On the study of effects on different types of natural sounds on the perception of combined sound environment with road traffic noise

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ABSTRACT

Previous studies suggested that individuals generally had high preferences for natural sounds. Natural sounds like water sounds and bird songs added to noises were determined to be able to improve the quality of acoustic environment. Although it has been revealed how different types of water sounds would affect the preferences for environment differently when adding to road traffic to noises, little effort was spent on investigating how different types of natural sounds would interact with noises in a combined sound environment. Accordingly, this study aimed at comparing the effects of bird songs and water sounds on the perception of combined sound environment. It also aimed at studying whether a particular range of signal-to-noise ratios existed for bird songs which could produce the best sound masking effect for traffic noise. Also, it aimed at revealing the relationship between the perceived dominant sound source and noise annoyance induced by the combined natural-traffic sounds. The findings arising from this study should provide more insights on open space planning for maximizing the acoustic comfort in the environment.

Keywords: Natura sounds, Traffic Noise, Noise Annoyance, Combined Sound Environment
I-INCE Classification of Subjects Number(s): 63.2

1. INTRODUCTION

Noise annoyance is a common problem in cities. It was estimated that about 33% of the population in the European Union suffered from noise annoyance in daytime (1). Road traffic noise was one of the major noise sources in compact cities, which was under active investigations. In response, substantial efforts have been put to reduce annoyance induced by traffic noise by controlling the noise level exposed by individuals. Besides, adding natural sounds to the existing soundscape was also found to be one of the feasible ways to enhance the perception of acoustic environment (2,3).

Water sound was found to be one of the natural sounds which could enhance urban soundscape in open spaces (4–6). Water sounds were found to possess the capability of enhancing the preferences of acoustic environment with traffic noise when a water sound was added (7). Previous studies also suggested that the capability differed for different types of water sounds. Adding stream sound to traffic noise would give the highest preference for the acoustic environment, followed by adding sound waves of lake (8). Another study also suggested that sounds of water stream and falling water were more effective in terms of enhancing the overall preferences for acoustic environment with traffic noise (9). Besides, fountain sound could help reduce the perceived loudness of traffic noise which would in turn enhance the preference of acoustic environment (10). Meanwhile, there were also studies which aimed at revealing the characteristics of water sounds that could effectively enhance the preferences for combined water-traffic sounds. In general, highest preferences for the acoustic environment would be attained when the sound level of water source was not less than 3 dB lower than that of traffic noise (9,11,12). Although there were a number of studies which revealed the effectiveness of water sound in enhancing quality of acoustic environment, few studies have been conducted on determining how other types of natural sounds such as bird songs would affect the preferences of acoustic environment with traffic noise. In fact, a previous study suggested that adding bird songs to traffic noise could reduce the perceived loudness of traffic noise and increase the pleasantness and eventfulness of the acoustic environment (2). However, it is still unclear about the difference in effectiveness between bird songs and water sounds in enhancing the quality of acoustic environment with traffic noise. It will also be of interest to know whether there exists an optimal

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signal-to-noise ratio between bird songs and traffic noise that will yield the lowest noise annoyance induced by the combined bird-traffic sound, as in the case of adding water sound to traffic noise.

Additionally, there was also no study which aimed at revealing the interaction between the perceived dominant sound source of natural-traffic sound and the perception of acoustic environment. It is also unknown about the relationship between the perceived dominant sound source and the signal-to-noise ratio (SNR) between sound sources. Nonetheless, it will help to gain a deeper understanding on the phenomenon of masking traffic noise by adding natural sounds if these relationships could be revealed.

Accordingly, this study aimed at investigating how bird songs and water sound would affect the perception of acoustic environment with traffic noise differently. It also aimed at revealing if there existed a range of signal-to-noise ratio between bird songs and traffic noise which would result in the lowest noise annoyance induced by the bird-traffic sound. The relationship between perceived dominant sound source and noise annoyance induced by the natural-traffic sound would also be examined.

