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Effects of Individual Sound Sources on the Subjective Loudness and Acoustic Comfort in Underground Shopping Streets

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Abstract

Previous studies have demonstrated that human evaluation of subjective loudness and acoustic comfort depends on a series of factors in a particular situation rather than only on sound pressure levels. In the present study, a large-scale subjective survey has been undertaken on underground shopping streets in Harbin, China, to determine how individual sound sources influence subjective loudness and acoustic comfort evaluation. Based on the analysis of case study results, it has been shown that all individual sound sources can increase subjective loudness to a certain degree. However, their levels of influence on acoustic comfort are different. Background music and the public address system can increase acoustic comfort, with a mean difference of 0.18 to 0.32 and 0.21 to 0.27, respectively, where a five-point bipolar category scale is used. Music from shops and vendor shouts can decrease acoustic comfort, with a mean difference of -0.11 to -0.38 and -0.39 to -0.62, respectively. The feasibility of improving acoustic comfort by changing certain sound sources is thus demonstrated.

Keywords: Sound source; underground shopping street; subjective loudness; acoustic comfort

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1. Introduction

Underground shopping streets are very common in China, and acoustic problems have become one of the major research topics as a result of the construction of underground shopping streets in recent years (Wang, 2000). Although several studies on reducing noise in underground shopping streets (Tong, 1996; CAE, 2001; Ding, 2008) have been conducted, other studies suggest that the human evaluation of subjective loudness and acoustic comfort depends on a series of factors, such as individual sound sources, social characteristics of users, and general environment, rather than on sound levels only (Schafer 1977; Gaver, 1993; Dubois, 2000; Yang and Kang, 2005; Zhang and Kang, 2007; Mao, 2009; Joynt and Kang, 2010; Kang and Zhang, 2010). In the current study, several main sound sources, such as background music, music from shops, public address (PA) system, and vendor shouts in underground shopping streets, are analysed to determine their influence on subjective loudness and acoustic comfort.

2. Methodology

A field study was conducted through a questionnaire survey at selected case study sites in Harbin, China. The locations for conducting the survey were in five typical underground shopping streets, namely, Shi Tou Dao (street type), Le Song (street type), Qiu Lin (street type), Hui Zhan (square type), and Harbin Railway Station (square type) underground shopping streets. In terms of subjective investigation, more than 2,800 valid questionnaires were obtained from the winter of 2007 to the autumn of 2008 in these underground shopping streets. Around 400 to 600 interviews were conducted at each site using the same questionnaires. 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 (Meng, 2010). The correlations between these factors and subjective loudness as well as acoustic comfort are shown in Table 1. The surveys covered four seasons (Kang, 2006), and were conducted at varying times from morning to evening, which were separated into three periods: 09:00 to 11:59, 12:00 to 14:59, and 15:00 to 18:00. A five-point bipolar category scale was used in the questionnaire design. Subjective loudness was divided into five levels: 1, very quiet; 2, quiet; 3, neither quiet nor noisy; 4, noisy; and 5, very noisy. 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 (Meng, 2010). Before filling the questionnaire, the interviewees were asked to spend one to two minutes to evaluate the subjective loudness and acoustic comfort (Yu and Kang, 2008). Considering the interviewees need a period of time to appreciate the sound environment (Szeremeta et al, 2009), those users who were in the underground shopping streets for less than half an hour were not interviewed. The survey

locations were distributed evenly in every underground shopping street to ensure that typical areas were considered. Figure 1 shows the plans of two typical underground shopping streets, namely Shi Tou Dao and Harbin Railway Station. The surveys were conducted every 10 minutes in these survey locations to ensure stochastic behaviour in the survey.

Table1. The correlations between other factor and subjective loudness as well as acoustic comfort.

