to be more sensitive to sound than men, and evidence suggests that females generally have a higher acoustic comfort than males. Kang (2006) indicated that people aged over 65 years favour birdsongs, while the younger people, conversely, are more favourable to, or tolerant towards, music and mechanical sounds.

The effect of sound-related activities that contain special sound sources, vary according to social characteristics of the users and may lead different evaluation of aural-visual on human behaviours or acoustic comfort in urban landscape, however, has not been researched enough in previous studies. Therefore, this aim of this research is to determine the relationships between sound-related activities and human behaviours as well as their acoustic comfort. In this paper, the first step is to determine the effect of sound-related activities from different sound sources such as music and manmade sounds on typical human behaviours. The next step is to determine the effect of sound-related activities on the users' evaluation of acoustic comfort at 3 levels: sound environment, background of pedestrians and behaviours of pedestrians. A typical pedestrian street was chosen as the case site, and 7 typical activities and 4 typical behaviours of pedestrians at the case site were selected for further analysis; the sound level measurements and acoustic comfort survey were used for data collection.

*2. **Methodology***

2.1. Survey site

Since some previous studies indicated that the environment or space differences may lead to the different evaluation of soundscape (Lercher and Schulte-Fortkamp 2003, Kang and Zhang 2010), the effect of sound-related activities should be studied generally in the same environment and places; therefore, a typical pedestrian street named Stalin park, in Harbin, China, was chosen as the case site, since there are many typical sound-related activities that simultaneously occur along the street.

Harbin is a typical international city in China, with long cultural and historical background; the sound-related activities in Harbin are common in China and most Asian countries and even in some European countries; therefore, the results of this case site are likely to be applicable to not only other areas in China, but also to some similar cases in Asian or European countries. The Stalin park, which was built in 1953, is nearly 1800 m in length and 30 m in width. A 10-m wide traffic road is present on one side of the park, while the Songhua River is present on the other side of the park. The Stalin park is a famous tourist site for visitors as well as a leisure place for local citizens; more than 20000 users visit the park everyday (Yao 2004). Therefore, there are enough investigation samples both on activities and users for this study. The map of Stalin park and the survey locations are shown in Figure 1.

Figure 1. The case site with different sound-related activities.

2.2 Sound-related activities

On the basis of the different sound sources, the activities were divided into two groups: one group is music sound-related activities, in which the persons perform activities with music, and the other group is human sound-related activities, in which the persons perform activities by speaking or creating manmade sounds. In the case site, 4 typical music-related activities and 3 typical human sound-related activities were chosen at different locations at more than 100-m intervals, since previous studies indicated that there is no influence of sound-related activities on each other at this distance (Hao et al. 2015). Music-related activities included Folk Dancing, Zombie Dancing, Qing Gong and Tai Ji. Human sound-related activities included Whip Whipping, Roller Skidding and Playing Cards. The details of these activities are shown in Table 1.

These typical sound-related activities are very common in open squares or parks in China and some Asian countries, and now even in some European countries.

Table 1. The details of typical sound-related activities

Type 1: Music-related activities			
Activity Name	Abbreviated Name	Details	Number of persons
Folk Dancing	FD	Persons wearing traditional Chinese folk clothing dancing together with traditional Chinese music.	8–10
Zombie Dancing	ZD	A new leisure exercise from Japan, involving people performing actions that look like zombies walking.	20–50
Qing Gong	QG	A holistic system of coordinated body posture and movement, breathing, and meditation used for health, spirituality, and martial arts training	20–40
Tai Ji	TJ	Traditional Chinese exercises with Tai Ji music.	20–40
Type 2:Human sound-related activities			
Whip Whipping	WW	Bodybuilding movements using a whip to whip the ground and making a big noise.	1–12
Roller Skidding	RS	Leisure activity generally by young people, involving travelling on surfaces with roller skates. The wheel friction against the surface of ground makes	1–12

		some noise.	
Playing Cards	PC	Several groups of persons sitting together to play cards.	4–100

2.3. Behaviour measurement

In these studies, the human behaviours imply some actions and mannerisms made by visitors or citizens in the urban open spaces, which is the important point in landscape study, since there are some relationships between behaviours and landscape design or ecological planning (Snowdon et al. 2001, Pearce 2013). Therefore, the behaviours of pedestrians was also measured at every survey point in an area from 0 to 10 m outside the area of activities (Figure 2), since a previous study indicated that behaviours at 10 m away from such activities or sound sources might not be generally influenced by them (Meng and Kang 2015). The areas of activities in this study are the areas in which people are performing some activities. Considering that people may move all the time during some activities, the area of such activities was expanded to include those areas where the people move to.

In the behaviour measurement, the interviewers shoot some group videos with a camera in different situations. To determine the effect of aural-visual stimuli in terms of music sound-related activities, 4 types of situations were analyzed: neither music sound nor activities, activities without music, music without activities, and activities with music. For human sound-related activities, the videos were shot with different persons who are performing the activities. Each video is 3–5 minutes long, and videos for 10–15 groups for every situation were shot to ensure the stochastic behaviour in the measurement (Yang and Kang, 2005). The behaviours of pedestrians in the survey locations were then classified and statistically analysed from the review of videos in the laboratory. Four main behaviours of pedestrians were analysed in this research: standing and watching, passing by, performing exercises, and sitting. In this study, performing exercises imply doing some standing exercises, while some moving exercises such as running were classified as passing by behaviour.

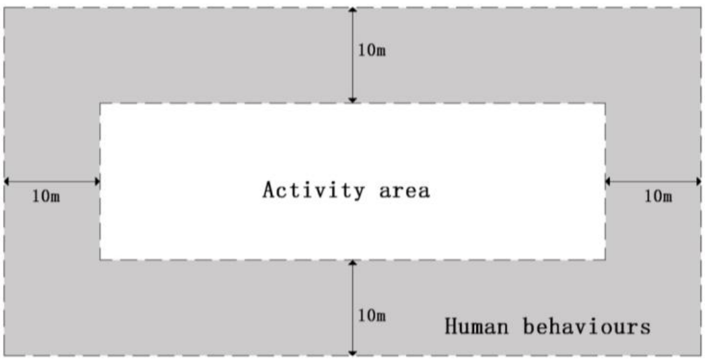


Figure 2. The measurement area of human behaviours.

2.4. Sound level measurement

Sound pressure level measurement was conducted immediately after each interview. During the measurement, the microphone of the sound level meter was positioned approximately 1 m away from any reflective surfaces and 1.2–1.5 m above the floor to reduce the effect of acoustic reflection (Zahorik 2002, Barron 2009). The sound level meters were set in slow-mode and A-weight, and reading were acquired every 3–5 s. A total of 5 min data were obtained in each survey position.

Considering that the activities themselves may dynamically change, 5–7 survey positions were selected randomly around the activity areas, and each survey position was 5 m away from the activity areas and main sound sources, if any, to avoid any instantaneous error (Eriksson 1991, Vincent et al. 2006); the corresponding LAeq of activities was derived as an average from the 5 positions.

Simultaneously, some other environment factors, for example air temperature, relative humidity, and luminance, were also measured for other further analysis (Frontczak and Wargocki 2011).

2.5. Acoustic comfort survey

The acoustic comfort survey was conducted immediately after every sound pressure level measurement. To study the influence of the activities on the evaluation of acoustic comfort, some questionnaire surveys were also conducted at the case site (Yu and Kang 2009). The questionnaire survey was conducted immediately after behaviour measurement, and every questionnaire survey was generally done by the interviewer in 3–5 minutes (Litwin 1995). In terms of subjective investigation, 1223 valid questionnaires were obtained at the survey site.

