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Effect of Temporary Open-Air Markets on the Sound Environment and Acoustic Perception Based on the Crowd Density Characteristics

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Abstract

The sound environment and acoustic perception of open-air markets, which are very common in high-density urban open spaces, play important roles in terms of the urban soundscape. Based on objective and subjective measurements of a typical temporary open-air market in Harbin city, China, the effects of the temporary open-air market on the sound environment and acoustic perception were studied, considering different crowd densities. It was observed that a temporary open-air market without zoning increases the sound pressure level and subjective loudness by 2.4 dBA and 0.21 dBA, respectively, compared to the absence of a temporary market. Different from the sound pressure level and subjective loudness, the relationship between crowd density and the perceived acoustic comfort is parabolic. Regarding the effect of a temporary open-air market with different zones on the sound environment and acoustic perception, when the crowd densities were the same, subjective loudness in the fruit and vegetable sales area was always higher than in the food sales area and the clothing sales area. In terms of acoustic comfort, with an increase in crowd density, acoustic comfort in the fruit and vegetable sales area decreased, and acoustic comfort in the food sales area and the clothing sales area exhibited a parabolic change trend of increase followed by decrease. Overall, acoustic comfort can be effectively improved by better planning temporary open-air markets in high-density urban open spaces.

Keywords: temporary open-air market; crowd density; acoustic perception; sound pressure level; acoustic comfort

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1. **Introduction**

"Temporary open-air markets" refers to a business type that is present in public spaces, such as streets, squares, or specific buildings, during a certain time period under effective control (Tangires, 2008). Such markets have a long history in time. Their earliest recorded appearance can be traced back to the sixth century BC (Hsieh & Chang, 2006). In high-density cities in Asian countries such as China and Japan, temporary open-air markets are common: nearly every 10 blocks has (or once had) a temporary open-air market (Suminski, Poston, Market, Hyder, & Sara, 2008). Studies indicate that 75% of all residents in these countries visit a temporary open-air market weekly (Susskind & Edwin, 2000). Temporary open-air markets are also places where tourists can experience a local area's characteristic cultural life (Zakariya, 2011). However, because of negligent management, the perception by nearby residents of the sound environment of temporary open-air markets is not ideal (Carles, Barrio, & de Lucio, 1999; Guéguen, Jacob, Lourel, & Guellec, 2007). Therefore, how to improve the sound environment in temporary open-air markets has become an issue that must be addressed by urban planners and the government.

The sound environment and acoustic perception in urban open spaces exhibit typical and variant features. For example, studies have demonstrated that the chirping of birds, church bells, the sound of running water, and the joyful shouts of children are sounds that people enjoy hearing in squares with recreational functions. In squares with commercial functions, the sound of music being played outdoors and inside shops is appreciated (Kang, 2007). Bruce and Davies (2011) demonstrated that the function of the soundscapes of religious spaces, commercial spaces, distribution spaces, and traffic spaces in historical districts exhibits clear differences. In commercial spaces, the design of the sound environment plays an important role in the creation of a commercial atmosphere (So & Kimura, 1998; Hao, Kang, & Krijnders, 2015). In addition, background music in shopping spaces effectively increases the acoustic comfort of shoppers. In contrast, the sound of hawkers promoting their wares decreases acoustic comfort (Song, Jin, & Kang, 2011). Meng and Kang (2015) found that human acoustic comfort is associated with the type of sound source. The acoustic comfort created by natural sounds is the most preferable, whereas the acoustic comfort of traffic sounds and mechanical sounds is the least preferable. Several researchers have begun to utilise the typicality and variance of sound sources in soundscape design (Song & Ma, 2012; Song, Yu, Zhang, & Ma, 2012). Different from general urban open spaces, temporary open-air markets are characterised by temporariness (Pottiesherman, 2013) and cannot exist independently. They are the product of human behavioural activity (Zakariya, 2011; Mohamad, Abdul, & Zakariya, 2015). Therefore, studies on the sound environment of open spaces should consider such activities.

The differences between the activities that occur in different zones also affect the sound environment and acoustic perception (Meng & Kang, 2016). Some previous studies revealed that the perception of traffic noise differs substantially from that of musical sounds (Wells, Evans, & Cheek, 2016; Quintero & Ferrer, 2015). In addition, music-related human activities may increase the sound pressure level by 10.8-16.4 dBA, while non-music-related human activities may increase the sound pressure level by 9.6-12.8 dBA (Meng & Kang, 2016). Studies on urban park soundscapes indicate that recreational areas and quiet areas are characterised by low-frequency sounds. However, in more active areas, intermediate-frequency sounds are more evident (Joo, Gage, & Kasten, 2011; Li, Xie, & Kang, 2014). Adding temporary water landscape experiences to urban open spaces effectively increases their acoustic comfort (You, Lee, & Jin, 2010; Jin, Lee, You, & Kang, 2012). Several studies also indicate that a variety of temporary activities in parks could alter the visual and auditory attention of tourists (Pirotta, New, Harwood, & Lusseau, 2014). The cited studies indicate that different functional zones in temporary open-air markets may differently affect the sound environment and acoustic perception.

A crowd is a special type of sound source (Crisler, 1976). In addition, a crowd also has a sound-absorption effect (Long, 2006). Therefore, crowd density may also affect the sound environment of urban open spaces (Meng & Kang, 2015). A number of studies indicate that the crowd density and the sound level of urban open spaces are strongly associated (Hayne, Rumble,

& Mee, 2006; Hayne, Taylor, Rumble, & Mee, 2011). In certain typical urban open spaces, crowd density can affect not only objective acoustic indicators, such as speech articulation and reverberation time (Zhang, 2010), but also subjective acoustic perception (Meng & Kang, 2015; Li & Meng, 2015). Previous studies indicate that the crowd density in temporary markets can vary substantially (Sun, Meng, Kang, & Han 2017). Therefore, in the study of the sound environment and acoustic perception of temporary open-air markets, crowd density should be considered an important indicator.

