The effects of neighborhood views containing multiple environmental features on road traffic noise perception at dwellings

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(Received 31 May 2016; revised 14 March 2017; accepted 15 March 2017; published online 5 April 2017)

The importance of non-acoustical factors including the type of visual environment on human noise perception becomes increasingly recognized. In order to reveal the relationships between long-term noise annoyance and different types of neighborhood views, 2033 questionnaire responses were collected for studying the effect of perceptions of different combinations of views of sea, urban river, greenery, and/or noise barrier on the annoyance responses from residents living in high-rise apartments in Hong Kong. The collected responses were employed to formulate a multivariate model to predict the probability of invoking a high annoyance response from residents. Results showed that views of sea, urban river, or greenery could lower the probability, while views of noise barrier could increase the probability. Views of greenery had a stronger noise moderation capability than views of sea or urban river. The presence of an interaction effect between views of water and views of noise barrier exerted a negative influence on the noise annoyance moderation capability. The probability due to exposure to an environment containing views of noise barriers and urban rivers would be even higher than that due to exposure to an environment containing views of noise barriers alone. © *2017 Acoustical Society of America*. [http://dx.doi.org/10.1121/1.4979336]

[KVH] Pages: 2399–2407

I. INTRODUCTION

Road traffic noise is considered as one of the most predominant noise sources in cities. Noise induces annoyance which poses adverse impacts on individual well-being and health (Babisch *et al.*, 2005; Willich *et al.*, 2006). In response, substantial efforts and resources have been spent on monitoring and mitigating the noise impacts within city areas by focusing mainly on measures targeting at lowering sound pressure levels (Klæboe *et al.*, 2000; Korfali and Massoud, 2003; Sato *et al.*, 1999). However, recent research has shown that reducing the noise level does not necessarily lead to better acoustic comfort as expected (Ballas, 1993; Kang, 2006; Paunović *et al.*, 2009; de Ruiter, 2005). The influences of non-acoustical factors in relation to source, receiver, and context on community's noise reactions have been determined to be as significant as pure acoustical factors (Gidlöf-Gunnarsson and Öhrström, 2007; King *et al.*, 2009).

Greater attention should be given to explore new neighborhood planning and design concepts that make use of human behavioral or psychological responses to resolve noise annoyance problems in dwellings. Visual stimuli have been widely reported in the literature to have a capability of modifying the auditory perception of individuals (Brown, 2012; Pheasant *et al.*, 2010a). As the impact of visual settings on noise perception was found to be quite significant (Hong and Jeon, 2013; Pheasant *et al.*, 2008; Pheasant *et al.*, 2010a; Viollon *et al.*, 2002; Zhang and Kang, 2007), the principle of auditory–visual interaction should be more actively explored.

A highly urbanized visual setting would make the perceptions of sound environment less pleasant and less relaxing (Viollon *et al.*, 2002). Views of buildings (Ren and Kang, 2015) and wind turbines (Pedersen and Larsman, 2008) generally deteriorated acoustic comfort and worsened noise annoyance problem. By contrast, visual perceptions of natural features could moderate annoyance responses. Proximity to greenery significantly improved the quality of acoustic environment, reduced dissatisfaction with traffic noise (Kastka and Noak, 1987), and moderated long-term noise annoyance of residents (Gidlöf-Gunnarsson and Öhrström, 2007; Li *et al.*, 2010; Ulrich *et al.*, 1991). In addition, the perceived proportion and degree of naturalness of greenery also influenced noise perception. Residents who perceived moderate proportion of greenery from their homes were found to be less annoyed by road traffic noise than those perceiving only a little proportion of greenery (Li *et al.*, 2010; Van Renterghem and Botteldooren, 2016). Noise barriers covered by vegetation not only received higher aesthetics preference ratings (Hong and Jeon, 2014), but also led to lower noise annoyance ratings (Maffei *et al.*, 2013). Besides, an environment containing views of water space was also found to be able to improve perception of

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acoustical environment. The annoyance caused by traffic noise could be moderated by perceiving views of the sea at home (Li *et al.*, 2010), and the acoustic comfort could be improved by perceiving a distant view of wetlands (Ren and Kang, 2015).