Around 150 to 200 interviews were conducted at each survey point using the same questionnaire. The interviewees in all the field surveys were randomly selected, and their educational and social backgrounds as well as on-site behaviours were proven to be representative (Yu and Kang, 2010). Considering that the pedestrians' social and behaviours may also influence their evaluation of soundscape, their social background (Table 2), for example gender, education level, age, occupation and income, as well as their behaviours before interviews were also assessed in the questionnaires (Rajeswari 2005).

In terms of evaluation of acoustic comfort, a five-point bipolar category scale was used in the questionnaire design (Meng et al. 2013). The evaluation of acoustic comfort was divided into five levels: 1, very uncomfortable; 2, uncomfortable; 3, neither comfortable nor uncomfortable; 4, comfortable; and 5, very comfortable.

Before the formal investigation was conducted, questionnaire reliability and validity were tested for the suitability of the final questionnaire (Dubois et al. 2006). Before the questionnaire survey, the interviewees were told to spend 3-5 min to evaluate the environment. Considering the interviewees need a period, approximately 20-30 min to appropriate the sound environment in the spaces (Meng and Kang, 2013), the users who were in the pedestrian street for less than half an hour were not interviewed.

Table 2. The detail of classification of social background of pedestrians

Sex	1, male; 2, female
Age	1, <18; 2, 18-24; 3, 25–34; 4, 35–44; 5, 45–54; 6, 55–64; 7, >64
Income	1, <1000; 2, 1000–2000; 3, 2001–3000; 4, 3001–4000; 5, 4001–5000; 6 >5000 RMB
Education	1, primary; 2, secondary; 3, higher education
Occupation	1, farmers; 2, workers; 3, soldiers; 4, teachers; 5, students; 6, unemployment persons

2.6. Statistical analysis

SPSS 15.0 was used to establish a database with all the subjective and objective results (Yin and Liu 2008). The data were analysed using the following: Chi-square correlations (two-tailed) for factors with three or more categories of ranked variables; Chi-square contingency correlations (two-tailed) for factors with three or more categories for categorical variables; and mean differences t-test (two-tailed) for factors with two categories. Both linear and nonlinear correlations were considered (Kang and Meng 2012).

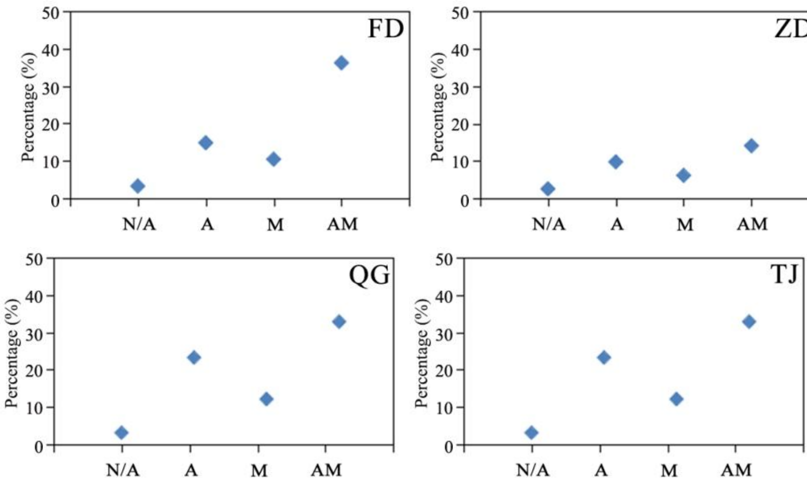
3. Effect of sound-related activities on human behaviours

On the basis of the survey and measurement results, this section presents the effect of music sound-related activities and human sound-related activities on selected typical human behaviours such as standing and watching, passing by, performing exercises, and sitting.

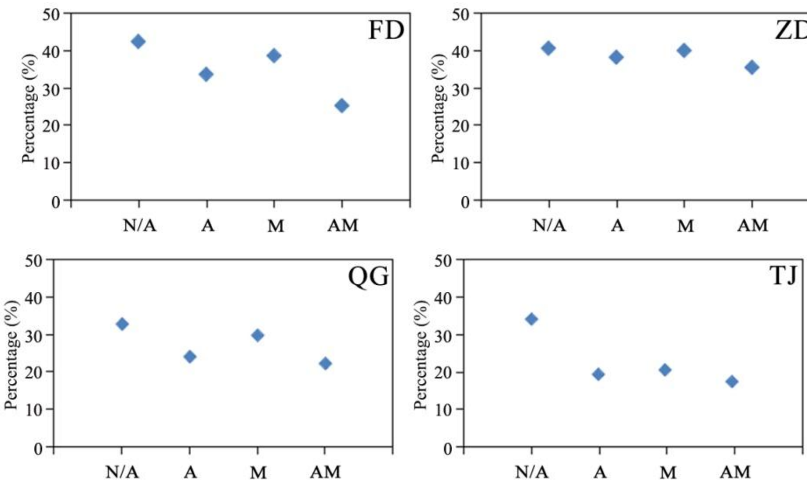
3. 1 Effects of music-related activities

Figure 3 shows the effect of music-related activities on human behaviours, where N/A is neither music sound nor activities, A is activities without music, M is music without activities, and AM is activities with music.

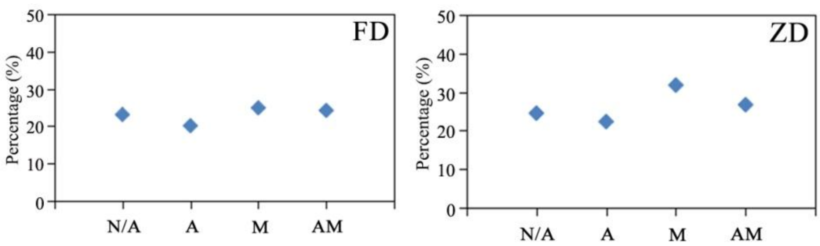
From Figure 3, it can be seen that the number of persons who stand watching is relatively fewer, 3.2% (RD area), 2.6% (ZD area), 4.5% (QG area), and 3.6% (TJ area), at the survey points when there are no music-related activities. These activities can significantly increase the number of persons who stand watching; moreover, even the activities without music can increase the number of persons who stand and watch to 14.8% (RD), 9.8% (ZD), 28.2% (QG) and 27.4% (TJ). Compared with activities without music, the effect of music without activities is lower on increasing the number of persons who stand watching, from 4.4% to 15.4%. It is interesting to note that the activities with music can markedly increase the number of persons who stand watching, while the sound environment changed little with music without activities. The number of persons who stand watching was increased to 36.2% (RD), 14.1% (ZD), 39.5% (QG), and 30.3% (TJ). This result proved again that the effect of audio-visual stimuli in the evaluation of landscape (or soundscape) is more than audio or visual stimuli alone, as reported in previous studies (Carles 1992, Fastl 2004, Ren and Kang 2015).