Variables		Subjective loudness					Acoustic comfort				
		Shi Tou Dao	Harbin Railway Station	Qiu Lin	Hui Zhan	Le Song	Shi Tou Dao	Harbin Railway Station	Qiu Lin	Hui Zhan	Le Song
Users' social backgrounds	Gender	0.05	-0.24*	0.13	0.01	0.00	-0.19*	-0.15	-0.05	-0.07	0.03
	Age	-0.06	0.08	0.10	-0.01	-0.02	-0.03	-0.01	-0.01	-0.05	0.09
	Income	0.38**	0.12**	0.21**	0.30**	0.26**	-0.45**	-0.44**	-0.52**	-0.51**	-0.37**
	Education	0.20**	0.06	0.07	0.04	0.05	-0.32**	-0.41**	-0.39**	-0.45**	-0.40**
	Occupation	0.22**	0.27**	0.19**	0.13	0.19**	0.19**	0.17	0.18*	0.16*	0.17**
Users' behaviours	Aim of coming	0.15**	0.19**	0.13*	0.18**	0.17**	0.10	0.13**	0.10	0.09	0.16**
	Frequency of coming	-0.29**	-0.37**	-0.20**	-0.18**	-0.30**	0.20**	0.16**	0.18**	0.13**	0.26**
	Seasons	0.08	0.18	0.15	0.17	0.20**	0.23*	0.18*	0.19*	0.18	0.19**
	Visit time	0.04	0.02	0.02	0.03	0.05	0.09	0.11	0.04	0.08	0.10
	Stay time	-0.16**	-0.32**	-0.08	-0.14**	-0.33**	0.06	0.27**	0.22**	-0.01	0.12*
	Partners	0.03	-0.31**	0.08	0.10*	-0.04	-0.09	0.01	0.11	-0.01	-0.12
Environmental variables	Density of people	0.27**	0.30**	0.34**	0.36**	0.38**	-0.21**	-0.16**	-0.15**	-0.19**	-0.17**
	SPL	0.69**	0.64**	0.74**	0.64**	0.79**	-0.26**	-0.39**	-0.25**	-0.16**	-0.21**
	Air temperature	-0.02	0.01	-0.11**	-0.01	-0.06	0.13**	0.04	0.05	0.09	0.07
	Relative humidity	-0.10	-0.29**	0.30**	0.26**	-0.33**	0.16**	0.35**	-0.32**	-0.33**	0.23*
	Horizontal luminance	0.02	-0.07	-0.11**	-0.10*	0.23**	0.32**	0.18**	0.27**	0.23**	0.29**
	Reverberation	-0.03	0.25**	0.30**	0.03	-0.09	-0.27**	-0.23**	-0.34**	-0.32**	-0.10**