2. METHODOLOGY

2.1 Preparation of acoustic stimuli

The annoyance induced by combined natural-traffic sound was elicited by a series of auditory experiments. Road traffic noise was recorded near a trunk road for half an hour. Natural sounds (water stream sound and bird songs) were purchased from professional audio effect websites. Sound scripts of duration 30s were extracted from these sources. Traffic noise and natural sounds were combined using Audacity 2.0.5. The spectral characteristics of the single and combined sound scripts were analyzed with B&K 4128C (Head and Torso Simulator) and B&K 2144.

2.2 Design of experiment

Both individual natural sounds / traffic noise and combined sounds of traffic noise and natural sounds were studied. Sound pressure levels (SPL) were fixed at 65 dB(A), 70 dB(A) or 75 dB(A) for all single sound scripts. To this end, 9 single sound scripts were generated. For combined sound scripts, traffic noises were also fixed at 65 dB(A), 70 dB(A) or 75 dB(A) while the signal-to-noise ratio of the two sound sources increased from -9 to 9 dB, in a step of 3 dB. As a result, there were a total of 42 combined sound scripts in the experiments. Here, a negative signal-to-noise ratio means that sound pressure level of natural sound is smaller than that of traffic noise, and vice versa.

The experiments were conducted in a study room in the Department of Building Services Engineering in the Hong Kong Polytechnic University. Pleasantness of the single sound scripts and annoyance responses to the combined sound scenarios were elicited by means of questionnaire survey. Participants were asked to sit in front of a desk and relax. Sound scripts of duration 30s were shown to the participants using a Sennheiser HD 280 Pro headset. After presenting each sound script there was a break of 15s for the participant to give the pleasantness / annoyance rating before the next script was shown. Pleasantness of single sound scripts was elicited using an 11-point scale (-5 to 5; where “-5” denotes “extremely unpleasant” and “5” denotes “extremely pleasant”). Similarly, annoyance ratings of combined sound scripts were elicited using an 11-point scale (0 to 10; where “0” denotes “not at all annoyed” and “10” denotes “unbearable”). The perceived dominance of sounds of the combined sound scripts was also revealed using an 11-point scale (-5 to 5; where “-5” denotes “traffic noise totally dominant” and “5” denotes “natural sound totally dominant”). Besides the questions related to the sound scripts, participants were also asked to report their personal characteristics such as age and gender in the questionnaire survey. In particular, their self-rated noise sensitivity was asked using a 5-point scale (1 to 5; where “1” denotes “not at all sensitive” and “5” denotes “extremely sensitive”). Self-rated health status of the participants was also elicited in a similar manner.

In total, there were 51 single and combined sound scripts. As there can be degrade of quality of response if participants were asked to respond to all 51 sound scripts. The combined scripts were randomly divided into three blocks such that each participant only had to respond to 9 single and 14 combined sound scripts.

3. RESULTS

A total of 95 participants were invited and successfully completed the experiments. Each of these participants was given a supermarket coupon of HKD50 in value (~USD6.5) as a gift. Most of the participants were university students of age between 20 and 25. 54.7% of participants considered themselves "healthy" or "extremely healthy". 65.3% of participants rated themselves as "sensitive" or "extremely sensitive" to noise. Meanwhile, none of the participants considered themselves either "extremely unhealthy" or "not at all sensitive" to noise. Table 1 summarizes the personal characteristics of the participants.

Table 1 – Summary statistics of personal characteristics of participants

Gender	*Male*	24.2%	
	Female	75.8%	
			Mean (S.D.)
Age	*<20*	16.8%	21.9 (4.24)
	20-25	70.5%	
	26-30	4.2%	
	>30	8.4%	
Health status	*Extremely unhealthy*	0%	3.45 (0.78)
	Unhealthy	13.7%	
	Normal	31.6%	
	Healthy	50.5%	
	Extremely healthy	4.2%	
Noise sensitivity	*Not at all sensitive*	0%	3.68 (0.84)
	Not sensitive	10.5%	
	Normal	24.2%	
	Sensitive	51.6%	
	Extremely sensitive	13.7%	

3.1 Spectral characteristics of sound scripts

Figure 1 shows the spectral characteristics of the single sound scripts at 60 dB(A). It can be seen that the energy contents of traffic noise at low and middle frequency ranges were higher while the energy content at high frequency range was lower. On the contrary, there were generally higher energy contents at the middle and high frequency ranges for water stream sound. Meanwhile, the energy of bird songs was more fluctuated along different frequency ranges. Figure 2 shows spectral characteristics of the combined sound scripts at 60 dB(A) with a signal-to-noise ratio of 0 dB. It can be seen that the energy is considered more "balanced" at different frequency ranges except that there was a significant drop in energy starting from 5000Hz when bird songs were added to traffic noise.