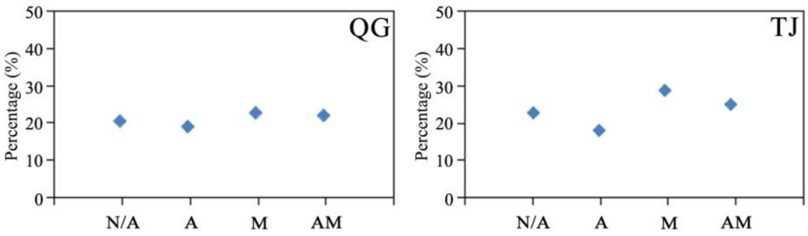


(a)

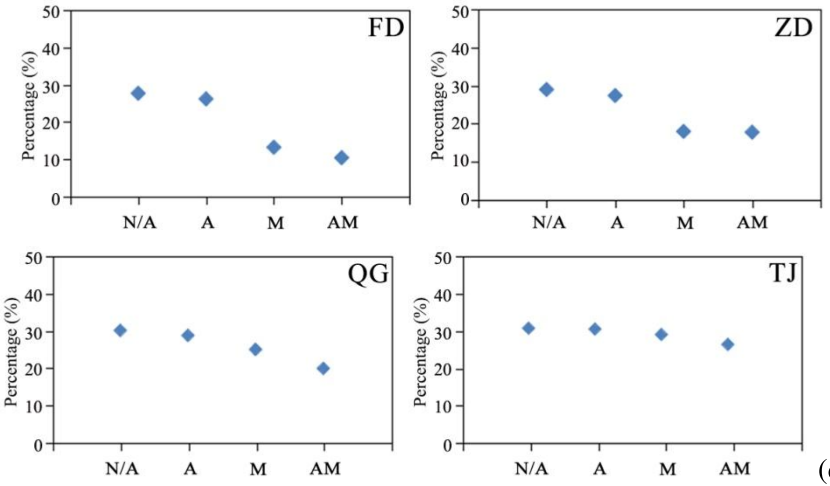


(b)





(c)



(d)

Figure 3. The percentage of behaviours with different music-related activities, where (a) indicates the percentage standing and watching with FD, ZD, QG, and TJ; (b) indicates the percentage passing by with FD, ZD, QG, and TJ; (c) indicates the percentage performing exercises with FD, ZD, QG, and TJ; (d) indicates the percentage sitting with FD, ZD, QG, and TJ. N/A indicates neither music sound nor activities, A indicates activities without music, M indicates music without activities, and AM indicates activities with music.

With regard to the behaviour of passing by, the number of persons who pass by is 42.3% (RD area), 40.5% (ZD area), 33.6% (QG area), and 37.8% (TJ area), when there are no such activities at the survey points. From Figure 5, it can be seen that the number of persons with passing by behaviour is decreased by music sound-related activities; the performance of activities with music or activities without music is better than that of music without activities. The influence of different music sound-related activities on passing by behaviours also varies, for instance TJ activities with music or without music can both decrease much more the number of persons with passing by behaviours, 21.5% (with music) and 19% (without music), while the ZD activities with music or without music did not much decrease the number of persons with passing by behaviour, 5.1% (with music) and 2.4% (without music). This result shows that the activities with higher sound level may not increase the number of persons with passing by behaviours, because the sound level of RD is much more higher than that of ZD activities, but causes less persons to show passing by behaviour.

The behaviour of persons performing exercises did not change much with music-related activities; the music environment increased the percentage of persons who were exercising only from 1.1% to 4.4%. Music without activities was better than music with activities in increasing the percentage of person who were performing exercises, because some excises can be disturbed by other activities.

With regard to the sitting behaviour, Figure 5 shows that the pedestrians who wanted to sit preferred quiet environment. When the sound environment did not change very much, for example in activities without music, the percentage of people who sat was almost the same as that for N/A situation. Compared with the N/A situation or activities without music, the music from activities decreased the percentage of persons who sat. Considering the FD activities as an example, about 27.7% and 26.2% persons sat during N/A situation and activities without music, whereas the value was 13.2% and 10.4% during music without activities and activities with music. The measured sound level correlated with the percentage of persons with sitting behaviours, with Pearson's correlation at 0.78 ($p < 0.01$); therefore, the TJ, which have a lower sound environment had decreased number of persons with sitting behaviours (only 5.7%,) while the FD, which lead to a higher sound environment, had a reduced number of persons with this behaviour (17.3%).

These results showed that the music sound-related activities change the behaviour of some persons who pass by to make them stand and watch the activity, while it had little effect on changing the numbers of persons who performed excises. These activities may also decrease the number of persons who sit when the sound level is higher.

3. 2 Effect of human sound-related activities

Figure 4 shows the effect of music-related activities on human behaviours, where N/A is no human sound-related activities and the numbers imply the number of persons.

From Figure 4, it can be seen that when the number of persons performing the activities are relatively fewer, the percentage of persons who stand watching is small, for instance when 1-3 persons performed WW or RS activity, there were only 3.3–4.3% (WW) or 3.6–4.3% (RS) persons who stood watching the activity; similarly, when 0–40 persons performed PC activity, there were only 2.6–5.6% persons who stood watching the activity. In contrast, the percentage of persons who stand watching increased when a large number of persons or a group performed the activity, for example, when 6–12 persons performed WW or RS or 40–100 persons performed PC, there were 24.5–26.3% (WW), 21.6—24.4% (RS) and 17.6–28.6% (PC) persons who stood watching the activity. It should be noted that the WW and RS activities can more easily keep the pedestrians focussed than the PC activity; there may be two reasons for this: one reason is that the sound source from WW and RS belongs to the category of noise, which is a sound mark in case sites, and is louder and easier for the pedestrians to focus than the surrounding speech, which is the main sound source from PC, and the second reason is that the WW and PS activities much easily form the 'group effect' based on the same activities and following unified styles, while the PC activity hardly forms such groups because random people are involved in this activity. The 'group effect' of human sound-related activities also influences the sitting or passing by behaviour of the pedestrians. Considering the sitting behaviour as an example, Figure 6 shows that when 0–3 persons perform WW or RS activity, 19.1–27.1% people sat, while when 6–12 persons performed

WW or RS activity, only 3.9-5.8%% people sat around the activities. It is interesting to note that generally, human sound-related activities such as RS and PC do not influence the exercise performing behaviour, but WW does because this activity is too noisy.

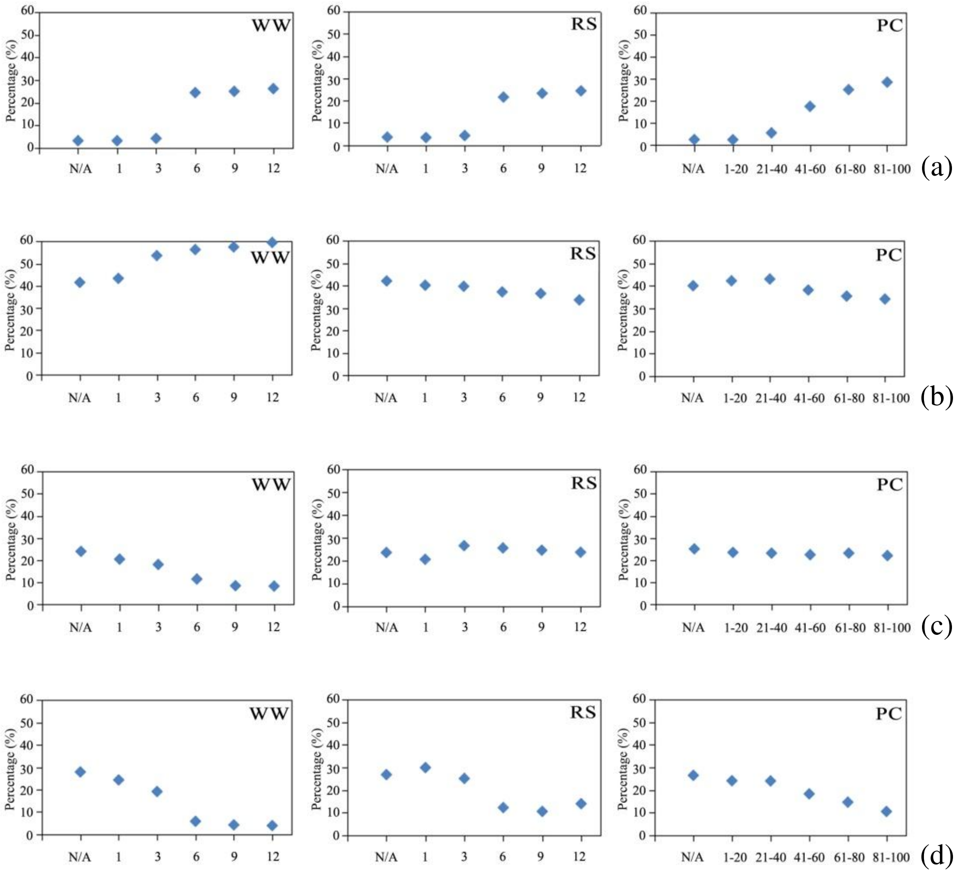


Figure 4. The percentage of behaviours with different human sound-related activities, where (a) indicates the percentage standing and watching with WW, RS, and PC; (b) indicates the percentage passing by with WW, RS, and PC; (c) indicates the percentage performing exercises with WW, RS, and PC; (d) indicates the percentage sitting with WW, RS, and PC. N/A indicates neither music sound nor activities, the numbers indicate the number of persons.