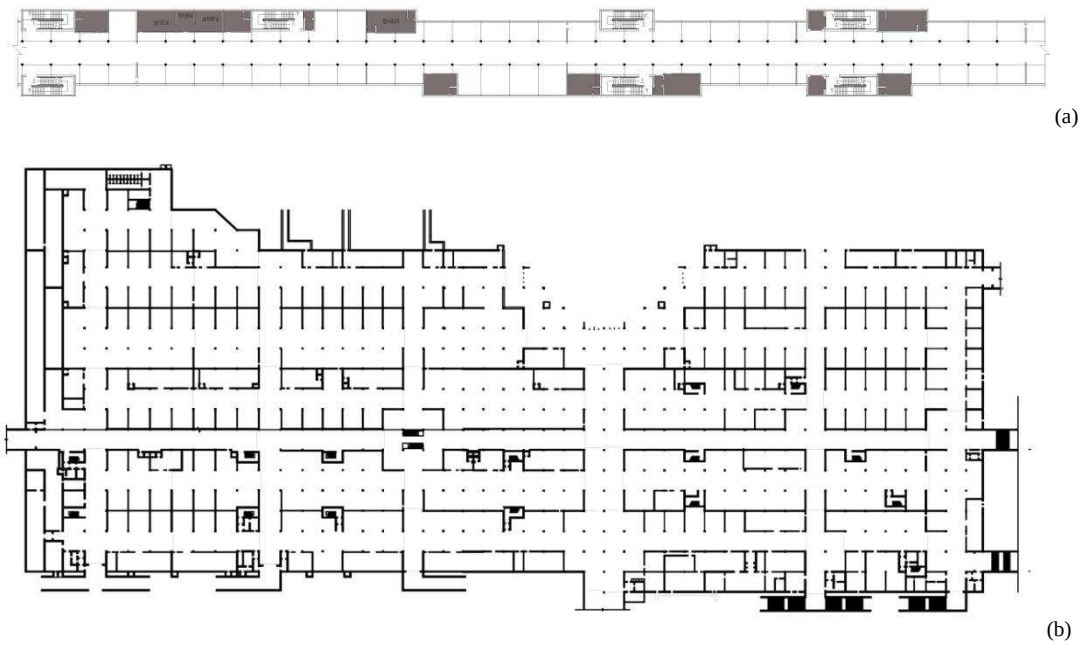


Figure 1. Plans of the Shi Tou Dao (a) and Harbin Railway Station (b) underground shopping streets indicating the survey locations

The SPSS 14.0 software was used to establish a database of all results. T-test (two-tailed) was used for factors with two scales, such as subjective loudness with any sound or without sound.

3. Results and Analysis

Interviewees were asked to describe up to 5 sounds they heard in the underground shopping streets during the interview, and to note the three sounds they heard at first (Yu and Kang, 2009). In the analysis below, if a sound was listed by the interviewee as one of the 5 heard sounds, it is called "with the sound", whereas if a sound was not listed by the interviewee, it is called "without the sound".

The statistical analysis of the survey results reveals four sound sources that were cited most frequently (>600 times) by the interviewees in the questionnaire survey. These sources are background music (1485 times), music from shops (1077 times), PA system (942 times), and vendor shouts (880 times). This section focuses on the relationships between these sounds and subjective loudness or acoustic comfort.

3.1. Background Music

In all survey sites, subjective loudness is higher with background music than without, with a mean difference of 0.21 in Shi Tou Dao ($p \leq 0.01$), 0.08 in Harbin Railway Station ($p \leq 0.05$), 0.24 in Qiu Lin ($p \leq 0.01$), 0.19 in Hui Zhan ($p \leq 0.01$), and 0.11 in Le Song ($p \leq 0.05$). Subjective loudness is also different in every survey location. For example, in Shi Tou Dao, the subjective loudness with background music ranges from 2.20 to 3.80, and that without

background music ranges from 1.80 to 3.50. In Harbin Railway Station, the subjective loudness with background music ranges from 2.00 to 3.40, and that without background music ranges from 2.10 to 3.30, as shown in Figure 2.