The aim of this paper was to study the effect of temporary open-air markets on the sound environment and acoustic perception under different crowd densities. Using a typical temporary open-air market as an example, the effect of temporary open-air markets on the sound environment and acoustic perception under different crowd densities was studied using a questionnaire and objective measurements. First, the effect of the temporary open-air market before zoning on the sound level, subjective loudness, and acoustic comfort was analysed. Then, the effects of the temporary open-air market with the different zones on the perception of sound sources, sound levels, subjective loudness, and comfort were analysed.

2. **Method**

The study methods included selection of a survey site, crowd density measurement, a questionnaire-based survey, and sound-level measurement.

2.1. Survey site

A typical temporary open-air market on Wenxing Street in Harbin, China, was selected as the survey site (Figure 1). The decision to study this location was based on the following 3 reasons. First, the mean height-to-width ratio of the street on which the market was located is 3:1; which is typical for high-density cities (Shan, 2008; Ng, Yuan, Chen, Ren, & Fung, 2011). Next, the temporary open-air market had a large scale and a long history. Therefore, a large number of local residents as well as domestic and international tourists visit the market. Thus, the market provides convenient conditions in which to study the sound environment and acoustic perception under different crowd densities. Finally, the market's business model (i.e., its scale and format) resembles that of markets encountered in Europe and Japan (Zakariya, 2010) and thus has typicality. Booths in this market are distributed on both sides of the road. The market operates Saturday to Wednesday from 17:00-22:00. The market's width is approximately 10 m, and its total length is approximately 600 m. Previous studies indicate that any area of a market within 25-35 m of a road might be affected by traffic noise (Meng & Kang, 2015). In addition, areas close (i.e., 10-15 m) to the end of the road on which the market is located experience highly unstable crowd-flow changes (Raimbault & Dubois, 2005; Yu & Kang, 2006). Therefore, both ends of the road on which the study object was located, which were 35 m from road traffic, were not included in the measurement range.

Prior to August 2016, this temporary open-air market primarily sold fruits and vegetables, other food, and clothing. The other food items primarily consisted of specialty snacks and drinks as well as groceries (Figure 1a). These 3 categories accounted for 96% of the market's business (Sun & Meng, 2017). The booth types were randomly distributed throughout the market. However, in August 2016, to facilitate improved management, the market management authority divided the market into 3 independent zones (Figure 1b): a fruit and vegetable sales area, a food sales area, and a clothing sales area. The booth distribution was not changed with zoning and is shown in Figure 1c. Therefore, to study the effects of the temporary open-air market on the sound environment and sound-source perception, measurements were performed twice: once before and once after the market was zoned.

Studies indicate that environmental changes, such as changes in temperature and humidity, influence subjective acoustic perception (Thwaites, Helleur, & Simkins, 2005; Val, Atauri, & Lucio, 2006). To avoid the effects of these environmental factors, measurements were performed in July and September 2016. The mean monthly temperatures and relative humidity of these months are approximately the same. To avoid the effects on the environment of the time of day, measurements were performed from 17:00-18:00 daily for 1 continuous month (Liu, Kang, Luo, Behm, & Coppack, 2013). The conditions that prevailed when the temporary open-air market was in operation were measured from Monday to Wednesday. The conditions that prevailed when the market was closed were measured from Thursday to Friday.

Some previous studies have indicated that the differences in behavioural characteristics may also influence the sound environment and users' acoustic perception in urban open spaces (Aletta, Lepore, Kostara-Konstantinou, Kang, & Astolfi, 2016; Meng & Kang, 2016). A pilot study of temporary open-air markets suggested that, although the proportions of behaviours, such as shopping, passing by, standing by, and talking to others, vary in different market zonings, they are generally not changed with crowd density (Li & Meng, 2015). Therefore, the differences in behavioural characteristics were not considered in this study.