4. Effect of activities on acoustic comfort

4.1 Effect on sound environment

Considering that the sound environment will lead to the different acoustic comfort of pedestrians, the effect of both music-related activities and human sound-related activities on sound environment has been described in this section.

Figure 5 shows the effect of music-related activities on sound environment, where N/A is neither music sound nor activities, A is activities without music, M is music without activities, and AM is activities with music. From Figure 5, it can be seen that the effect of activities without music on sound environment is limited; the LAeq is 56.5 dBA (TJ), 58.3 dBA (QG), 58.2 dBA (ZD) and 59.7 dBA (FD), which is increased from 0.7 dBA (TJ), 1.2 dBA (QG), 1.7 dBA (ZD) and 1.8 dBA (FD) by activities from N/A situation, since the activities without the music are only footsteps. The sound level was strongly increased by music without activities; the LAeq is 66.7 dBA (TJ), 69.2 dBA (QG), 71.7 dBA (ZD) and 74.3dBA (FD), which is increased from 10.8 dBA (TJ), 12.1 dBA (QG), 15.2 dBA (ZD) and 16.4 dBA (FD) from N/A situation. Compared with music without activities, the activities with the music cannot increase the sound level any more. These results indicated that the music itself is the main factor that influences sound environment in music-related activities.

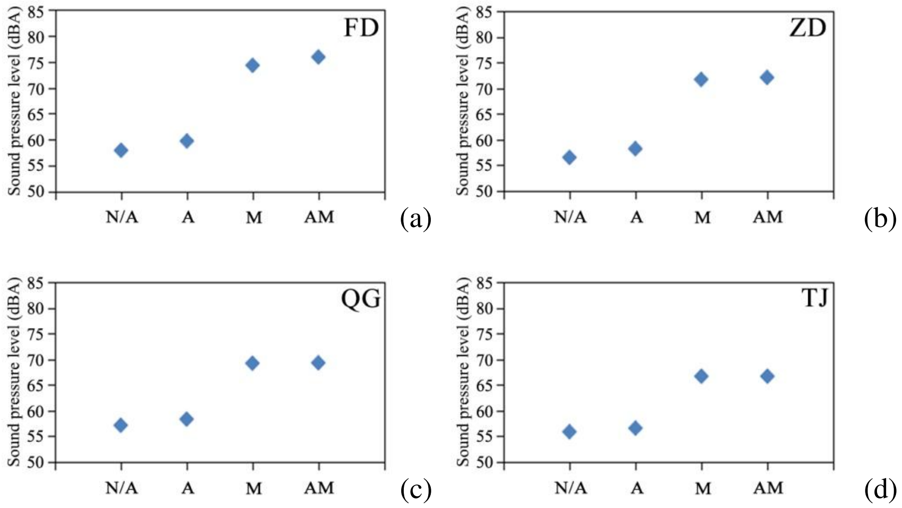


Figure 5. The sound pressure level with different music-related activities, where (a) indicates the sound pressure level of FD; (b) indicates the sound pressure level of ZD; (c) indicates the sound pressure level of QG; (d) indicates the sound pressure level of TJ. N/A indicates neither music sound nor activities, A indicates activities without music, M indicates music without activities, and AM indicates activities with music.

Figure 6 shows the effect of human sound-related activities on sound environment, where N/A is no person doing such activities and the number implies the number of persons. From Figure 6, it can be seen that the effect of whipping whip on sound environment is strong; even if only one person is doing that activity, the LAeq increases from 57.2 to 72.9 dBA. With the increase in the number of persons performing this activity, the measured sound level increased generally by 0.76 dBA per person in average, that is, 76.2 for 3 persons and 81.3 for 12 persons. For RS and PC activities, when the number of persons performing the activities is generally fewer, 1–3 persons (RS) or 0–40 persons (PC), the sound level is increased by 3.4 to 4.1 dBA (RS) or by 0.9 to 2.8 dBA (PC) from background sound environment, while when the number of persons performing the activities is relatively more, 6–12 persons (RS) or 40–100 persons (PC), the measured sound level increased by 11.6 to 12.7 dBA (RS) or 8 to 9.6 dBA (PC) from the N/A situation. This indicated that the sound level can only be significantly increased by when a large number of persons are involved in performing the activities. This result indicated that when there are a large number of persons, they can markedly increase the sound environment. In sections 4.2 and 4.3, we discuss that the effect of these activities on sound environment may lead to the different acoustic comfort of pedestrians.

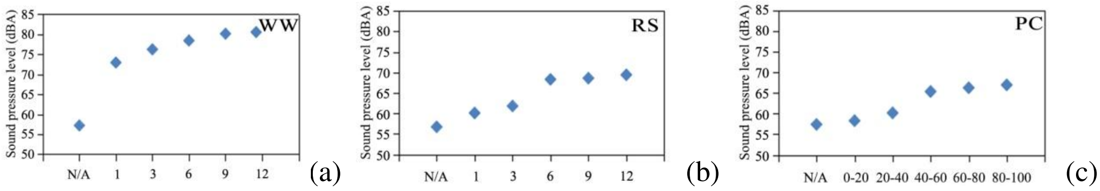
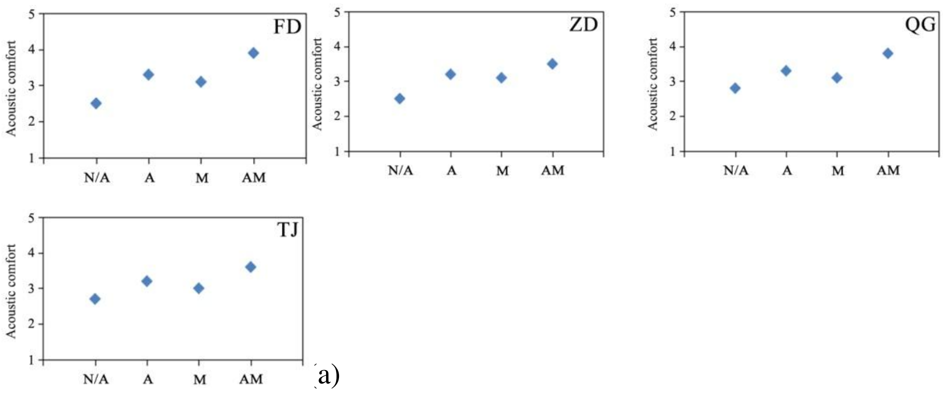


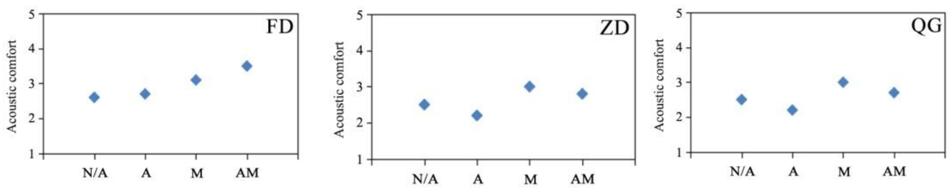
Figure 6. The sound pressure level with different human sound-related activities, where (a) indicates the sound pressure level of WW; (b) indicates the sound pressure level of RS; (c) indicates the sound pressure level of PC. N/A indicates neither music sound nor activities, the numbers indicate the number of persons.