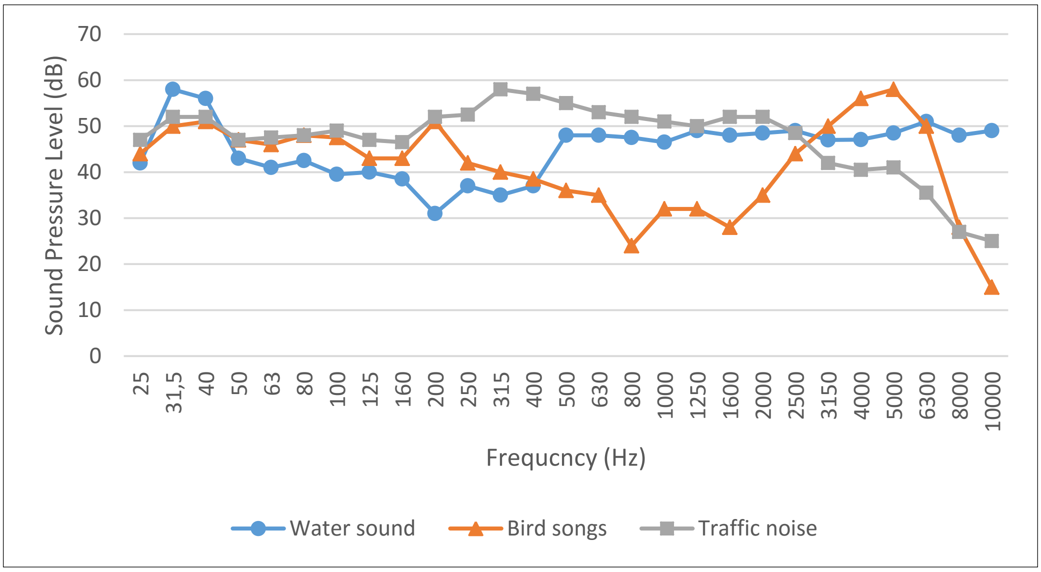

Figure 1 – Spectral characteristics of single sounds at 60 dB(A)