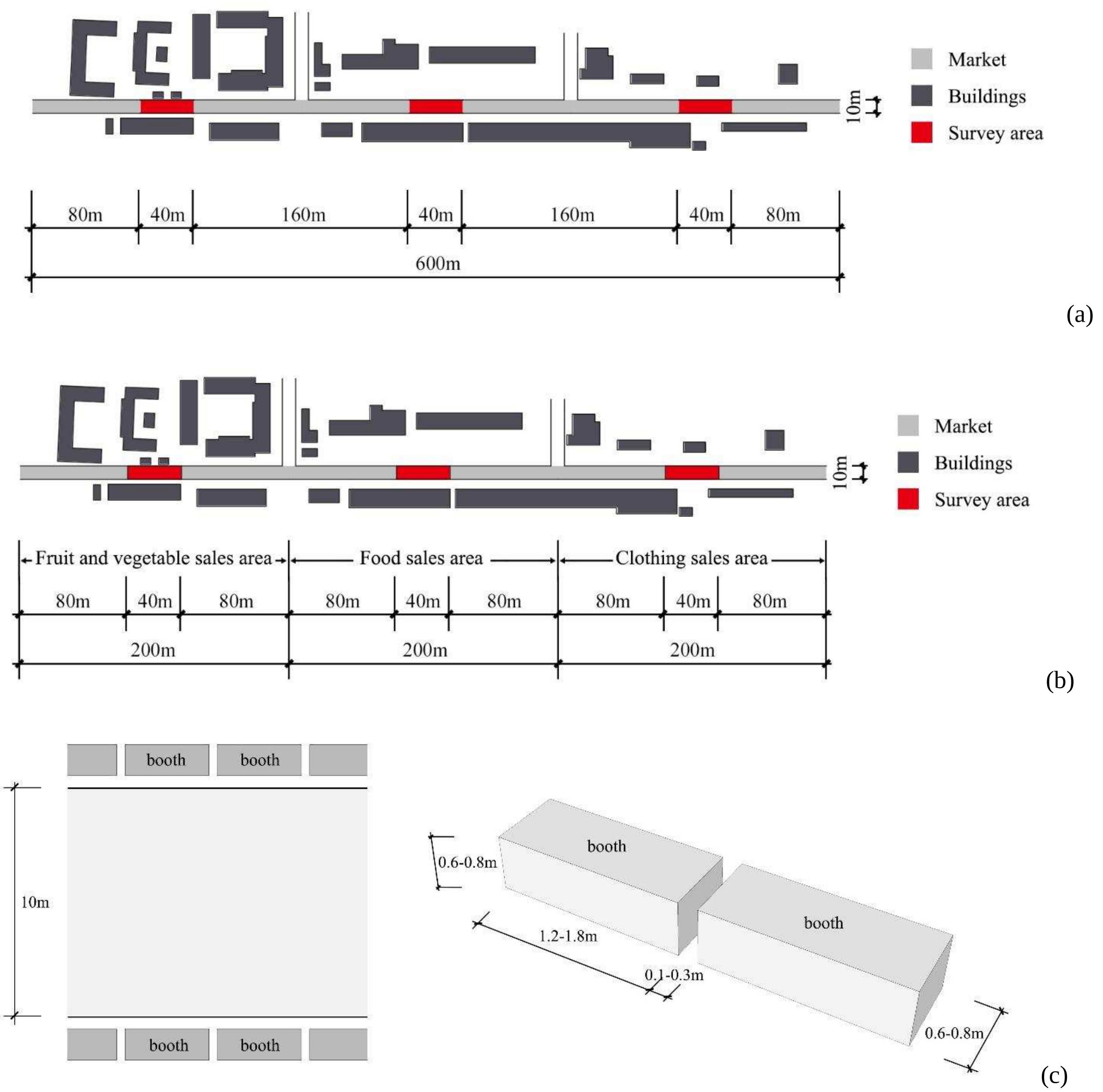

Figure 1. The basic information about the case site: (a) market without zoning; (b) market with zoning; (c) the basic information about booth.

2.2. Measurement of crowd density

To study the effect of a crowd on the sound environment and acoustic perception in the temporary open-air market, crowd density was measured using a photography method (Oakes & North, 2008). Study areas of 40 m x 10 m in the 3 zones were used to measure the temporary open-air market both prior to zoning and after zoning was instituted. To avoid interference among the areas, the distance between them was at least 80 m (Yu & Kang, 2008). Photos were taken from an elevated position at each of the areas (Figure 2). One photograph was taken every 30 s for a continuous 5 min (Westover, 1989; Meng & Kang, 2015). In the laboratory, the locations of the pedestrians who appeared in each picture were labelled with round dots, and a 5 m x 5 m grid was used to calculate the mean value of the total number of individuals in the photographed area within a 5-min period. This value was divided by the measurement area to obtain a mean value of the crowd density as the average number of persons per square metre. The unit was person/m^2 (Zhang & Meng, 2016; Yu & Kang, 2017).

Figure 2. Crowd density measurement, using the survey area as an example.

2.3. Questionnaire survey

For acoustic perception in urban open spaces, subjective loudness and acoustic comfort are two important evaluation indicators (Chartier & Semidor, 2005; Kang & Zhang, 2010). The sound preference is typically used to explain the differences among these subjective feelings (Ren, Kang, & Liu, 2016). Therefore, this study used the questionnaire survey method to establish the subjective loudness, acoustic comfort, and sound preferences of individuals in the survey locations. Individuals in the measurement areas were randomly selected to complete the questionnaire. In the questionnaire, respondents were first asked to list at least three of the sounds they heard and then to evaluate their preferences regarding the three sound sources using the following scale: 1-highly dislike, 2-dislike, 3-neither like nor dislike, 4-like, and 5-highly like (Ren, Kang, & Liu, 2016). Next, subjective loudness and acoustic comfort in the temporary open-air market were evaluated. Subjective loudness was assessed using the following scale: 1-very soft, 2-soft, 3-neither soft nor loud, 4-loud, and 5-very loud (Meng, Kang, & Jin, 2010). Acoustic comfort was assessed using the following scale: 1-very uncomfortable, 2-uncomfortable, 3-neither comfortable nor uncomfortable, 4-comfortable, and 5-very comfortable (Yu & Kang, 2009). Before the formal survey was performed, the validity and reliability of the questionnaire were examined (Dubois, Guastavino, & Raimbault, 2006). Because respondents required a period of time to adapt to the sound environment of the temporary open-air market, respondents who remained in the night market for less than 30 min were excluded. To ensure that the sampling was random, the survey was performed every 10 min, and each questionnaire was completed within 3-5 min (Litwin, 1995). Studies indicate that demographic differences such as age effect the subjective evaluation of a sound environment (Yang & Kang, 2005). Therefore, during the questionnaire survey, to avoid errors caused by demographic differences, the sample size for each age and income segment was not less than 30 individuals (Yin & Liu, 2008).

2.4. Measurement of sound pressure levels

Previous studies indicate that the acoustic perception of urban open spaces can be affected by the sound pressure level (Liu & Kang, 2016). To evaluate the effects on sound pressure levels, the equivalent continuous A-weighted sound pressure level (LAeq) was immediately recorded using an 801 sound-level meter after each questionnaire was completed. During measurement, the sound-level meter was adjusted to the slow speed (Kang & Zhang, 2010). Additionally, the distance between the measurement location and walls and other major reflective surfaces was ensured to be at least 1 m, and the distance between the measurement location and the ground was 1.2-1.5 m (Barron, 1993; Zahorik, 2002). One measurement was performed every 10 s. The data for each location were recorded for 5 min. A mean value was calculated to obtain the corresponding LAeq (Zhang, Zhang, Liu, & Kang, 2016).

