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The influence of crowd density on the sound environment of commercial pedestrian streets

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HIGHLIGHTS

- Traffic noise can be masked by sound from crowd.
- Acoustic comfort can be improved by changing crowd density.
- Examined the sound sources in commercial pedestrian streets

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ABSTRACT

Commercial pedestrian streets are very common in China and Europe, with many situated in historic or cultural centres. The environments of these streets are important, including their sound environments. The objective of this study is to explore the relationships between the crowd density and the sound environments of commercial pedestrian streets. On-site measurements were performed at the case study site in Harbin, China, and a questionnaire was administered. The sound pressure measurements showed that the crowd density has an insignificant effect on sound pressure below 0.05 persons/m^2, whereas when the crowd density is greater than 0.05 persons/m^2, the sound pressure increases with crowd density. The sound sources were analysed, showing that several typical sound sources, such as traffic noise, can be masked by the sounds resulting from dense crowds. The acoustic analysis showed that crowd densities outside the range of 0.10 to 0.25 persons/m^2 exhibited lower acoustic comfort evaluation scores. In terms of audiovisual characteristics, the subjective loudness increases with greater crowd density, while the acoustic comfort decreases. The results for an indoor underground shopping street are also presented for comparison.

1. Introduction

Commercial pedestrian streets are common urban open spaces in China, and they are often situated within historic or cultural centres. Despite many recent studies on how to enhance the comfort and safety of commercial pedestrian streets (Folt^ete and Piombini, 2007; Leng and Sun, 2009), the 2011 environmental bulletin of China cited environmental problems, particularly acoustic problems, as major detrimental factors affecting the community's use and evaluation of commercial pedestrian streets (Ministry of Environmental Protection of the People's Republic of China, MEPPRC, 2011).

Previous studies have suggested that the evaluation of the sound environment of an urban open space strongly depends on the sound sources, the specific characteristics of the space, various physical environmental conditions, and users' social and behavioural characteristics (Ballas, 1993; Gaver, 1993; Maffiolo et al., 1997; Dubois, 2000; Ge and Hokao, 2004, 2005; Kang and Zhang, 2010). Sounds with multiple tonal components are perceived differently from sounds with single tonal components because sounds with multiple components do not automatically capture interviewees' attention (Bodden and Heinrichs, 2001). Several special sound sources can also capture more attention than other sources, even if their sound levels are generally low (Farina et al., 2011; Nilsson et al., 2010; Jeon et al., 2012). In terms of spatial characteristics, Kang (2001) indicated that a suitable reverberation time, e.g., 1–2 s, can make street music more enjoyable. In terms of environmental characteristics, the temperature and humidity have been demonstrated to be important characteristics affecting acoustics (Yang and Kang, 2005; Yu, 2009). Regarding user characteristics, the results primarily focus on individual differences such as gender, age, income, occupation, education, and behavioural characteristics (Zimer and Ellermeier, 1999; Karlsson, 2000; Ellermeier et al., 2001; Crociata et al., 2012, 2013).

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Crowd density is an environmental factor that is expressed as the number of people in a space divided by the area of the space (Marana et al., 1998). The estimation of crowd density was first used for crowd monitoring to determine when an area reaches a greater than projected crowd density that can endanger people's safety (Marana et al., 1998). Subsequently, crowd density has been used in a variety of research fields such as environmental pollution, building technology, and landscape design. Previous studies have shown that in certain spaces, crowd density can affect some spatial or environmental characteristics (Hui and Bateson, 1991). Furthermore, previous studies have also shown that crowd density can affect behaviour (Westover, 1981; Oakes and North, 2008). However, only a limited number of studies have investigated the influence of the crowd distribution on the sound environment, in which case the people within the crowd can be seen as both the sound sources and as sound absorbers.

Therefore, the present study examines the influence of crowd density on the sound environment using the objective characteristics of sound pressure level and sound sources and subjective characteristics such as the evaluation of acoustics and audiovisual interactions, based on measurements and a series of subjective surveys in a typical commercial pedestrian street. For comparison, results from an indoor underground shopping street are also presented.

2. Methodology

2.1. Survey site

Nearly every city centre in China features commercial pedestrian streets. As most of these streets are traditional streets, the building heights on both sides of the street are generally low, e.g., from 2 to 4 floors (8 to 16 m in height), with the aspect ratio of the street cross-section typically ranging from 1:1 to 1:3 (Guo, 2010). These types of streets are similar to many streets in Europe (Ashihara, 1983).