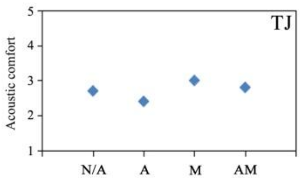
4.2 Effect on acoustic comfort

4.2.1 Music sound-related activities

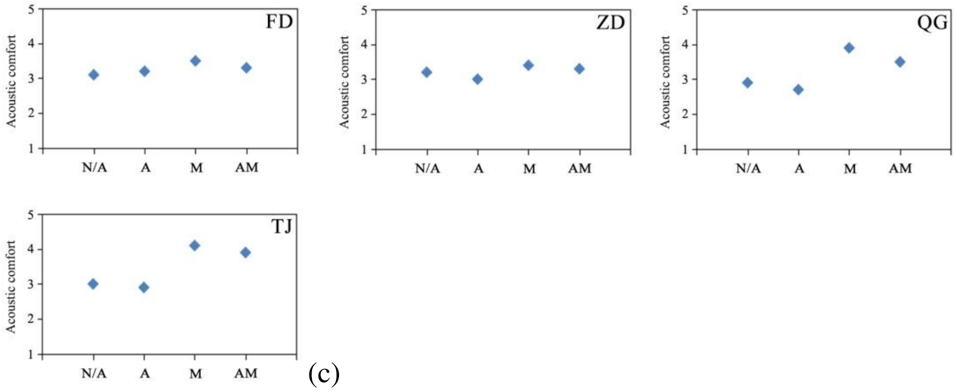
Figure 7 shows that the acoustic comfort of persons who stand watching can be increased by music sound-related activities; moreover, even if there are only activities without music or music without activities, the acoustic comfort of persons who stand watching can be increased from 0.5 to 0.7. Compared with the effect of activities without music on acoustic comfort, the effect of music without activities is slightly lower, 0.1–0.2 lower than activities without music. The effect of activities with music on acoustic comfort is much better than both music without activities and activities without music, that is, 0.3–0.6 higher. Compared with other music sound-related activities, the RD has the highest acoustic comfort for persons who stand watching (3.9), while the ZD has the lowest acoustic comfort for persons who stand watching (3.5).



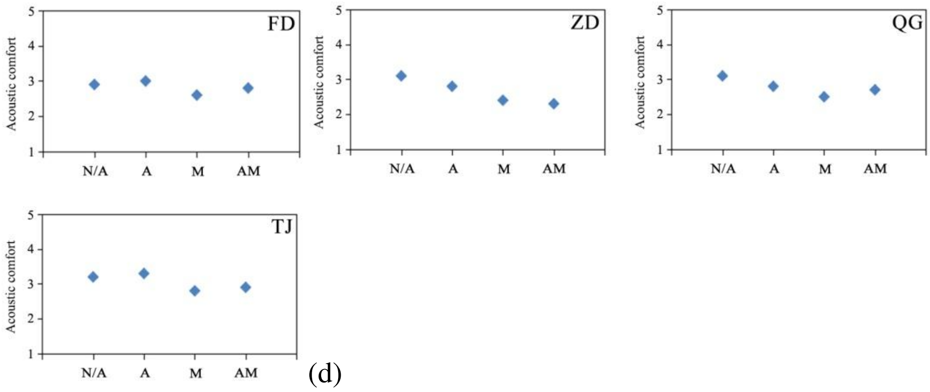




(b)



(c)



(d)

Figure 7. Acoustic comfort with different music-related activities, where (a) indicates the acoustic comfort of standing and watching with FD, ZD, QG, and TJ; (b) indicates the acoustic comfort of passing by with FD, ZD, QG, and TJ; (c) indicates the acoustic comfort of performing exercises with FD, ZD, QG, and TJ; (d) indicates the acoustic comfort of sitting with FD, ZD, QG, and TJ. N/A indicates neither music sound nor activities, A indicates activities without music, M indicates music without activities, and AM indicates activities with music.

For passing by behaviours, it is interesting to note that music with activities or without activities can give higher acoustic comfort to persons who pass by than activities alone or N/A situations. The mean difference between activities with and without music is from 0.3 to 0.7, with significant at $p<0.01$. The effect of music without activities and activities with music on acoustic comfort of persons who pass by is not significant ($p>0.1$). This result indicates that the music is a key point to provide higher acoustic comfort to the persons who pass by, regardless of the activities they are playing.

For exercise performing behaviour, the effect of music can provide higher acoustic comfort to most persons who perform exercises. It should be noted that the higher sound level of the music may cause lower acoustic comfort to persons who perform exercises, for example RK has the highest LAeq (75.9 dBA) but the lowest acoustic comfort (3.3) for persons who perform exercises, while TJ has the lowest LAeq (66.7 dBA) but the highest acoustic comfort (3.9) for persons who perform exercises. In addition, music without activities has better effect on the acoustic comfort of persons who perform exercises than activities with music, 0.1–0.4 higher than activities with music; the effect of N/A situation is also better than that of activities without music. This result indicates that persons who performed exercises preferred to ignore the other activities occurring near them.

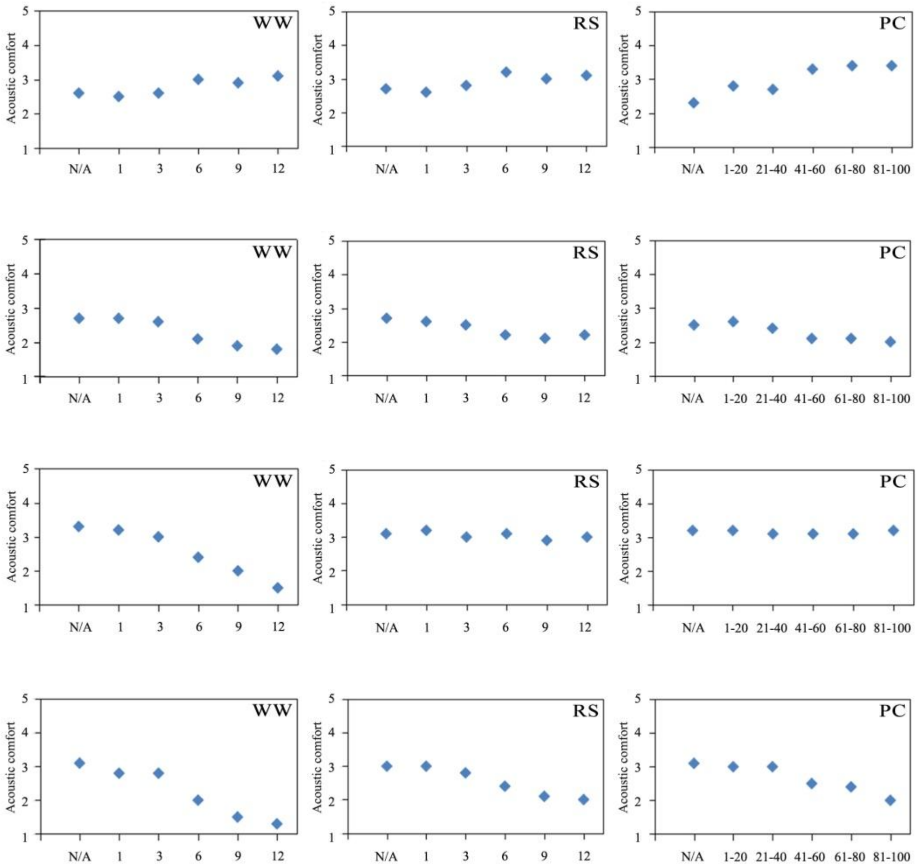
In contrast to exercise performing and passing by behaviours, the effect of music can have lower acoustic comfort for persons who sit, 0.2-0.6. Some interviewers' reply may explain the reason that the persons who sit usually want to talk with others, and the music may influence their subjective speech intelligibility; therefore, the sitting behaviour was reduced during activities with music or music without activities.