3. **Results and analyses**

Based on the previously described measurements and the survey, this section describes the effect of the temporary open-air market, both before zoning and after zoning, on sound-source perception, sound level, subjective loudness, and acoustic comfort.

3.1. Effect of the temporary open-air market before zoning

3.1.1. Effect on the sound level

To assess the effect of a temporary open-air market on the sound level, this study performed regression analyses between the crowd density and the LAeq under 2 conditions: the presence and the absence of the temporary open-air market (Figure 3). The results indicated that when the crowd densities were the same, the mean sound pressure level when the market was open was 2.43 dBA, higher than when the market was closed. In addition, with the change in crowd density, the difference in the sound level between an operating temporary open-air market and the absence of the market changed. When the crowd density was low, for example, 0.20 person/m^2, the sound pressure level when the market was open was 2.96 dBA higher than when the market was absent. In contrast, when the crowd density was intermediate, for example, 0.50 person/m^2, the sound pressure level was 2.56 dBA higher. Finally, when the crowd density was high, for example, 1.00 person/m^2, the sound pressure level was 1.90 dBA higher. These results demonstrate that with an increase in crowd density, the difference in sound pressure between a temporary open-air market in operation and the absence of such a market decreased.

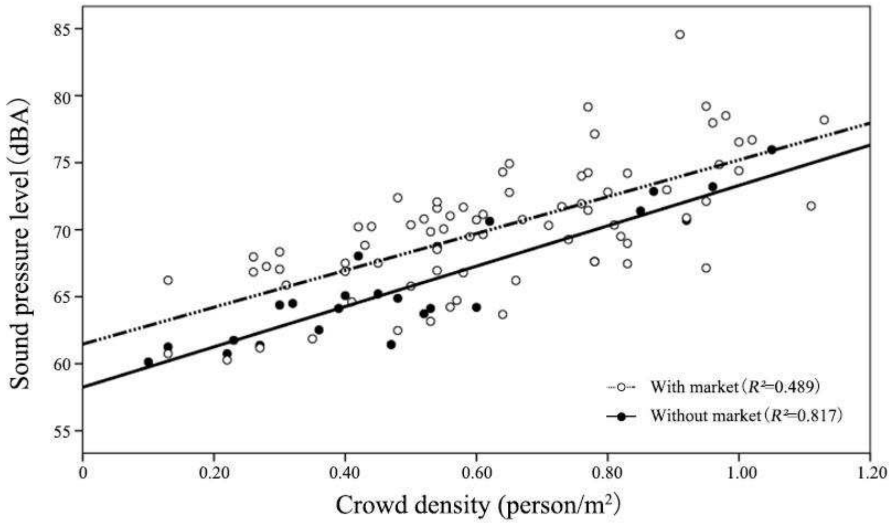

Figure 3. Relationships between the crowd density and the measured sound pressure level at the case site with the corresponding linear trend curves and coefficient of determination R^2 and significance $p < 0.001$.

3.1.2. Effect on subjective loudness

The results for subjective loudness were similar to those for LAeq. When the crowd densities were the same, the subjective loudness experienced by shoppers when the temporary open-air market was open was larger than when there was no market (Figure 4). When the crowd densities were the same, the mean subjective loudness when the market was in operation was 0.21 higher than when the market was closed. In addition, with changes in crowd density, the difference in subjective loudness between the presence and the absence of the market changed. When the crowd density was low, for example, 0.10 person/m^2, the subjective loudness when the market was open was 0.25 higher than when the market was closed. In contrast, when the crowd density was intermediate, for example, 0.50 person/m^2, the subjective loudness when the market was open was 0.22 higher. When the crowd density was high, for example, 1.00 person/m^2, the subjective loudness was 0.18 higher. These results demonstrate that with an increase in crowd density, the difference in the subjective loudness experienced when the market was open and when the market was closed decreased. The change in the trends of the subjective loudness and LAeq were the same. These results were the same as those found by Yang and Kang for other urban open spaces (Yang

& Kang, 2005).

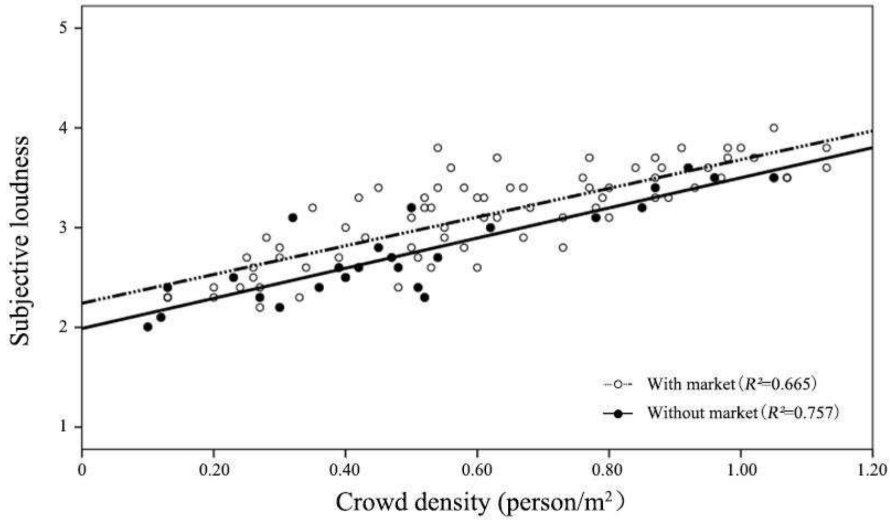

Figure 4. Relationships between the crowd density and the subjective loudness at the case site with the corresponding linear trend curves and coefficient of determination R2 and significance p < 0.001.