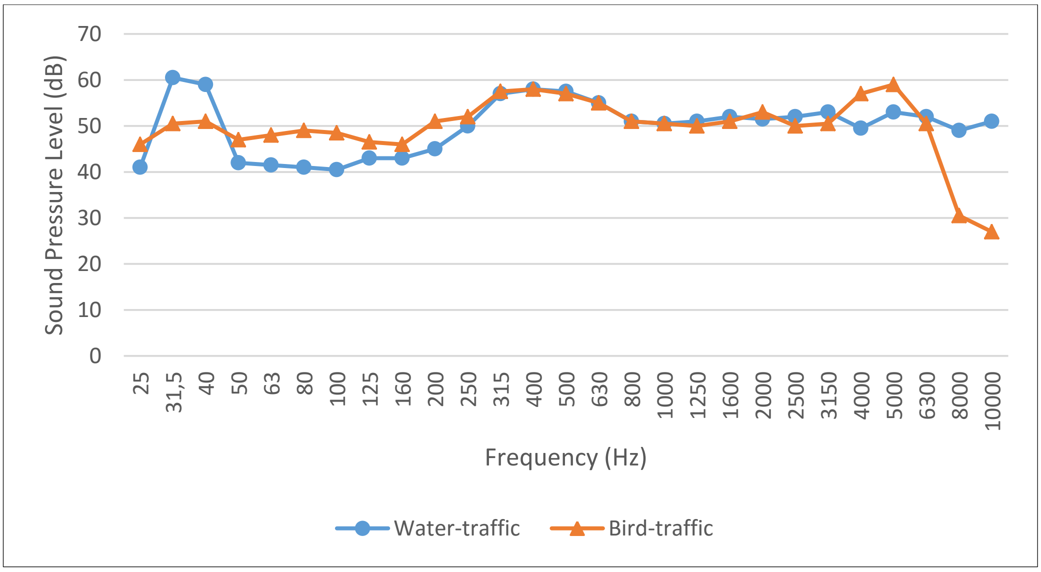

Figure 2 – Spectral characteristics of combined sounds of SNR 0 dB at 60 dB(A)

3.2 Types of natural sounds adding to traffic noise and noise annoyance

Figure 3 shows the mean annoyance ratings when different types of natural sounds (bird songs and water stream sound) were added to traffic noise. Basically, the annoyance ratings of combined bird-traffic sound and combined water-traffic sound were similar when the sound pressure level of traffic noise was 55 dB(A). Independent sample t-test also confirmed that there was no significant difference in the mean annoyance ratings between combined bird-traffic sound and combined water-traffic sound in this case. However, the annoyance ratings of combined bird-traffic sounds were found to be slightly lower than combined water-traffic sounds when sound pressure levels of traffic noise were 60 dB(A) and 65 dB(A). Upon performing independent sample t-test, it was found that there were significant differences in mean annoyance ratings between combined bird-traffic sounds and combined water-traffic sounds ($p<0.05$). This indicates that bird songs would produce a stronger noise annoyance moderation effect than water stream sound when adding to traffic noise whose level lying between 60 dB(A) and 65 dB(A). However, the annoyance moderation effects of these two types of natural sounds were similar when noise level of traffic noise was 55 dB(A). This probably suggested that the type of natural sounds added to traffic noise would not affect the perception of acoustic environment at low total sound pressure level.

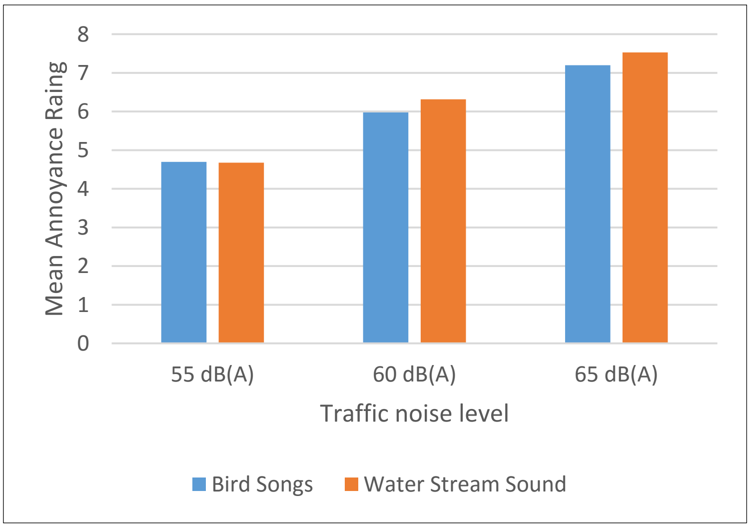

Figure 3 – Mean annoyance ratings when bird songs / water stream sound was added to traffic noise

Meanwhile, bird songs were generally perceived to be more pleasant than water stream sound (i.e.

the mean pleasant scales of bird songs = 2.47 > water stream sound =1.63; with independent sample t-test results of $p<0.01$). Bird songs performed better in enhancing the acoustic environment with traffic noise, which probably suggested that a more pleasant natural sound would perform better in enhancing the acoustic environment.

3.3 Perceived dominance of sound source and noise annoyance

The correlation between perceived dominance of sound sources and signal-to-noise ratio was found to be 0.397. Individuals generally found the natural sound to be more dominant if the sound pressure level of added natural sound was higher than that of traffic noise, and vice versa.

