1. Introduction

Promoting wanted sounds to mask the unwanted sounds is one of the prominent soundscape design approaches. Using fountain sounds for masking the traffic noise could be a good example of the application of this approach. Numerous studies have shown that pleasant water sounds could both reduce the perceived loudness of noise and overall soundscape quality [1–4]. Most of these studies have been conducted with the assumption that the location of the target noise coincides with the masker (co-location), while paying little attention to the spatial aspects of the masker. In fact, a fountain is a physical feature that has dimensions such as width, length, and height. This indicates that fountains with different spatial configurations will generate water sounds with different spatial impressions, such as a width of sound source.

Thus, it is necessary to consider spatial impression of fountain sounds to use as masker sounds in the soundscape approach. Apparent source width (ASW) is one of the recognised subjective attributes of the spatial impression in room acoustics. ASW is defined as the acoustical width of the sound source as perceived by a listener. The concept of ASW has been also adopted for evaluating environmental noise [5–7] showing that spatial factors can be used to characterize the environmental noise. Therefore, this study aims to examine the effects of ASW of water sounds on masking traffic noise. Fountain sounds were recorded at the in-situ acoustic environment with different ASW. Listening experiments were conducted to evaluate masking effect of the fountain sounds for traffic noise in laboratory conditions.
2. **Method**

2.1 **Recording water sounds**

Acoustic recording for water sounds was conducted in the vicinity of a fountain in Nanyang Technological University, Singapore. As shown in Fig. 1(a), the fountain is composed of jets and a basin. The length of the fountain is 20 m. To vary the width of water sounds, the recording was performed at five different distances from the fountain (0, 2, 4, 6 and 8 m) as shown in Fig.1(b). The recordings were conducted using an ambisonic microphone (Sennheiser AMBEO VR 3D Microphone, Germany) via a recorder (Zoom F8 Multi-Track Field Recorder, Japan). A-weighted sound pressure level ($L_{Aeq}$) at each distance was calculated based on the recording by a calibrated class 1 microphone (G.R.A.S. Type 40PH CCP Microphone, Denmark). The microphones were placed at a height of 1.5 m.

![Figure 1: photograph (a) of the fountain and the five recording positions of the fountain sounds](image)

2.2 **Acoustic parameters**

The recorded A-format ambisonic tracks were down-mixed to create the binaural tracks using KE-MAR small pinnae Head-Related Transfer Function (HRTF). For the listening test, 10-second of the fountain sounds were excerpted from original recordings. As shown in Fig. 2, A-weighted equivalent sound pressure level ($L_{Aeq,10s}$) decreased from 71.3 to 59.1 dBA as the source-receiver distance increased from 0 m to 8 m. It is shown that $L_{Aeq}$ decreased by approximately 3 dBA as the source-receiver distance increased by 2 m.

![Figure 2: $L_{Aeq,10s}$ as a function of source-receiver distance](image)
Generally, the magnitude of the interaural cross-correlation function (IACC) is closely related to the ASW. Ando [8] proposed the width of the interaural cross-correlation function ($W_{IACC}$), which is defined as the interval of delay time at a value of 10% below the IACC, as an objective parameter to measure the ASW of the sound source. Previous studies show that there is a positive relationship between $W_{IACC}$ and ASW [5,9]. As plotted in Fig. 3, $W_{IACC}$ values of the fountain sounds tend to increase as the source-receiver distance increases. Specifically, when the source-receiver distance is less than 4 m, there are no significant differences in $W_{IACC}$, while $W_{IACC}$ dramatically increases as the source-receiver distance increases beyond 6 m.

![Figure 3: $W_{IACC}$ as a function of source-receiver distance](image)

### 2.3 Experimental design

The main aim of the laboratory experiment is to explore the relationship between ASW of masker sound and masking effect. According to the previous studies, ASW is affected by the spectral component of the source, the IACC and SPL [5,9,10]. Thus, four fountain sounds at a distance of 0, 2, 6 and 8 m were selected as auditory maskers based on the $W_{IACC}$ values. The fountain at a distance of 4 m was omitted because the difference in $W_{IACC}$ was relatively smaller than the other recorded fountain sounds. The four selected fountain sounds used as maskers were fixed at two different SPLs ($L_{Aeq,10s}$), 62 and 65 dBA to examine the effects of SPL on ASW and auditory masking. As a maskee, road traffic noise, recorded from the expressway at a distance of 35 m from the closest lane, was used in this experiment. The recorded road traffic was set to 65 dBA.