3.1.3. Effect on acoustic comfort

Regarding acoustic comfort, the regression curves for crowd density and acoustic comfort in the presence and absence of the temporary open-air market are shown in Figure 5. When the market was absent, with an increase in crowd density, acoustic comfort exhibited a parabolic change trend of increase followed by decrease ($R^2 = 0.626$, $P < 0.001$). When the crowd density was 0.32-0.78 person/m^2, the acoustic comfort was good, at 3.3-3.6. When the market was in operation, with an increase in crowd density, the acoustic comfort exhibited a parabolic change trend of increase followed by a decrease ($R^2 = 0.310$, $P < 0.001$). When the crowd density was approximately 0.50-0.78 person/m^2, the acoustic comfort was good at 3.3-3.5. The change trend of acoustic comfort was similar to that found for other urban open spaces (Li & Meng, 2015). When the crowd density was 0.11-0.73 person/m^2, the acoustic comfort when the market was closed was higher than when the market was open. When the density was lower or higher than this interval, the acoustic comfort of the respondents when the market was closed was lower than when the market was open. Therefore, holding a temporary open-air market in an urban open space with a high crowd density (higher than 0.73 person/m^2) can effectively increase the acoustic comfort.

3.2. Effect of the temporary open-air market after zoning

3.2.1. Effect on sound-source perception

For the 3 typical zones, the relationship between crowd density and the sound sources heard by market visitors is shown in Figure 6. The sound sources primarily included talking, hawking, footsteps, cooking noise, and the sound produced by shopping bags. According to statistical analyses, this study found that shoppers heard 3 major types of sound source in each area. For example, in the food sales area, talking, hawking, and cooking noise were the three sound-source types that received the most attention. The results demonstrate that the sound sources heard by shoppers significantly differed among the various zones. Cooking noise was only heard in the food sales area. The sound made by shopping bags was only heard in the fruit and vegetable sales area. Most respondents only heard footsteps in the clothing sales area. When the crowd density was less than 0.40 person/m^2, footsteps could also be heard in the fruit and vegetable sales area. Notably, compared to the other two areas, hawking was heard by most respondents in the fruit and vegetable sales area, and the effect of this sound on the sound environment in the fruit and vegetable sales area was the largest.

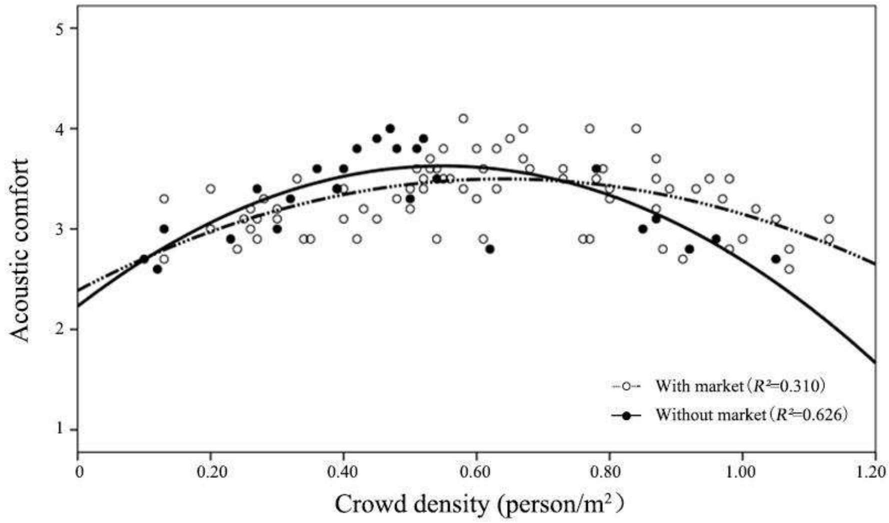

Figure 5. Relationships between the crowd density and the acoustic comfort at the case site with the corresponding linear trend curves and coefficient of determination R2 and significance p < 0.001.

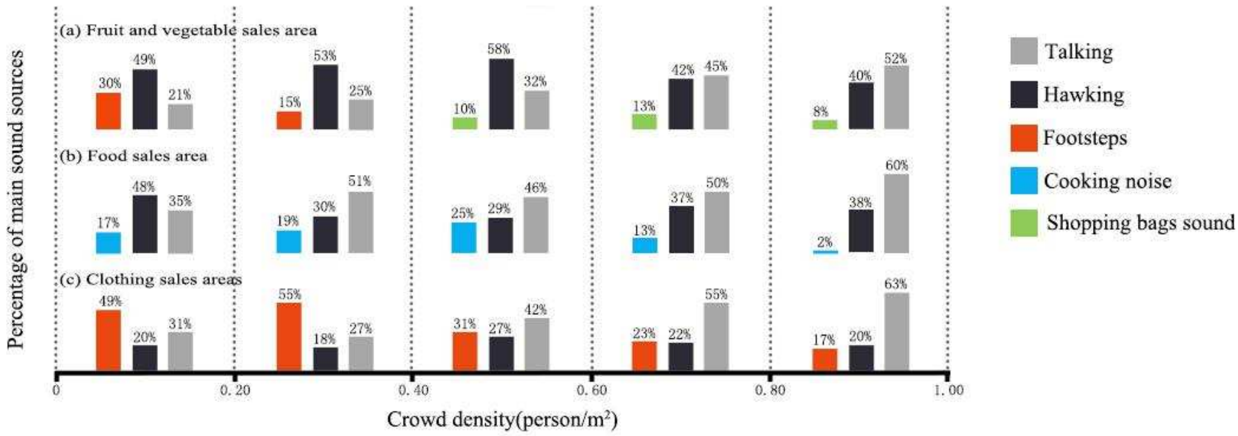

Figure 6. Relationships between the crowd density and the sound perception at the case site.