Figure 4 shows the relationship between mean annoyance ratings of the combined sounds and the level of perceived dominance. Annoyance rating would become lower when the natural sound was perceived to be the dominant sound (level of perceived dominance >0). On the contrary, the annoyance rating would become higher when the combined sound was perceived to be dominated by traffic noise. This suggested that the phenomenon of masking of traffic noise by adding natural sounds was related to the perceived dominance of natural sounds. The capability of masking traffic noise by adding natural sound would be greater if an individual perceived that the natural sound was more dominant. Additionally, it can be seen that the annoyance rating would drop when the natural sound was perceived to be extremely dominant (level of perceived dominance > 3). This could probably be explained by the phenomenon that perceived dominance was positively correlated with signal-to-noise ratio. A higher level of perceived dominance would suggest a higher signal-to-noise ratio and hence a higher sound pressure level of the natural sound. This would result in a higher sound pressure level of the combined sound. Thus, the increase in annoyance rating was probably due to the increase in the total sound pressure level.

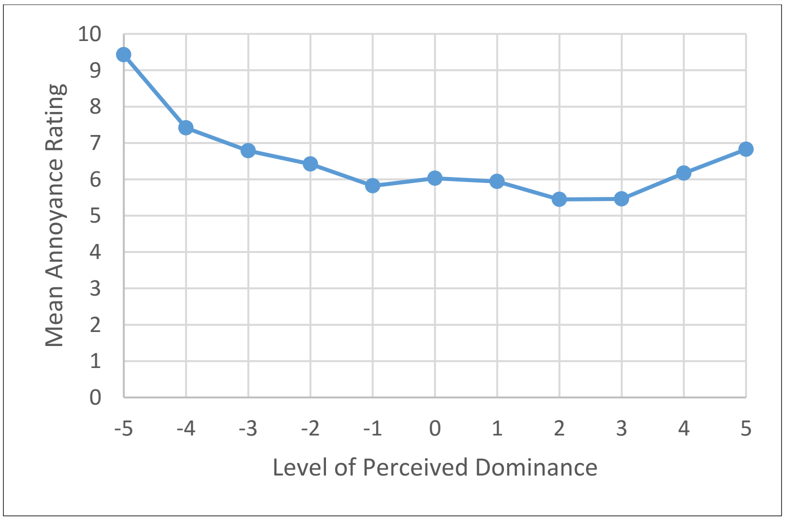

Figure 4 – Relationship between mean annoyance ratings and levels of perceived dominance of combined sounds

3.4 Signal-to-noise ratio and noise annoyance

Figures 5 and 6 show the relationship between mean annoyance rating and signal-to-noise ratio of the combined sounds. When traffic noise was combined with water stream sound, the mean annoyance ratings tended to be lower when the signal-to-noise ratio lying between -3 to 3 dB. This basically agreed with previous results that highest preferences for acoustic environment would be attained when the sound pressure level of water sound was not less than 3 dB lower than that of traffic noise (9,11,12). However, it should also be noted that the range of signal-to-noise ratio found in this study was slightly different from that reported in previous studies. One of the possible explanations for this slight deviation is that noise annoyance was not directly correlated with sound preference. When traffic noise was at 65 dB(A), the annoyance rating induced by water-traffic sound was found to be the lowest at a signal-to-noise ratio of -9 dB(A). It was probably due to the relatively low total sound pressure level of water-traffic sound. As a matter of fact, previous studies (9,11,12) focusing on the relationship between signal-to-noise ratio of water-traffic sound and perception of acoustic environment only investigated signal-to-noise ratio ranging from -6 to 6 dB. This study expanded the range of single-to-noise ratios to be investigated so as to give a more holistic picture on revealing the relationship between signal-to-noise ratio of the water-traffic sound and perception of acoustic environment. On the other hand, a signal-to-noise ratio of 0 dB or 6 dB of bird-traffic sound would give the lowest annoyance rating when sound pressure level of traffic noise was 55 dB(A). However, the annoyance ratings were found to be lowest when signal-to-noise ratio of bird-traffic sound was 9 dB if the sound pressure levels of traffic noises were 60 dB(A) or 65 dB(A). This suggested that quality of the combined acoustic environment would be enhanced to the greatest extent if the signal-to-noise ratio of bird-traffic sound ranged from 6 dB to 9 dB.