4.2.2 Human sound-related activities

Figure 8 shows that the acoustic comfort of persons who stand watching is relatively decreased when there are fewer persons who perform human sound-related activities, that is, the acoustic comfort of persons who stand watching near the WW activity is 2.5–2.6, when 1–3 persons perform this activity. When more number of persons are involved in human sound-related activities, the 'group effect', in which the persons doing the activities follow unified styles, the acoustic comfort of persons who stand watching increased, that is, the acoustic comfort of persons who stand watching near the WW activity was 2.9-3.1 when 6–12 persons performed this activity. It should be noted that when the number of persons who perform activities is relatively more, there is generally less change in the acoustic comfort of persons who stand watching. This result indicated that the continuous increase in the number of persons who perform activities does not lead to the continuous increase in the acoustic comfort of persons who stand watching.

The 'group effect' of human sound-related activities also influences the sitting or passing by behaviour of pedestrians. When the persons performing the activities reached a certain number, the acoustic comfort of persons who sat or passed greatly reduced. Considering the passing by behaviour as an example, from Figure 8, when the number of persons performing the activities is 1–3 (WW and RS) and 1–40 (PC), the acoustic comfort of persons with passing by behaviour is reduced only by 0.1 (WW), 0.1–0.2 (RS) and 0–0.1 (PC) from the N/A situation, while when the number of persons doing the activities is 6–12 (WW and RS) and 41–100 (PC), the acoustic comfort of persons with passing by behaviour reduced by 0.5–0.6 (WW), 0.4–0.5 (RS) and 0.4–0.5 (PC). The effect of activities that increased the number of persons with sitting or passing by behaviour is different. When the number of persons who perform activities was from 6 to 12 (WW and RS) and from 41 to 100 (PC), the acoustic comfort of persons who passed by did not change much, and reduced only by 0.1, while when the number of persons who performed activities was from 6 to 12 (WW and RS) and from 41 to 100 (PC), the acoustic comfort of persons who sat continuously reduced, that is, reduced by 0.7 (WW), 0.4 (RS) and 0.5 (PC). This result indicated that the continuous increase in the number of persons who performed activities can continuously influence the acoustic of persons who sit.

It is interesting to note that the human sound-related activities (example RS and PC) generally cannot influence the acoustic comfort of persons who perform excises, but WW can because this activity is too noisy.



(a) (b) (c) (d)

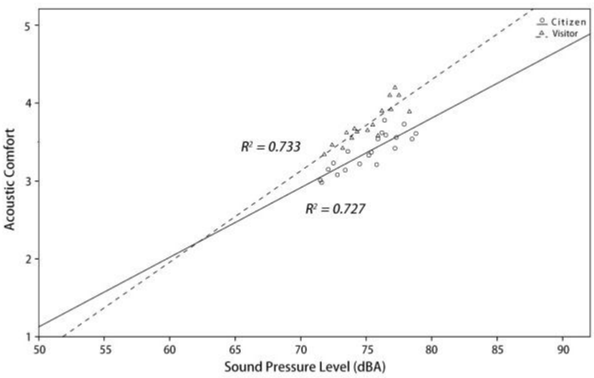
Figure 8. The acoustic comfort with different human sound-related activities, where (a) indicates the acoustic comfort of standing and watching with WW, RS, and PC; (b) indicates the acoustic comfort of passing by with WW, RS, and PC; (c) indicates the acoustic comfort of performing exercises with WW, RS, and PC; (d) indicates the acoustic comfort of sitting with WW, RS, and PC. N/A indicates neither music sound nor activities, the numbers indicates the number of persons.

4.3 Influence of social background

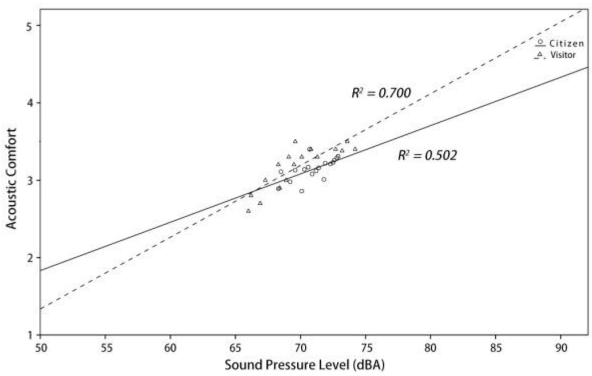
4.3.1 Differences between visitors and citizens

Since the visitors and citizens are two special groups of users, who may have different social background and behaviours, the acoustic comfort of visitors and citizens with different sound-related activities are also compared. Because the ZD activities did not have enough visitor examples, it is not analyzed in this section.

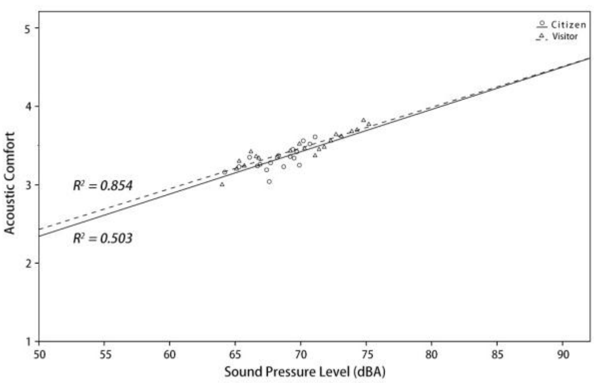
The relationships between acoustic comfort of visitors (dotted lines) and the measured LAeq as well as acoustic comfort of citizens (solid lines) with different sound-related activities are shown in Figure 9, where linear regressions and the coefficient of determination R^2 are also presented.



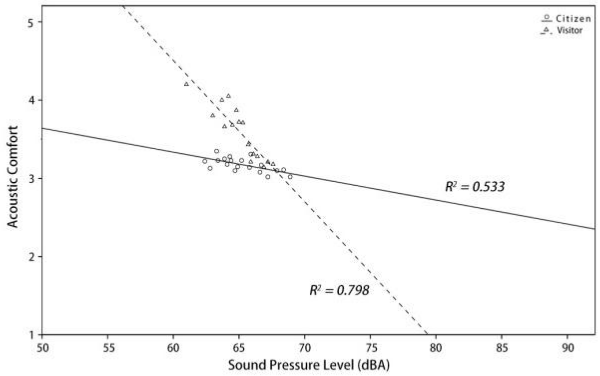
(a)



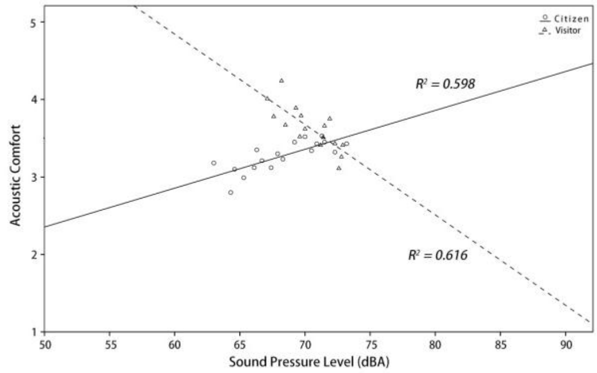
(b)



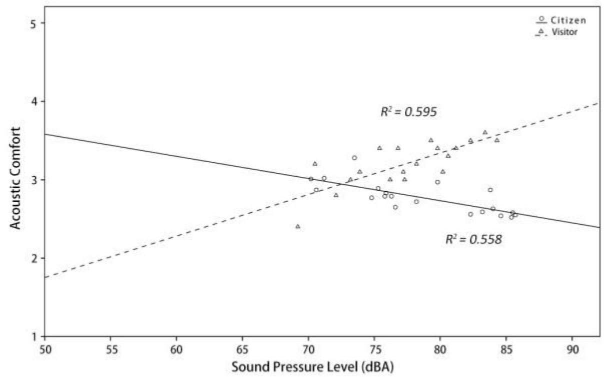
(c)



(d)



(e)



(f)

Figure 9. The relationship between sound pressure level of activities and the acoustic comfort of visitors and citizens, where the dotted line and circle represents visitors and the solid line and triangle represents citizens. (a) relationship between acoustic comfort and sound pressure level of FD; (b) relationship between acoustic comfort and sound pressure level of QG; (c) relationship between acoustic comfort and sound pressure level of TJ; (d) relationship between acoustic comfort and sound pressure level of RS; (e) relationship between acoustic comfort and sound pressure level of PC; (f) relationship between acoustic comfort and sound pressure level of WW.