Under different crowd densities, the types of sound sources that were heard also exhibited substantial differences. In the fruit sales area, when the crowd density was 0.00-0.40 person/m^2, the sound sources most heard by respondents were hawking, talking, and footsteps. When the crowd density was higher than 0.40 person/m^2, footsteps could not be heard, but the sound made by shopping bags could be heard by respondents. When the crowd density was 0.60-0.80 person/m^2, at most 13% of the respondents heard the shopping bag sound. When the crowd density was higher than 0.80 person/m^2, the number of respondents who heard the shopping bag sound decreased to 8%. In the food sales area, with an increase in crowd density, respondents who heard the cooking sound initially increased and then decreased. When the crowd density was 0.00-0.80 person/m^2, the major sound sources heard by respondents were hawking, talking, and cooking noise. When the crowd density was higher than 0.80 person/m^2, 60% of the respondents heard talking, whereas only 2% heard cooking noise. In the clothing sales area, when the crowd density was 0.00-0.60 person/m^2, the number of respondents who heard footsteps gradually increased to 43%. When the crowd density was higher than 0.60 person/m^2, the number of respondents who heard footsteps gradually decreased to 17%, and the number of respondents who heard talking increased to 63%. Because of the increase in crowd density, the masking effect of talking on the sound of footsteps gradually increased. Compared to the other 2 areas, the number of times that hawking was heard in the clothing sales areas was lower.

For the three typical zones, the preferences for various sound sources are shown in Figure 7. In the fruit and vegetable sales area, the respondents had a lower preference for the sound of hawking and the sound produced by shopping bags (2.4 and 2.1, respectively). The preference for the sound of footsteps was the highest (3.7). In the food sales area, although the percentage of respondents who heard the cooking sound was no higher than 25%, their preference for the cooking sound was higher (3.7). In the clothing sales area, the preference of the respondents for the sound of footsteps was the highest (3.9), while their preference for the sound of hawking was lower (2.7). A favourable sound environment could be achieved by controlling a location's sound-source percentages based on the sound-preference results presented here.

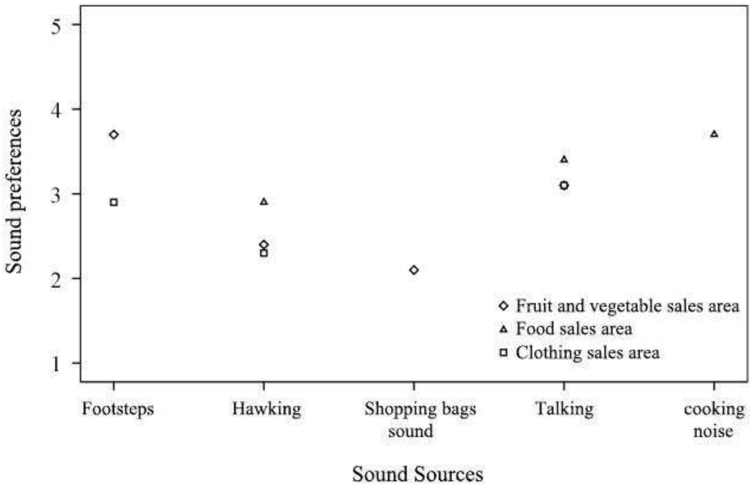

Figure 7. Sound preference at the case site

3.2.2. Effect on the sound level

To study the effect of a temporary open-air market with zoning on the sound level, regression analyses on the crowd density and LAeq were performed for the three 3 typical areas. The relevant linear regression curve and the coefficient of determination R^2 are shown in Figure 8. The results indicate that the crowd density and LAeq were strongly correlated ($P < 0.001$) and that the LAeq increased with an increase in crowd density. For each increase of 0.10 person/m^2 in the crowd density, the LAeq of the fruit and vegetable sales area, the food sales area, and the clothing sales area increased 1.74 dBA, 1.32 dBA, and 1.41 dBA, respectively. That is, the LAeq of the fruit and vegetable sales area was the highest, followed by that of the clothing sales area, and the increase in the LAeq of the food sales area was the lowest. A possible reason for this outcome is that in the food sales area, shoppers were busy tasting food. Thus, the interaction frequency among the shoppers decreased. As shown in Figure 3, when the crowd density increased from 0 to 1.20 person/m^2, the number of respondents in the food sales area who heard talking increased 25%, which was lower than that in the fruit and vegetable area (31%) and the clothing sales area (29%). When the crowd densities were the same, the LAeq in the clothing sales area was always lower than that in the fruit and vegetable sales area and the food sales area. When the crowd density was 0.00-0.25 person/m^2, the LAeq in the food sales area was higher than that in the fruit and vegetable sales area. When the crowd density was higher than 0.25 person/m^2, the LAeq in the food sales area was lower than in the fruit and vegetable sales area. For example, the LAeq in the fruit and vegetable sales area was 74.42 dBA when the crowd density was 0.60 person/m^2, which was higher than 1.46 dBA and 6.51 dBA in the food sales area and the clothing sales area, respectively. As shown in Figure 3, a possible reason for this outcome is that compared to the other 2 areas, shoppers in the fruit and vegetable sales area primarily heard the sound of hawking. The higher sound pressure level of the sound resulted in the higher sound pressure level in the fruit and vegetable sales area. When the crowd density was lower than 0.25 person/m^2, there was no large difference in the frequency of the hawking that was heard between the food sales area and the fruit and vegetable sales area. In the food sales area, 35% of the respondents heard the sound of talking, which was higher than 25% in the fruit and vegetable sales area. This outcome might explain the higher LAeq in the food sales area than in the fruit and vegetable sales area when the crowd density was 0.00-0.25 person/m^2. A previous study demonstrated that the noise of a crowd could mask several common sound sources (Meng & Kang, 2015). Therefore, to effectively mask traffic noise, the fruit and vegetable sales area, with its higher LAeq equivalent, should be positioned in the section of a temporary open-air market close to the traffic.

As shown in Figures 3 and 8, the LAeq in the food sales area and the fruit and vegetable sales area is even higher than that of a temporary open-air market without zoning. Interestingly, the LAeq in the clothing sales area was even lower than that without a market, possibly because the clothing and other items sold in the clothing sales area acted as sound absorbers.