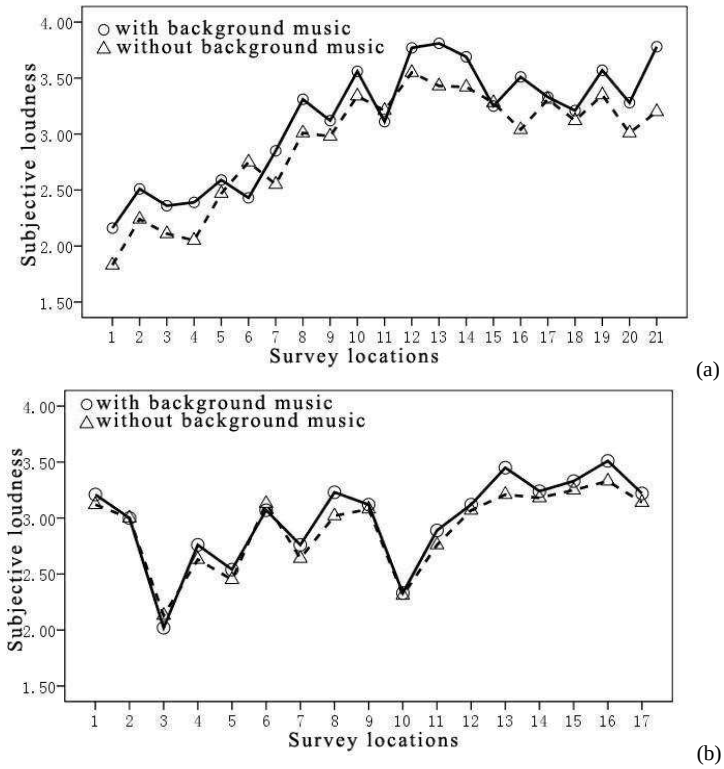
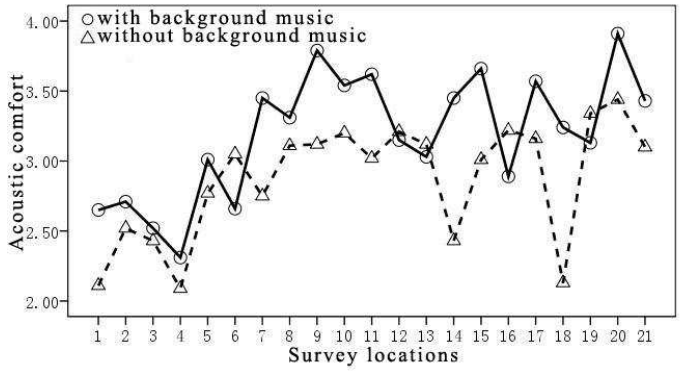
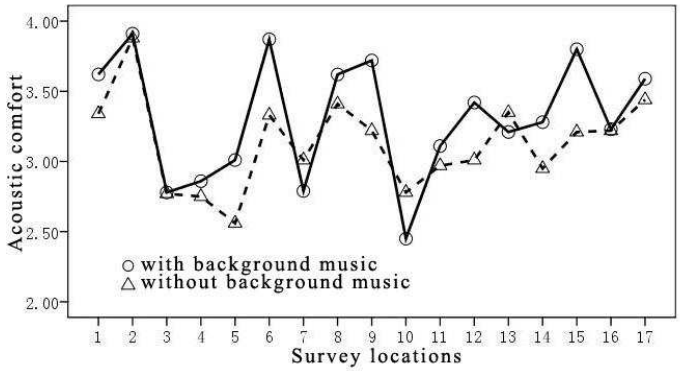


Figure 2. Influence of background music on the subjective loudness evaluation in Shi Tou Dao (a) and Harbin Railway Station (b) underground shopping streets

Acoustic comfort is also higher with background music than without background music, with a mean difference of 0.32 in Shi Tou Dao ($p \leq 0.01$), 0.18 in Harbin Railway Station ($p \leq 0.05$), 0.22 in Qiu Lin ($p \leq 0.01$), 0.29 in Hui Zhan ($p \leq 0.01$), and 0.26 in Le Song ($p \leq 0.01$). Acoustic comfort is also different in every survey location. For example, in Shi Tou Dao, the acoustic comfort with background music ranges from 2.30 to 3.90, whereas without background music it ranges from 2.20 to 3.40. In Harbin Railway Station, the acoustic comfort with background music ranges from 2.40 to 3.90, whereas without background music it ranges from 2.60 to 3.40, as shown in Figure 3.



(a)



(b)

Figure 3. Influence of background music on the acoustic comfort evaluation in Shi Tou Dao (a) and Harbin Railway Station (b) underground shopping streets

3.2. Music from Shops

In all survey sites, subjective loudness is higher with than without music from shops, with a mean difference of 0.36 in Shi Tou Dao ($p \leq 0.01$), 0.64 in Harbin Railway Station ($p \leq 0.01$), 0.28 in Qiu Lin ($p \leq 0.01$), 0.34 in Hui Zhan($p \leq 0.01$), and 0.40 in Le Song ($p \leq 0.01$). Subjective loudness also varies in every survey location. In Shi Tou Dao, the subjective loudness with music from shops ranges from 3.20 to 3.90, whereas that without music from shops ranges from 2.70 to 3.40. In Harbin Railway Station, the subjective loudness with music from shops ranges from 3.30 to 4.20, whereas that without music from shops is 2.50 to 3.40, as shown in Figure 4.