From figure 9, it can be seen that there is a general correlation between the acoustic comfort of visitors and the measured sound level as well as the acoustic comfort of citizens

(p<0.001). With the increase in the measured sound level, the acoustic comfort of both the visitors and citizens is increased for RD, QJ, and TJ activities: coefficient of determination R^2 was 0.733 (visitors) and 0.727 (citizens), 0.700 (visitors) and 0.502 (citizens) and 0.854 (visitors) and 0.503 (citizens), respectively. This result indicated that the music-related soundscape activities generally can make acoustic comfort higher for both visitors and citizens, when their sound level increases. It is interesting to note that the acoustic comfort of visitors is higher than that of citizens. A possible reason is that the case site and these soundscape activities are familiar to the citizens who usually come here, but are fresh for visitors who may have come here for the first time; therefore, the difference in the feeling between visitors and citizens may have lead to this result.

With the increase in the measured sound level, the acoustic comfort of both the visitors and citizens decreases for RS activity; the coefficient of determination R^2 was 0.798 (visitors) and 0.533 (citizens). This result indicates that the noise from the RS, which is similar to traffic noise, is not generally accepted by both visitors and citizens. However, the acoustic comfort of visitors is also higher than that of citizens.

It is interesting to note that with the increase in the measured sound level, the acoustic comfort of citizens increased while that of visitors decreased for PC activity; the coefficient of determination R^2 was 0.798 (visitors) and 0.533 (citizens). A possible reason for this difference is that the PC activity itself is organized by citizens, although it usually increases the surrounding speech and even brings shouting and whistling; the citizen think about this as part of their daily life, but the visitors consider the case site as a beauty landscape and want to enjoy better environment. Because the aims of visitors are different from those of citizens, this may lead to the difference in acoustic comfort. The acoustic comfort of citizens and visitors is also opposite with regard to the WW activity. Different from PC activity, with the increase in the measured sound level, the acoustic comfort of citizens decreased while that of visitors increased; the coefficient of determination R^2 was 0.595 (visitors) and 0.558 (citizens). From the interview of citizens and visitors, the reason is that the citizens complain of noise from WW everyday, which is not meaningful noise and is different from music, but the visitor considered this activity as an interesting thing because they stand near the activity only for 10–20 min.

4.3.2 Other social factors

The mean difference in the evaluation of acoustic comfort was determined between males and females for every sound-related activities; as shown in Table 3, there is no significant difference (p>0.1) between males and females for sound-related activities. These results were consistent with those of previous studies which suggested that the effect of gender on sound annoyance evaluation is generally insignificant. It is interesting to note that the mean difference in acoustic comfort between males and females in WW is 0.22 and was significant (p<0.01); the reason may be that the WW activity is liked only by males, while most of the females do not like it. The age difference was significant (p<0.01 or p<0.05) with the correlation coefficient ranging from 0.12 to 0.30; for most sound-related activities, the acoustic comfort was higher when the pedestrians were older except for RS, which was preferred by younger persons. Income and education level difference was also significant ($p<0.01$ or $p<0.05$) in pedestrians' acoustic comfort, with the correlation coefficient ranging from 0.13 to 0.31 for income and 0.12 to 0.28 for education level for the chosen sound-related activities. It is interesting to note that the acoustic comfort was increased with the interviewees' higher income or education level for music sound-related activities, while it usually decreased with the interviewees' higher income or education level for human sound-related activities. This result indicates that the pedestrians with different income level have different preferences for sound-related activities.

Table 3. The relationship between acoustic comfort and the social background of pedestrians.

	Whipping a Whip	Roller Skidding	Folk Dancing	Zombie Dancing	Qing Gong	Playing Cards	Tai Ji
Sex	**0.22****	0.03	0.03	0.01	0.04	0.01	0.02
Age	0.07	**–0.16***	**0.30****	**0.14***	**0.12***	**0.22****	**0.23****
Income	**–0.15***	**–0.23****	**0.27****	**0.18****	**0.13***	**–0.31****	**0.30****
Education Level	**–0.12***	**–0.15***	**0.22****	**0.13***	**0.14***	**0.24****	**0.28****
Occupation	**0.22****	**0.19****	**0.25****	**0.15***	**0.12***	**0.25****	**0.21****

5. Conclusions

On the basis of measurements and a questionnaire survey conducted in a pedestrian street, the effect of sound-related activities on human behaviours and their evaluation of acoustic comfort were evaluated.

With regard to the effect of activities on pedestrians' behaviours, music-related activities caused an increase from 5.1% to 21.5% in the number of persons who passed by to stand and watch, while it is generally had little effect on the number of persons who performed exercises. The activities with music caused the pedestrians to focus much more than activities without music or music without activities. Human sound-related activities generally had little effect on the behaviours of pedestrians, when only 1 to 3 persons performed the activities, while it significantly affected the behaviours of pedestrians when more than 6 persons performed the activities. The percentage of persons who stood watching the activity increased when a large number of persons or a group was involved in the activities, and the WW and RS activities more easily allowed the pedestrians to focus than the PC activity. Furthermore, people who performed exercises were generally not influenced by human sound-related activities such as RS and PC.

With regard to the effect of activities on pedestrians' acoustic comforts, the music-related activities increased the sound level from 10.8 to 16.4 dBA, while the human sound-related activities such RS and PC increased the sound level from 9.6 to 12.8 dBA; this lead to a difference in acoustic comfort. With regard to the different behaviours of pedestrians, the acoustic comfort of persons who stood watching the activity increased by music sound-related activities, and for people with passing by behaviours, the music with activities or without activities yielded higher acoustic comfort than activities alone or N/A situation. The 'group effect' of human sound-related activities also influenced the sitting or passing by behaviours of the pedestrians. Moreover, the human sound-related activities generally cannot influence the acoustic comfort of persons performing exercises. On the basis of the difference in the aims of visitors and citizens, the acoustic comfort of citizens was increased while that of visitors was decreased with the increase in the measured sound level of PC activities; however, the acoustic comfort of visitors was increased while that of citizens was decreased with the increase in the measured sound level of WW activities. With regard to the other social backgrounds, persons with higher income or education level preferred music sound-related activities, while persons with lower income or education level preferred human sound-related activities.

***Acknowledgments*:** This work was funded by the State Natural Science Foundation of China (Project Number: 51678180).

References

Aucouturier, J. J., Defreville, B., & Pachet, F. (2007). The bag -of -frames approach to audio pattern recognition: A sufficient model for urban soundscapes but not for polyphonic music. The Journal of the Acoustical Society of America, 122(2), 881-891.

Barron, M. (2009). Auditorium acoustics and architectural design. Routledge.

Brown, A. L., Kang, J., & Gjestland, T. (2011). Towards standardization in soundscape preference assessment. Applied Acoustics, 72(6), 387-392.

Carles, J., Bernáldez, F., & Lucio, J. D. (1992). Audio - visual interactions and soundscape preferences. Landscape research, 17(2), 52-56.