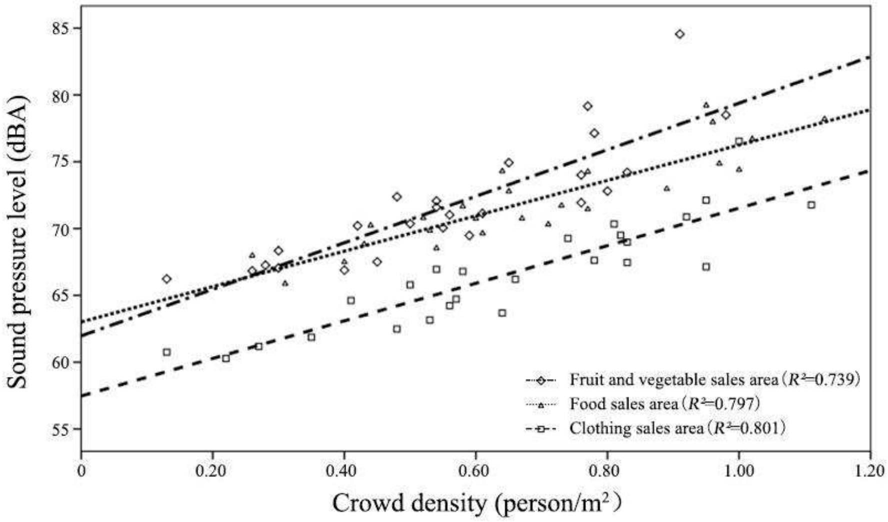

Figure 8. Relationships between the crowd density and the measured sound pressure level in the 3 areas with the corresponding linear trend curves and coefficient of determination R2 and significance p < 0.001.

3.2.3. Effect on subjective loudness

This section addresses the effect of crowd density on the subjective loudness in the different zones. As shown in Figure 9, with an increase in crowd density, subjective loudness increased accordingly. For each increase in crowd density of 0.10 person/m^2, the subjective loudness in the fruit and vegetable sales area, the food sales area, and the clothing sales area increased 0.17, 0.14, and 0.16, respectively. That is, with an increase in crowd density, the increase in the subjective loudness in the fruit and vegetable sales area was the highest, followed by the clothing sales area. The increase in the subjective loudness in the food sales area was the lowest. When the crowd density was the same, the subjective loudness in the fruit and vegetable sales area was always higher than that in the food sales area and the clothing sales area. For example, when the crowd density was 0.80 person/m^2, the subjective loudness in the fruit and vegetable sales area, the food sales area, and the clothing sales area was 3.7, 3.4, and 3.2, respectively.

A comparison among the absence of a temporary open-air market, a market without zoning (Figure 4), and a temporary open-air market with different zones (Figure 9) shows that the subjective loudness in the study areas was approximately the same as in the food sales area when there was no zoning in the market. In the absence of a temporary open-air market, the subjective loudness in the study areas was always lower than in the food sales area and the fruit and vegetable sales area. However, there was no significant difference in the clothing sales area. Possible reasons for this outcome were as follows: (1) people like to shop in a relatively quiet environment, (2) with an increase in crowd density, the sound level increased, and the surrounding environment became noisier, and (3) shoppers in the clothing sales area were more sensitive to sound.

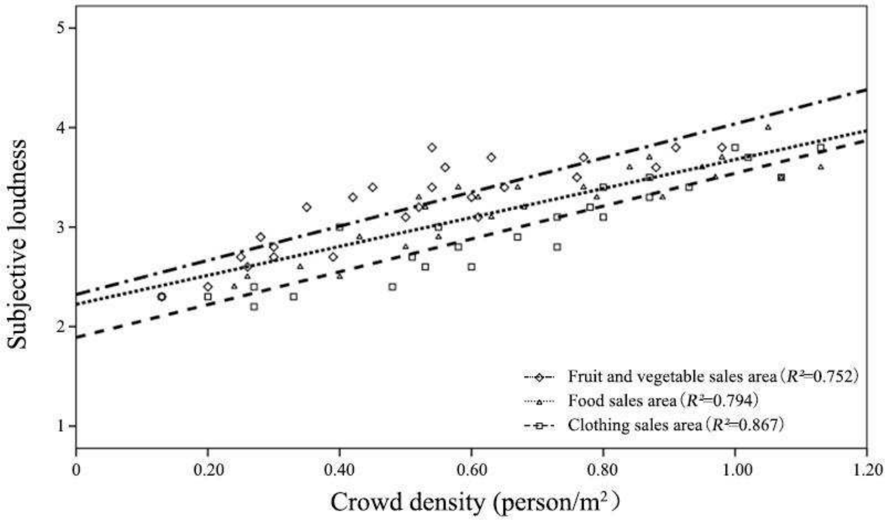

Figure 9. Relationships between the crowd density and the subjective loudness in the 3 areas with the corresponding linear trend curves and coefficient of determination R2 and significance p < 0.001.