As illustrated in Figs. 4(a) and 4(b), the road traffic noise has larger energy between 250 to 315 Hz and constant SPLs in the range from 400 Hz to 4 kHz. The fountain sounds contain higher sound energy at frequencies from 2 to 4 kHz than those below 1.25 kHz. There are significant differences in SPLs at frequencies below 1 kHz. Overall, the fountain sound has higher energy at low frequencies as source-receiver distance increases.

The auditory experiments consist of two sessions to investigate the effect of ASW of water fountain on masking traffic noise. Session I aimed to evaluate the apparent source width of acoustic stimuli. In total, nine individual acoustic stimuli (one road traffic noise and eight fountain sounds) were used in Session I. Paired-comparison tests of the nine stimuli were performed to obtain scale values of ASW. Paired combinations of the nine stimuli resulted in 36 pairs. The participants were asked to choose the wider stimulus in each pair. Session II was conducted to evaluate the perceived loudness of noise (PLN) for the acoustic stimuli. Magnitude estimation (ME) was applied to evaluate the PLN. In the ME method, the participants were asked to assign a reference value of 100 to the road traffic noise at 65 dB to express the perceived loudness of noise. The participants are then requested to assign a number for the following stimuli in proportion to their loudness of traffic noise. For instance, they were asked to assign a value of 50 if it is perceived as twice as half.
A total of 10 participants (male: 6 and female 4) with normal hearing took part in the experiments. The acoustic stimuli were presented to the participants via headphones (Beyerdynamic Custom One Pro). During the experiments, the participants were allowed to listen to the acoustic stimuli as many times as they wanted to answer the questions. Each pair of stimuli was presented in a random order.

3. Results

3.1 Apparent source width of fountain sounds

The paired comparison test in Session I aims to compare the ASW of the acoustic stimuli. The scale values of ASW were calculated based on Thurstone’s Law of Comparative Judgment Case V [11]. The calculated scale value of ASW for nine acoustic stimuli including the fountain sounds and the road traffic noise as a function of the $W_{IACC}$ is shown in Fig. 5. Overall, the scale value of ASW increases with increasing $W_{IACC}$, showing a good agreement with findings of the previous studies [5,9]. The scale value of the road traffic noise was much higher than those of the fountain sounds. Regarding the fountain sounds, the participants judged the fountain sounds at 68 dBA to be wider than the fountain sounds at 62 dBA supporting a previous study [5].

Figure 4: 1/1 octave band spectra for the road traffic noise at 65 dBA and four fountain sounds at (a) 62 dBA and (b) 68 dBA

Figure 5: Scale values of ASW for the acoustic stimuli as a function of $W_{IACC}$
3.2 Perceived loudness of traffic noise

Geometric mean values of the magnitude estimates for the PLN across all acoustic stimuli were calculated and the results are plotted as a function of $W_{IACC}$ in Fig. 6. In terms of masking effect, only the fountain sounds at 68 dBA slightly deceased the PLN by 10 %, whereas the fountain sound at 62 dBA even increased the PLN. These findings can be explained by the spectral-temporal characteristics of the fountain sounds and the traffic noise. The fountain sounds have weak energy at low frequencies so that it is difficult to energetically mask the traffic noise at low frequencies. In particular, the fountain sounds at 62 dBA shows similar frequency characteristic with the traffic noise over 2 kHz which might cause target-masker confusions thereby increasing the PLN. Moreover, the temporal characteristics of the fountain sounds and traffic noise are considered as stationary, and thus attentional masking was minimal. Regarding the effect of ASW on masking, there are weak and negative correlations between PLN and $W_{IACC}$ for both fountain sound at 62 and 68 dBA.

![Figure 6: Geometric mean values of the perceived loudness of noises as a function of $W_{IACC}$. The red dashed line indicates the perceived loudness of the reference (road traffic noise of 65 dBA) assigned as a value of “100”.](image)

4. Conclusions

The fountain sounds were recorded in-situ environment varying the source-receiver distance. It was found that the ASW of the fountain sounds increases as the distance from the fountain increase. The effects of ASW and SPL of fountain sound on masking traffic noise were examined based on auditory experiments under laboratory conditions. The results show that both ASW and SPL affect masking of traffic noise. The fountain sounds at higher SPL resulted in greater masking effect than those at lower SPL. The fountain sound with wider ASW might be more effective to reduce the traffic noise even though the effect of ASW was smaller than that of SPL on masking. The present study has some potential limitations. Only one type of fountain sound was used in this study. It is known that the spectral-temporal characteristics of water sound significantly influence on masking effect. In addition, the ranges of $W_{IACC}$ was limited to examine the effect of ASW on masking. Thus, further study using a wider range of fountain sounds and $W_{IACC}$ are necessary to understand the effect of ASW on auditory masking.
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REFERENCES