Acoustic comfort, however, is lower with music from shops than that without in most survey sites, with a mean difference of -0.38 in Harbin Railway Station ($p \leq 0.01$), -0.11 in Qiu Lin ($p \leq 0.05$), -0.20 in Hui Zhan ($p \leq 0.05$), and -0.28 in Le Song ($p \leq 0.05$). The mean difference of acoustic comfort is not significant in Shi Tou Dao, and acoustic comfort lacks regularity with or without music from shops. In Harbin Railway Station, the acoustic comfort with music from shops ranges from 2.40 to 3.90, whereas that without music from shops is 2.60 to 3.40, as shown in Figure 5.

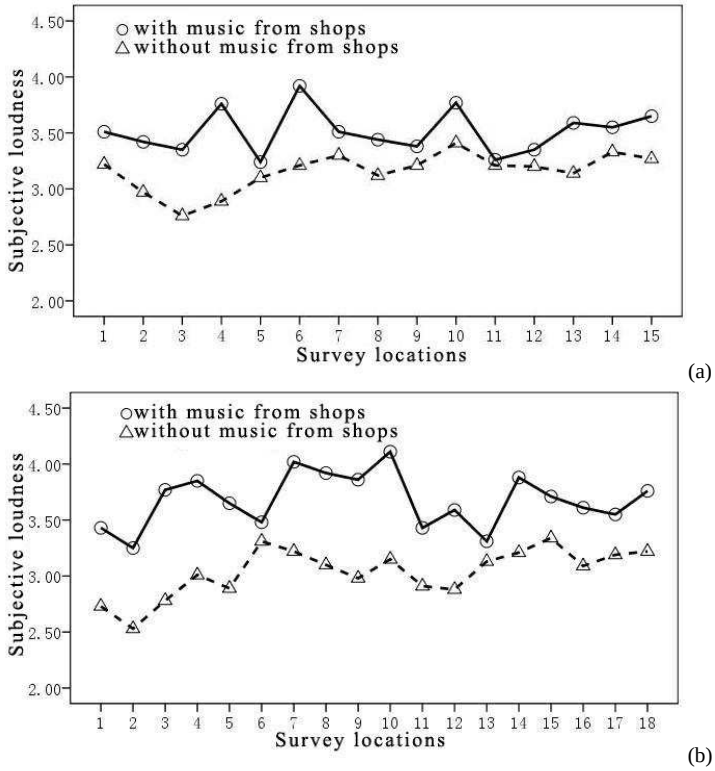


Figure 4. Influence of music from shops on the subjective loudness evaluation in Shi Tou Dao (a) and Harbin Railway Station (b) underground shopping streets

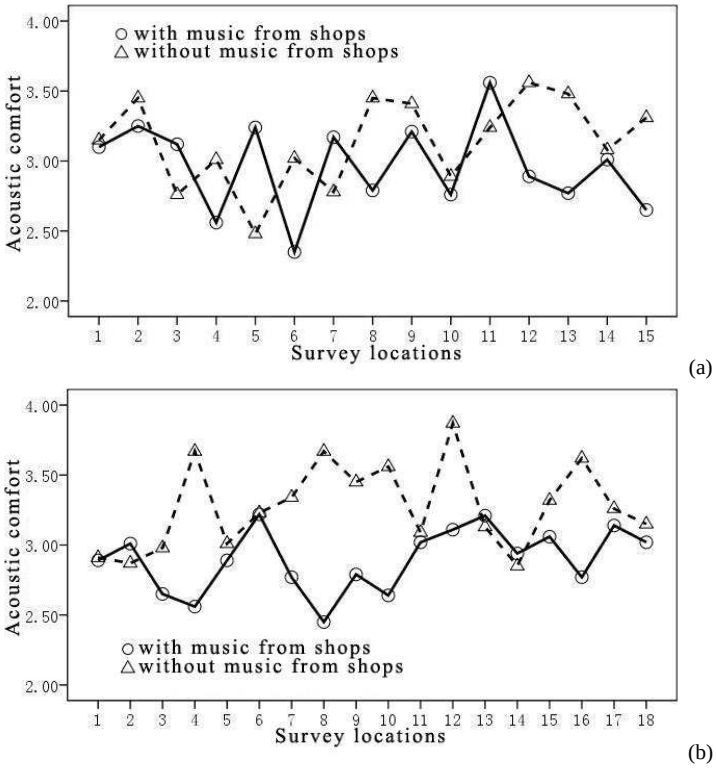
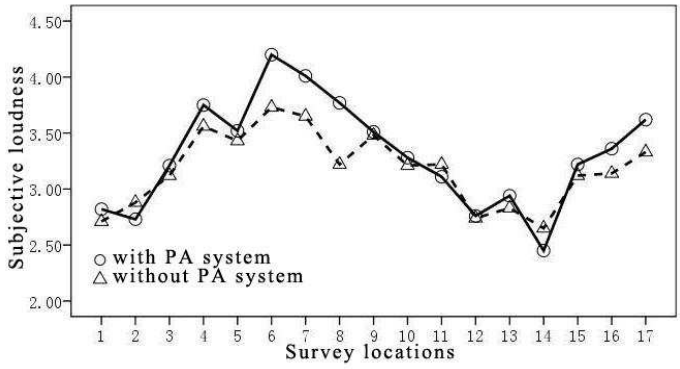