3.2.4. Effect on acoustic comfort

Regarding the acoustic comfort, the regression curves for crowd density and acoustic comfort in the 3 typical areas are shown in Figure 10. In the fruit and vegetable sales area, when the crowd density was 0-1.20 person/m^2 ($R^2 = 0.668$, $P < 0.001$), the acoustic comfort decreased from 3.6 to 2.2. A possible reason for this outcome is that with an increase in crowd density, the footstep sound that respondents liked in the fruit and vegetable sales area was not heard. However, the sound produced by plastic bags, which received a lower preference evaluation, was heard. Therefore, the acoustic comfort decreased. In the food sales area, with an increase in crowd density, the acoustic comfort exhibited a parabolic change trend of increase followed by decrease ($R^2 = 0.724$, $P < 0.001$). When the crowd density was 0-0.73 person/m^2, the acoustic comfort increased from 2.1 to 3.7. When the crowd density was 0.73-1.20 person/m^2, the acoustic comfort decreased by 0.7. A possible reason for this outcome is that when the crowd density was lower, shoppers could hear cooking noise. However, with an increase in crowd density, the cooking noise was gradually masked by other sounds, and the comfort of the shoppers decreased. In the clothing sales area, with an increase in crowd density, the acoustic comfort exhibited a parabolic change trend of increase followed by decrease ($R^2 = 0.642$, $P < 0.001$). When the crowd density was 0-0.62 person/m^2, the acoustic comfort increased from 2.1 to 3.7, and when the crowd density was 0.62-1.20 person/m^2, the acoustic comfort decreased by 1.4. A possible reason for this outcome is that when crowd density was lower, the frequency with which the sound of hawking (which received a lower sound-preference evaluation) was heard was higher, causing lower acoustic comfort. When the crowd density was higher over a certain range, the sound of footsteps (which received a higher sound-preference evaluation) was masked, reducing the acoustic comfort.

Therefore, temporary open-air markets should be zoned such that variations in crowd density enable shoppers to obtain their preferred shopping experience. Using an acoustic comfort level of no lower than 3.5 as an example, we suggest that the fruit and vegetable sales zone should be located in an area with a crowd density of 0.00-0.12 person/m^2. The food sales zone should be located in an area with a crowd density of 0.47-0.99 person/m^2. Finally, the clothing sales zone should be located in an area in which the crowd density is controlled at 0.42-0.82 person/m^2.

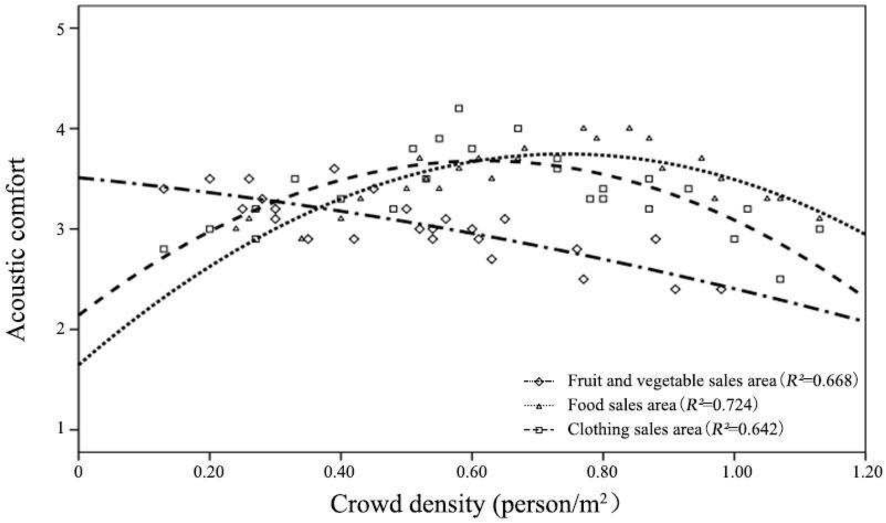

Figure 10. Relationships between the crowd density and the acoustic comfort in the 3 areas with the corresponding linear trend curves and coefficient of determination R2 and significance p < 0.001.

4. **Conclusion**

Based on a questionnaire survey and acoustic measurements, this study analysed the effects of a temporary open-air market and differences made by zoning on sound-source perception, LAeq, subjective loudness, and acoustic comfort. The conclusions are as follows.

Without zoning, the effect of the presence or absence of a temporary open-air market on the sound environment and acoustic perception was such that the sound pressure level and subjective loudness were higher when the market was in operation. However, this difference decreased with an increase in the crowd density. The change trend of subjective acoustic comfort differed from that of subjective loudness. With an increase in crowd density, acoustic comfort exhibited a parabolic change trend of increase followed by decrease regardless of the presence or absence of the market. When the market was open, the acoustic comfort was good when the crowd density was 0.50-0.78 person/m^2. When the market was closed, the acoustic comfort was good when the crowd density was 0.32-0.78 person/m^2. When the crowd density was lower (< 0.11 person/m^2) or higher (> 0.73 person/m^2), the acoustic comfort when the market was open was higher than when the market was closed.

Regarding the effect of a temporary open-air market with different zones on the sound environment and acoustic perception, according to the zone, when the crowd density was lower, the sound sources heard by respondents displayed obvious differences. When the crowd density was higher, the most important sound source was the sound of talking. Regarding the effect on the sound level, with an increase in the crowd density, the sound level in the fruit and vegetable sales area had the largest increase, followed by the clothing sales area. The sound level in the food sales area had the smallest increase. Interestingly, the sound level in the clothing sales area was lower than when the market was absent. Regarding the effect on subjective loudness, when the crowd densities were the same, the subjective loudness in the fruit and vegetable sales area was always higher than in the food sales area and the clothing sales area. Regarding acoustic comfort, with an increase in the crowd density, the acoustic comfort in the fruit and vegetable sales area decreased, and the acoustic comfort in the food sales area and the clothing sales area exhibited a parabolic change trend of increase followed by decrease. Notably, when the acoustic comfort was higher, the appropriate crowd density in each area displayed larger differences. Therefore, a reasoned distribution of zones could effectively adjust the acoustic comfort in urban spaces.

Overall, these results are expected to help urban planners and relevant government sectors in establishing and operating temporary open-air markets. It is evident that well-planned arrangements and zoning in temporary open-air markets in high-density cities can effectively improve the soundscape in the market area. For example, before zoning, temporary open-air markets should be located on a street with a relatively high crowd density. After zoning, zones for fruits and vegetables should be located in a street area with a relatively low crowd density, and the zone for food sales should be located in a street area with a relatively high crowd density. Compared to the clothing zone and food zone, fruit and vegetable zones, with a fairly high LAeq in general, should be positioned in the section of a temporary open-air market close to the road traffic to effectively mask traffic noise (Meng & Kang, 2015).

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