Carles, J. L., Barrio, I. L., & de Lucio, J. V. (1999). Sound influence on landscape values. Landscape and urban planning, 43(4), 191-200.

Davies, W. J., Adams, M. D., Bruce, N. S., Cain, R., Carlyle, A., Cusack, P., Hall, D.A., Hume, K. I., Irwin, A., Jennings, P., Marselle, M., Plack, C.J. & Poxon, J. (2013). Perception of soundscapes: An interdisciplinary approach. Applied Acoustics, 74(2), 224-231.

Eriksson, L. J. (1991). Development of the filtered - U algorithm for active noise control. The Journal of the Acoustical Society of America, 89(1), 257-265.

Fastl, H. (2004). Audio-visual interactions in loudness evaluation. InProceedings of the 18th International Congress on Acoustics (Vol. 2, pp. 1161-1166). Kyoto Japan.

Forza, C. (2002). Survey research in operations management: a process-based perspective. International journal of operations & production management, 22(2), 152-194.

Frontczak, M., & Wargocki, P. (2011). Literature survey on how different factors influence human comfort in indoor environments. Building and Environment, 46(4), 922-937.

Guastavino, C. (2006). The ideal urban soundscape: Investigating the sound quality of French cities. Acta Acustica United with Acustica, 92(6), 945-951.

Guski, R. (1997). Psychological methods for evaluating sound quality and assessing acoustic information. Acta Acustica united with Acustica, 83(5), 765-774.

Hao, Y. Y., Kang, J., Krijnders, J. D. (2015) Integrated effects of urban morphology on birdsong loudness and visibility of green areas. Landscape and Urban Planning. 137, 149-162.

Hellbrück, J. (2000). Memory effects in loudness scaling of traffic noise. How overall loudness of short-term and long-term sounds depends on memory. The Journal of the Acoustical Society of Japan (E), 21(6), 329-332.

Hoffman, M. L. (1977). Sex differences in empathy and related behaviors.Psychological bulletin, 84(4), 712.

ISO, T. (2014). 43/SC 1/WG 54, 12913-1 Acoustics—Soundscape—Part 1: Definition and conceptual framework. International Standard Organization.

Iwamiya, S. I., & Yanagihara, M. (1998). Features of the soundscape in Fukuoka city, a major city in Japan, recognized by foreign residents. In INTER-NOISE and NOISE-CON Congress and Conference Proceedings (Vol. 1998, No. 6, pp. 83-88). Institute of Noise Control Engineering.

Kang, J. (2006). Urban sound environment. CRC Press.

Kang, J., & Zhang, M. (2010). Semantic differential analysis of the soundscape in urban open public spaces. Building and environment, 45(1), 150-157.

Kang, J., Meng, Q., & Jin, H. (2012). Effects of individual sound sources on the subjective loudness and acoustic comfort in underground shopping streets. Science of the Total Environment, 435, 80-89.

Lercher, P., & Schulte-Fortkamp, B. (2003). The relevance of soundscape research to the assessment of noise annoyance at the community level. In Proceedings of the Eighth International Congress on Noise as a Public Health Problem (pp. 225-231).

Litwin, M. S. (1995). How to measure survey reliability and validity (Vol. 7). Sage Publications.

Liu, J., Kang, J., Luo, T., & Behm, H. (2013). Landscape effects on soundscape experience in city parks. Science of the Total Environment, 454, 474-481.

Liu, J., Kang, J., Behm, H., & Luo, T. (2014a). Effects of landscape on soundscape perception: Soundwalks in city parks. Landscape and Urban Planning, 123, 30-40.

Liu, J., Kang, J., Behm, H., & Luo, T. (2014b). Landscape spatial pattern indices and soundscape perception in a multi-functional urban area, Germany. Journal of Environmental Engineering and Landscape Management, 22(3), 208-218.

Meng, Q., & Kang, J. (2013). Influence of social and behavioural characteristics of users on their evaluation of subjective loudness and acoustic comfort in shopping malls. PloS one, 8(1), e54497.

Meng, Q., Kang, J., & Jin, H. (2013). Field study on the influence of spatial and environmental characteristics on the evaluation of subjective loudness and acoustic comfort in underground shopping streets. Applied Acoustics, 74(8), 1001-1009.

Meng, Q., & Kang, J. (2015). The influence of crowd density on the sound environment of commercial pedestrian streets. Science of the Total Environment, 511, 249-258.

Parsons, S., & Towsey, M. W. (2012). Report on a workshop to investigate the current status of environmental bio-acoustic monitoring.

Pearce, P. L. (2013). The social psychology of tourist behaviour: International Series in Experimental Social Psychology (Vol. 3). Elsevier.

Rajeswari, R., Muniyandi, M., Balasubramanian, R., & Narayanan, P. R. (2005). Perceptions of tuberculosis patients about their physical, mental and social well-being: a field report from south India. Social science & medicine,60(8), 1845-1853.

Ren, X., & Kang, J. (2015). Effects of soundscape on rural landscape perception: Landscape visual aesthetic quality and landscape tranquillity of rural landscapes in China. facilities, 1, 0-84.

Snowdon, D., Churchill, E. F., & Munro, A. J. (2001). Collaborative virtual environments: Digital spaces and places for CSCW: An introduction. In Collaborative virtual environments (pp. 3-17). Springer London.

Southworth, M. (1969). The sonic environment of cities. Environment and behavior, 1(1), 49.

Tamura, A. (1998). An environmental index based on inhabitants' recognition of sounds. Proceedings of Noise Effects '98, November, 22-26.

Thwaites, K., Helleur, E., & Simkins, I. M. (2005). Restorative urban open space: Exploring the spatial configuration of human emotional fulfilment in urban open space. Landscape Research, 30(4), 525-547

Tuan, Y. F. (2013). Topophilia: A study of environmental perceptions, attitudes, and values. Columbia University Press.

Vincent, E., Gribonval, R., & Févotte, C. (2006). Performance measurement in blind audio source separation. Audio, Speech, and Language Processing, IEEE Transactions on, 14(4), 1462-1469.

Viollon, S., & Lavandier, C. (2000). Multidimensional assessment of the acoustic quality of urban environments. In Conf. proceedings "Internoise", Nice, France, 27-30 Aug (Vol. 4, pp. 2279-2284).

Viollon, S., Lavandier, C., & Drake, C. (2002). Influence of visual setting on sound ratings in an urban environment. Applied acoustics, 63(5), 493-511.

Yang, W., & Kang, J. (2005). Soundscape and sound preferences in urban squares: a case study in Sheffield. Journal of Urban Design, 10(1), 61-80.

Yao, Y. F. (2004). The Study on the Aesthetics in Contemporary Urban Park and its Landscape Planning. Journal of Capital Normal University, 1, 013.

Yin, H.J., Liu, E. (2008). SPSS15.0 for Windows. Social Sciences Academic Press, Beijing, China (in Chinese).

Yu, L., & Kang, J. (2009). Modeling subjective evaluation of soundscape quality in urban open spaces: An artificial neural network approach. The Journal of the Acoustical Society of America, 126(3), 1163-1174.

Yu, L., & Kang, J. (2010). Factors influencing the sound preference in urban open spaces. Applied Acoustics, 71(7), 622-633.

Zahorik, P. (2002). Assessing auditory distance perception using virtual acoustics. The Journal of the Acoustical Society of America, 111(4), 1832-1846.

Zhang, Y., Yang, Z., & Yu, X. (2006). Measurement and evaluation of interactions in complex urban ecosystem. Ecological modelling, 196(1), 77-89.

Zhang, M., & Kang, J. (2007). Towards the evaluation, description, and creation of soundscapes in urban open spaces. Environment and Planning B: Planning and Design, 34(1), 68-86.

Zwicker, E., & Fastl, H. (2013). Psychoacoustics: Facts and models (Vol. 22). Springer Science & Business Media.