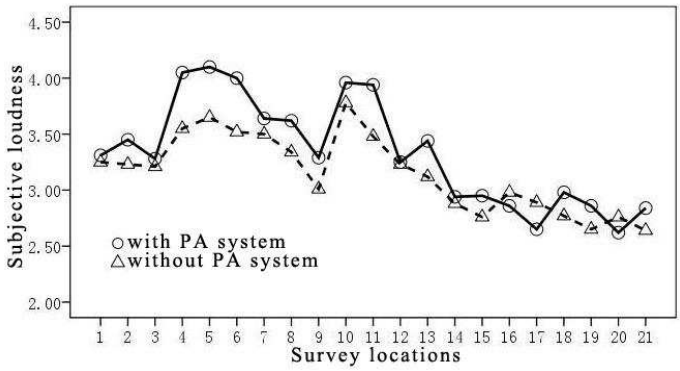
Figure 5. Influence of music from shops on the acoustic comfort evaluation in Shi Tou Dao (a) and Harbin Railway Station (b) underground shopping streets

3.3. PA System

In all survey sites, the subjective loudness with the PA system is higher than that without, with a mean difference of 0.20 in Shi Tou Dao ($p \leq 0.01$), 0.20 in Hui Zhan ($p \leq 0.01$), and 0.15 in Le Song ($p \leq 0.05$). It is noted that the PA system did not work in Qiu Lin and Harbin Railway Station. Subjective loudness also varies in every survey location. In Shi Tou Dao, the subjective loudness with the PA system ranges from 2.40 to 4.30, whereas that without the PA system ranges from 2.60 to 3.70. In Hui Zhan, the subjective loudness with the PA system ranges from 2.60 to 4.10, whereas that without the PA system ranges from 2.70 to 3.80, as shown in Figure 6. The influence on subjective loudness by the PA system is lower than that by music from shops in several locations because the music from shops was too loud that the PA system could not be heard by the interviewees.



(a)



(b)

Acoustic comfort is also higher with the PA system than that without, with a mean difference of 0.27 in Shi Tou Dao ($p \leq 0.01$), 0.25 in Hui Zhan ($p \leq 0.01$), and 0.21 in Le Song ($p \leq 0.01$). The influence on acoustic comfort by the PA system is lower than that by background music, although their levels of influence on subjective loudness are nearly the same. In Shi Tou Dao, the acoustic comfort with the PA system ranges from 2.20 to 3.80, whereas that without the PA system is from 2.10 to 3.60. In Hui Zhan, the acoustic comfort with the PA system ranges from 2.60 to 3.90, whereas that without the PA system is 2.90 to 3.70, as shown in Figure 7. Based on the questionnaire survey, many interviewees considered the PA system helpful in obtaining shopping information, whereas others considered the PA system annoying because of repetition. Therefore, a decrease in the PA system's repetitive information may increase the acoustic comfort of the users.

