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Developing a multivariate model for predicting the noise annoyance responses due to combined water sound and road traffic noise exposure

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ABSTRACT

People in an urban environment are exposed to different types of natural and man-made sounds. Human sound perceptions due to exposure to a single noise source, in particular road traffic and aircraft noises, have been investigated for a long time. However, only very few studies have been focused on exposure to a combination of sound sources. Also, there is a lack of multivariate models that can help to predict the preferences or annoyance responses as a result of adding a wanted sound to an unwanted sound. Accordingly, this study aimed at developing a multivariate model to predict the probability of invoking a high noise annoyance response due to combined water sound and road traffic noise exposure. A series of laboratory experiments were performed. Participants were presented with a series of acoustical stimuli before being asked to assign their annoyance ratings. Results suggested that other than acoustical properties like sound pressure levels, personality traits were found to exert considerable influences on the maximum likelihoods of the model prediction and thus should not be excluded from the model specification form. Also, the quality of the acoustical environment could be improved by adding water sounds to road traffic noises at high levels. The capability of stream sound to moderate noise annoyance was found to be slightly stronger than that of fountain sound. In addition, the formulated multivariate model enables to reveal the tradeoff decisions performed by people. An increase in the SPL of road traffic noise by 1 dB was considered to be equivalent to a reduction in the SPL of water source by 1.7 dB for a given probability value. Results arising from this study should provide valuable insights on understanding how humans respond to the combined water sound and road traffic noise exposure.

1. Introduction

People in an urban environment are often exposed to acoustical environments containing multiple sound sources. Some are wanted sounds that people prefer [1], e.g. natural sounds including water sound and bird songs [2]. Some are unwanted sounds or noises that people do not prefer, e.g. road traffic noise [3]. However, annoyance responses have quite often been assumed to be only induced by a single dominant noise source, e.g. road traffic or aircraft noises. Models have been formulated to predict the noise annoyance responses caused by aircraft noise, railway noise or road traffic noise [4–9]. In fact, annoyance may not be only induced by a single sound source. Exposure to two noise sources (e.g. road traffic and railway) may invoke more extensive reactions than exposure to a single noise source at the same sound pressure level [10].

A number of empirical models have been formulated to predict the effect of exposure to two or more types of unwanted sounds on human sound perceptions. Among all the unwanted sounds, transportation noises in particular road traffic noises have always been captured the most attention. Physical models and perpetual models have frequently been employed for describing the annoyance responses due to transportation noise exposure.

Physical model operates on the assumption that the total annoyance response due to exposure to a combination of sounds can be expressed as a function of sound levels of individual sources. A model with the sound levels of two individual noise sources as explanatory variables was found to perform as good as that with the global sound level of the combined sound environment as an explanatory variable in predicting the total annoyance responses due to combined aircraft and traffic noise exposure [11]. An empirical model with the sound levels of two noise sources as an explanatory variable was shown to be able to reasonably predict the overall dissatisfaction due to combined residential noise exposure [12]. In addition to sound levels of individual sources, differences in sound levels between two sound sources

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(i.e. signal-to-noise ratio) were also introduced as an additional explanatory variable for predicting the total annoyance responses due to combined industrial noise exposure [13].

Perpetual models aim to predict the total annoyance responses due to combined noise exposure based on a function of the annoyance response or loudness of individual noise sources. For example, dominance model assumes that the noise annoyance due to combined noise exposure is equal to or lower than the annoyance responses due to the most annoying noise source within the combined sources [14]. It was successfully applied in predicting the annoyance responses due to combined aircraft and road traffic noise exposure in Vietnam where road traffic noises were the dominant noise sources [15]. On the other hand, Miedema [16] developed an annoyance-equivalents model to predict the total annoyance responses due to combined noise source exposure by first transforming the annoyance responses due to individual noise sources to an equivalent scale. This model was later successfully applied by Lee et al. [17] to predict the total annoyance responses due to combined construction noise exposure. The model was also modified by Alayrac et al. [18] for portraying the total annoyance responses due to exposure to a combination of background noises and industrial sound having a main spectral component.

However, a majority of the multivariate models developed so far only targeted at predicting the total annoyance responses due to exposure to a combination of unwanted sounds [19,20]. There is a lack of multivariate models that can be used to predict the effects of adding wanted sounds to unwanted sounds on human sound perceptions, e.g. adding water sounds to unwanted road traffic noises.