The present study used a traditional commercial pedestrian street as the case site, the Central Avenue in Harbin, China. This site is a historic and cultural centre that was built in 1898 by the Russians, with 3-to-4 storey buildings on both sides of the street. The street is 1450 m in length and 20 m wide. As this study is limited to the specific area selected, the ability of this site to represent other sites was considered. Out of 325 typical commercial pedestrian streets in 62 major Chinese cities, 86% of streets have streets and buildings of similar scales. Therefore, the results of this case site are likely applicable to a majority of similar sites. The influence of reverberation time (RT) on the evaluation of sound environments was also considered. The T60, as estimated by formulas (Kang, 2002), is affected by no more than 0.2 s as the frequency of sound ranges from 125 Hz to 4000 Hz and the crowd density ranges from 0 to 0.5 persons/m^2. Therefore, the influence of RT is not discussed in this research. As traffic noise is typically the primary source of noise in urban open spaces (Miedema and Vos, 1998; Lebiedowska, 2005), survey locations were selected from a section on this street with a 20 m wide road, as shown in Fig. 1a. One side of this road mainly houses shops selling clothes and Russian goods, which attract the majority of visitors to the street, while the other side mainly contains glasses shops and banks, which draw fewer customers. Therefore, the crowd density of the street varies between the two sides, as the visitors most often buy some clothes or Russian goods and then depart from the street. Therefore, the survey points are along both sides of the street and are denoted R1 to R6 on the generally high crowd density side and R1′ to R6′ on the generally low crowd density side. The spacing between survey points is 5 m. R1 and R1′ are 10 m away from the border of the road to ensure that the pedestrians' behaviour is generally the same (Yu and Kang, 2006, 2008).

2.2. Questionnaire

To study the influence of crowd density on acoustic characteristics, including the subjective loudness and acoustic comfort, a questionnaire was administered at the same time that the crowd density measurements were collected, with questionnaires generally completed in 3–4 min. A total of 662 valid questionnaires were obtained, and the social and behavioural characteristics determined from these questionnaires are reported in Table 1. Approximately 20 to 30 interviews were conducted at each survey point. The interviewees in all field surveys were randomly selected. Each interviewer was assigned to a 5 m * 5 m area and was tasked with administering a questionnaire once every 10 min to an interviewee in this area. The case sites were chosen in the middle of Central Avenue, home to a variety of shops that attracted visitors with different social backgrounds and behaviours. Comparisons with previous studies in which local questionnaires were more widely administered, for example to more than 300 individuals, demonstrate that the

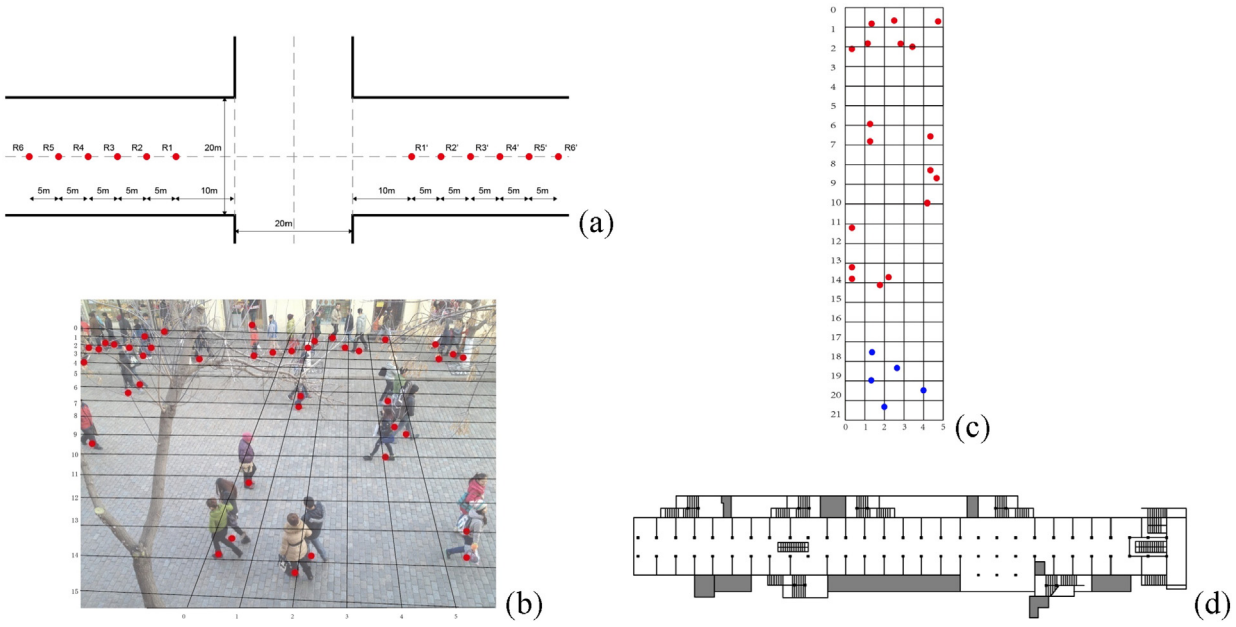

Fig. 1. The survey site and the measurement points along the commercial pedestrian street (a), photograph of the crowd density at point R2 (b), measurement of crowd density at point R2 (c), and schematic of the underground shopping street (d). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)