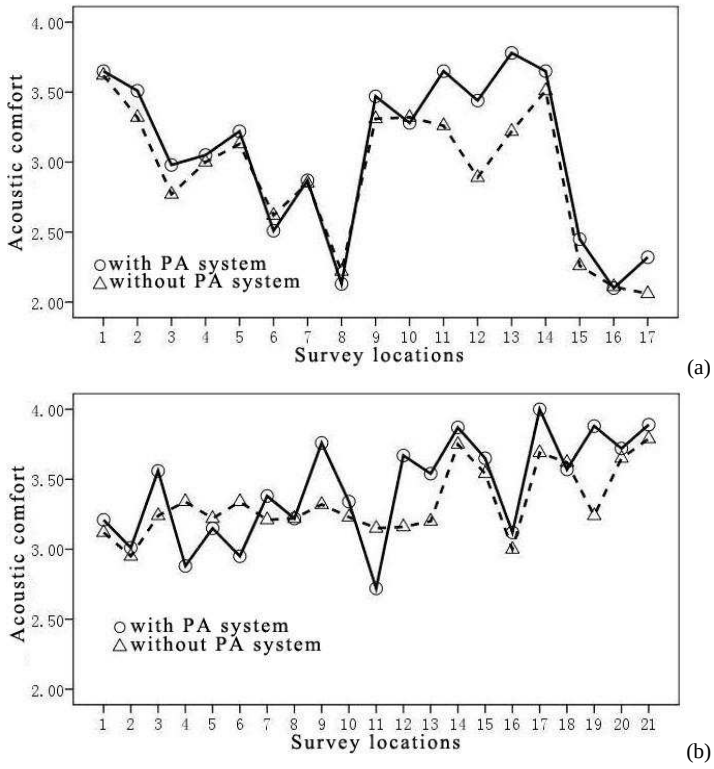


Figure 7. Influence of the PA system on the acoustic comfort evaluation in Shi Tou Dao (a) and Hui Zhan (b) underground shopping streets

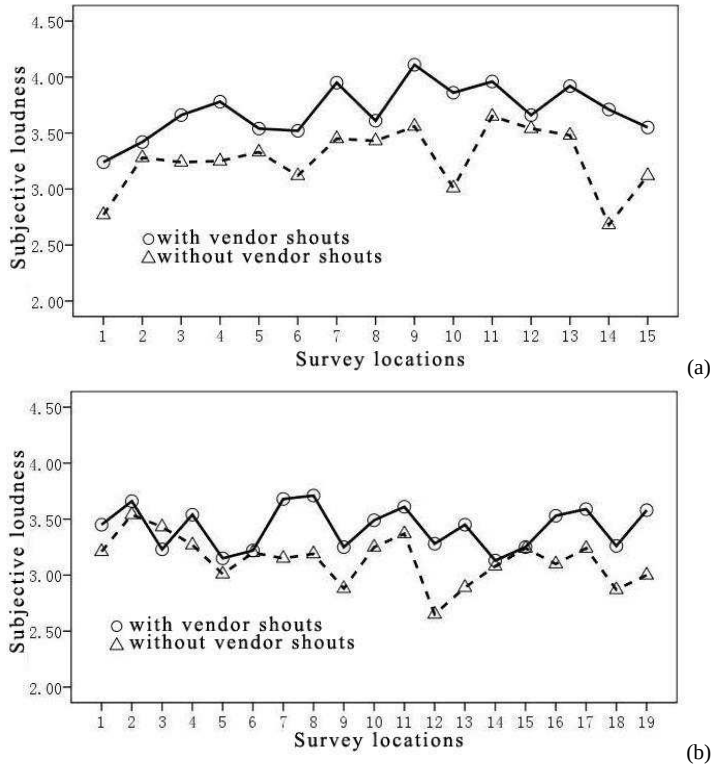


Figure 8. Influence of vendor shouts on the subjective loudness evaluation ion Qiu Lin (a) and Harbin Railway Station (b) underground shopping streets