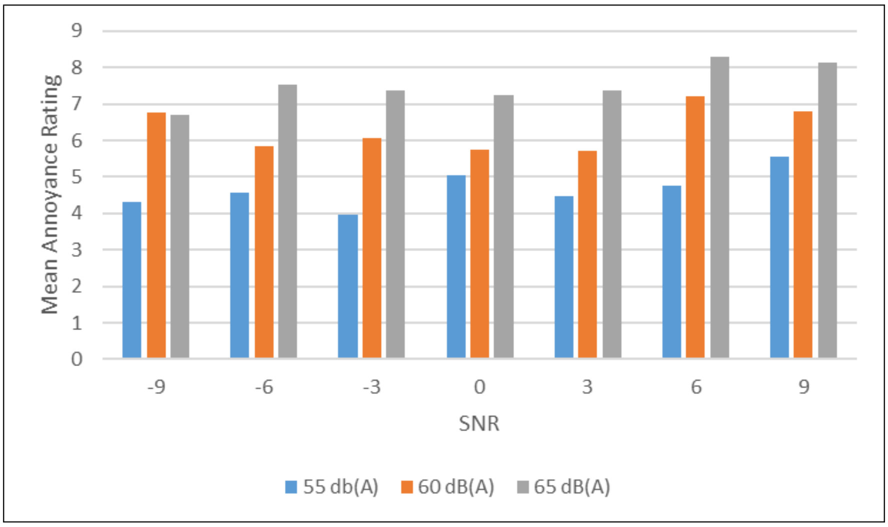

Figure 5 – Relationship between mean annoyance ratings and SNR of water-traffic sound at different traffic noise levels

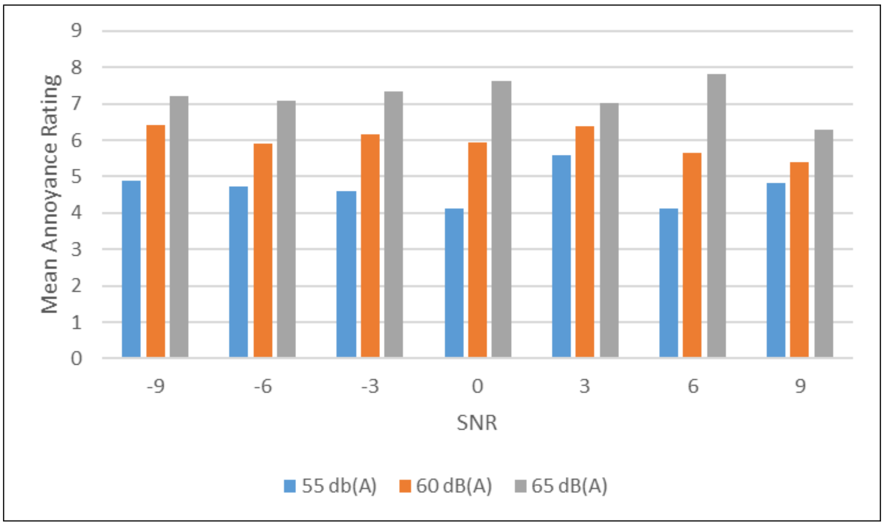

Figure 6 – Relationship between mean annoyance ratings and SNR of bird-traffic sound at different traffic noise levels

4. CONCLUSIONS

In this study, noise annoyance responses invoked by adding bird songs / water stream sound to traffic noise were investigated. Basically, it was found that adding bird songs, which were perceived to be more pleasant by individuals, to traffic noise would yield a lower annoyance rating. The annoyance rating tended to be lower if an individual perceived that natural sound was the dominant sound in the combined acoustic environment with traffic noise. This should partly explain the phenomenon of sound masking of traffic noise by adding natural sounds. Additionally, it was found that quality of acoustic environment was enhanced to the greatest extent if signal-to-noise ratio of bird-water sound was between 6 dB and 9 dB. These results should be able to give valuable insight for urban planners when planning open space with traffic noise being one of the major noise sources.

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