Sounds arising from water features have been widely perceived as an effective means for enhancing urban soundscape in open spaces especially in urban parks [21–23]. In addition, water sounds have often been proposed to be used for masking unwanted sounds like road traffic noise [22,24,25]. However, water sounds might not benefit the overall quality of urban soundscape when the sound level of road traffic was high, e.g. 70 dBA [26]. Among all types of water sounds, fountain sound and stream sound were the widely studied in the urban soundscape environment perception, e.g. [22,27,28]. Both types of water sounds can improve the sound quality under certain operating conditions. The operating conditions vary with the type of sound quality parameters in focus. For instance, the level of fountain sounds in urban parks needed to be 5–10 dB higher than that of road traffic noise in order to reduce its perceived loudness [29]. The level of water sound should be at least 3 dB lower than that of road traffic in order to increase the preference ratings of the acoustic environment [24,25,30]. However, it is still not clear how the differences in sound levels between two sources will affect sound perceptions, and how the total annoyance responses vary with the exposure to different combinations of water sound and road traffic noise at high noise levels.

Other than acoustical properties, some personality traits are anticipated to exert influences on annoyance responses. For instance, people rating themselves as sensitive to noises are usually more annoyed by noises [31–37]. Although the foregoing factors exert influences on the preferences/annoyance responses due to combined water and road traffic sound exposure, results were usually derived from pairwise comparisons [e.g. [21,22,28]. It lacks quantitative information for revealing the relative influences of individual factors on total annoyance responses due to combined water and road traffic sound exposure.

Of particular interest of this study is to explore whether annoyance responses due to exposure to high road traffic noise levels will be moderated by adding water sounds. Accordingly, the first objective is to explore whether the physical model forms commonly employed for predicting the total annoyance responses due to exposure to two unwanted sounds are appropriate for predicting the total annoyance responses due to exposure to a combination of road traffic noises (unwanted sound) and water sounds (wanted sound). Second, this study aims to formulate a multivariate model that can help predict the effect of acoustical properties and personality traits on the probability of invoking a high annoyance response due to combined water and road traffic sound exposure. Finally, it aims to reveal the relative influences of acoustical properties and personality traits on the total annoyance responses.

2. Methodology

2.1. Preparation of acoustical stimuli

A series of laboratory experiments was set up to determine the extent of human noise annoyance that could be moderated by adding water sound to the acoustic environment containing high road traffic noise levels. Participants were presented with a series of acoustical stimuli before being asked to assign the total annoyance ratings. The total annoyance rating corresponds to the extent of disturbance for reading activities caused by the combined sound exposure. The combined sound stimuli were generated from a pure road traffic noise source and a water sound recorded in advance. The sample of road traffic noise was extracted from a 30-min record of a busy trunk road, while the samples of fountain sound and stream sound were extracted from the sound clips purchased from a professional audio effect website (www.prosoundeffects.com). Software Audacity 2.0.5 was employed to generate 30-s combined sound clips by mixing sound clips containing water (stream/fountain) with those containing road traffic sounds. The spectral properties of the individual and combined sound sources were analyzed using the spectrum analyzer Bruel & Kjaer Type 2144 and a Head and Torso Simulator (HATS). The HATS embracing a head mounted on a torso represents the international average dimensions of an adult. A low-impedance headphone (64 Ω) of Model HD 280 Pro made by Sennheiser, which has an ambient attenuation of up to 32 dB, was used in the experiments so as to minimize sound spillage from outside. The HATS was equipped with two microphones near the ear region. The sound signals received by the microphones were transmitted to an analyzer for analyzing their acoustical properties. Immediately before performing the experiments, the sound signals from the sound clips were input into the simulator via the headphone to measure the sound levels that would have been heard by a participant via the headphone.

2.2. Experimental design and questionnaire survey

Stream sound and fountain sound were the two types of water sound selected for this study. In this study, 3 sound clips of 30-s each at global sound pressure levels (SPLs) of 65 dBA, 70 dBA and 75 dBA respectively were generated for each type of water source. In addition, 36 sound clips of 30-s each were generated for the combined sounds. The global SPLs of the combined sound clips were also fixed at 65 dBA, 70 dBA or 75 dBA, while the water signal-to-noise ratio (*WSNR*) of the two sound sources increased from −9 to 6 dB, in a step of 3 dB. *WSNR* is the difference in sound pressure levels between water source and road traffic. A negative *WSNR* value denotes that the SPL of road traffic is higher than that of water source, and vice versa.

All the experiments were carried out in a study room located in the Department of Building Services Engineering in the Hong Kong Polytechnic University. Participants were asked to sit in front of a desk and read magazines as if they were reading for leisure at home. 30-s auditory stimuli were presented to the participants.