3.4. Vendor Shouts

In several underground shopping streets where the PA system does not work, such as Qiu Lin and Harbin Railway Station, vendors have to shout to attract the attention of customers. In these survey sites, subjective loudness is higher with vendor shouts than without vendor shouts, as expected, with a mean difference of 0.43 in Qiu Lin ($p \leq 0.01$), and 0.29 in Harbin Railway Station ($p \leq 0.01$). In Qiu Lin, the subjective loudness is 3.30 to 4.00 with vendor shouts, whereas that without vendor shouts is 2.60 to 3.60. In Harbin Railway Station, the subjective loudness with vendor shouts ranges from 3.10 to 3.70, whereas that without vendor shouts is 2.60 to 3.40, as shown in Figure 8.

However, the acoustic comfort with vendor shouts is lower than without in most survey sites, with a mean difference of -0.62 in Qiu Lin ($p \leq 0.01$), and -0.39 in Harbin Railway Station ($p \leq 0.01$). In Qiu Lin, the acoustic comfort with vendor shouts ranges from 2.20 to 3.30, whereas that without vendor shouts is 3.10 to 3.90. In Harbin Railway Station, the acoustic comfort with vendor shouts ranges from 2.60 to 3.40, whereas that without vendor shouts is 3.00 to 3.70, as shown in Figure 9. Comparing the PA system and vendor shouts, which have the same goal of providing shopping information, the latter is usually considered as noise, hence causing discomfort to respondents. Therefore, a PA system instead of vendor shouts may be a better way to increase acoustic comfort.

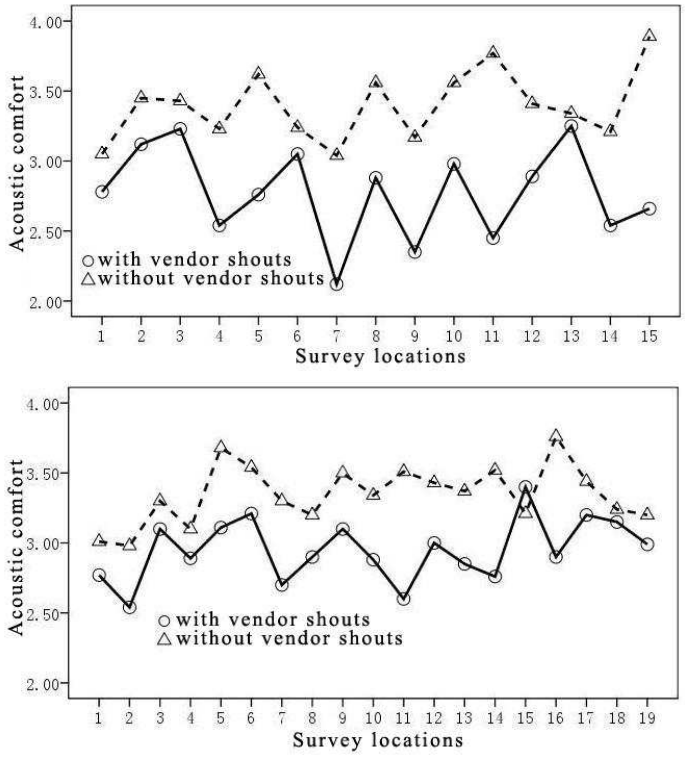


Figure 9. Influence of vendor shouts on the acoustic comfort evaluation in Qiu Lin (a) and Harbin Railway Station (b) underground shopping street

6. Conclusions

Based on the analysis of the case study results, all individual sound sources can increase subjective loudness to a certain degree in underground shopping streets. However, their levels of influence on acoustic comfort are different. Background music and the PA system can increase acoustic comfort, with a mean difference of 0.18 to 0.32 and 0.21 to 0.27, respectively. Music from shops and vendor shouts can decrease acoustic comfort, with a mean difference of -0.11 to -0.38 and -0.39 to -0.62, respectively.

These results can enhance knowledge on the effect of individual sound sources. With these results, acoustic comfort can be improved by changing certain sound sources.

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