However, it is not clear whether the noise annoyance moderation capability varies with the types of settings of greenery and water space. Besides, a majority of findings reported from laboratory tests were mainly drawn from bivariate statistical tests rather than multivariate quantitative models explicitly relating annoyance responses to visual, acoustical, and other relevant factors. Recently, models have been developed to predict the tranquility rating of a place based on both visual and acoustical factors (Pheasant *et al.*, 2008, Pheasant *et al.*, 2010a; Pheasant *et al.*, 2010b; Watts *et al.*, 2011; Watts *et al.*, 2013; Watts and Pheasant, 2015) by using the percentages of visible environmental features perceived and noise levels. However, these models did not differentiate the effects of different types of natural and built features within the visual environment.

Accordingly, this study formulates a multivariate quantitative model to predict the long-term annoyance responses of residents exposed to different types of neighborhood views. The formulation of multivariate model enables comparison of noise annoyance moderation capability of individual natural/built environmental features. In addition, it also helps reveal whether the noise annoyance moderation capability differs among different types of water space. The findings arising from the formulated model can facilitate urban planners and building designers in making decisions on how to improve the acoustical perception of residents living near traffic noise sources and their dwelling environment containing views of multiple environmental features.

II. METHODOLOGY

This study aims to elicit the long-term noise annoyance responses from residents who can perceive views of multiple environmental features in real-life situations. To achieve this, a questionnaire was employed as a main survey instrument to reveal the effect of different types of neighborhood views from apartments in high-rise buildings on the noise annoyance responses given by residents exposed to road traffic noises.

A. Site selection

A series of field studies were carried out in five residential estates in Hong Kong to investigate how the visual perceptions of the residents would affect their annoyance responses. A number of criteria had been defined for identifying suitable survey sites. First, road traffic should be the major noise source for the identified sites. Second, some of the residents could perceive views of greenery and/or water space such as sea or urban rivers from their apartments, while some could perceive views of noise barrier. As it was very difficult to identify a site that possessed all the different types of predetermined environmental features, a site would only be selected if it possessed a majority of them. In consequence, five different residential estates were identified, which are located in Kwun Tong (KT), Sheung Shui (SS), Tai Po (TP), Shatin (ST), and Tsuen Wan (TW) [see Figs. 1(a)–1(e)]. In sites KT, SS, and TP, some of the residents could perceive views of noise barriers from their apartments. In these sites, all the noise barriers were covered by trees planted along the boundaries of residential estates. In sites ST and TP, some residents could perceive views of urban rivers. Some residents in sites TP and TW could perceive views of the sea. Besides, views of different proportions of greenery could be perceived from different apartments located in all five sites. Table I summarizes the characteristics and types of environmental features that could be perceived from the five sites, respectively.

B. Noise level prediction

Noise levels were predicted for individual apartments before revealing their relationships with noise annoyance responses. In this study, noise levels in terms of L_{A10} (1 h), at 1 m from the facades of different apartments in buildings were predicted using ODEN software (ODEN Systems, 2016). ODEN is a web-based noise mapping platform utilizing the scheme calculation of road traffic noise (CRTN) (Department of Transport Welsh Office, 1988). With the aid of CRTN, noise levels were predicted based on the locations and orientations of apartments relative to the major trunk roads, as well as traffic data such as vehicle speeds and the average number of heavy and light vehicles. In addition, CRTN was also used to predict the noise levels behind noise barriers. In fact, CRTN was a widely used method for prediction of noises at building facades of apartments since access could not be gained for performing noise measurements (Job *et al.*, 2001; Miedema and Vos, 1999). CRTN was shown previously to be able to predict noise levels in Hong Kong within a standard error of 2 dB (Tang and Tong, 2004).

Past experience suggested that there were some differences in noise levels between CRTN predictions and site measurements (Lam and Tam, 1998). These differences were mainly due to the unknown effects of local terrains and their surroundings, which are independent of road traffic. With the measured traffic flows and noise levels, the noise level predicted by CRTN could be compared against the noise level measured at a particular measurement point. The differences between CRTN predicted noise levels and measured noise levels were then expressed as constants and added to all the later CRTN predictions. Noise levels in five sites were measured at 1 m from the facades on roof top, ground floor, as well as an intermediate floor level of the buildings during rush hours. Two measuring points were monitored at each floor, i.e., one facing the main trunk road and the other facing the opposite side. Each measurement period lasted for 1 h.

C. Survey instrument

Questionnaire surveys were conducted via face-to-face manner in the public spaces located within the five sites. Surveys were conducted only during daytime on weekends and public holidays to avoid capturing only those elderly or

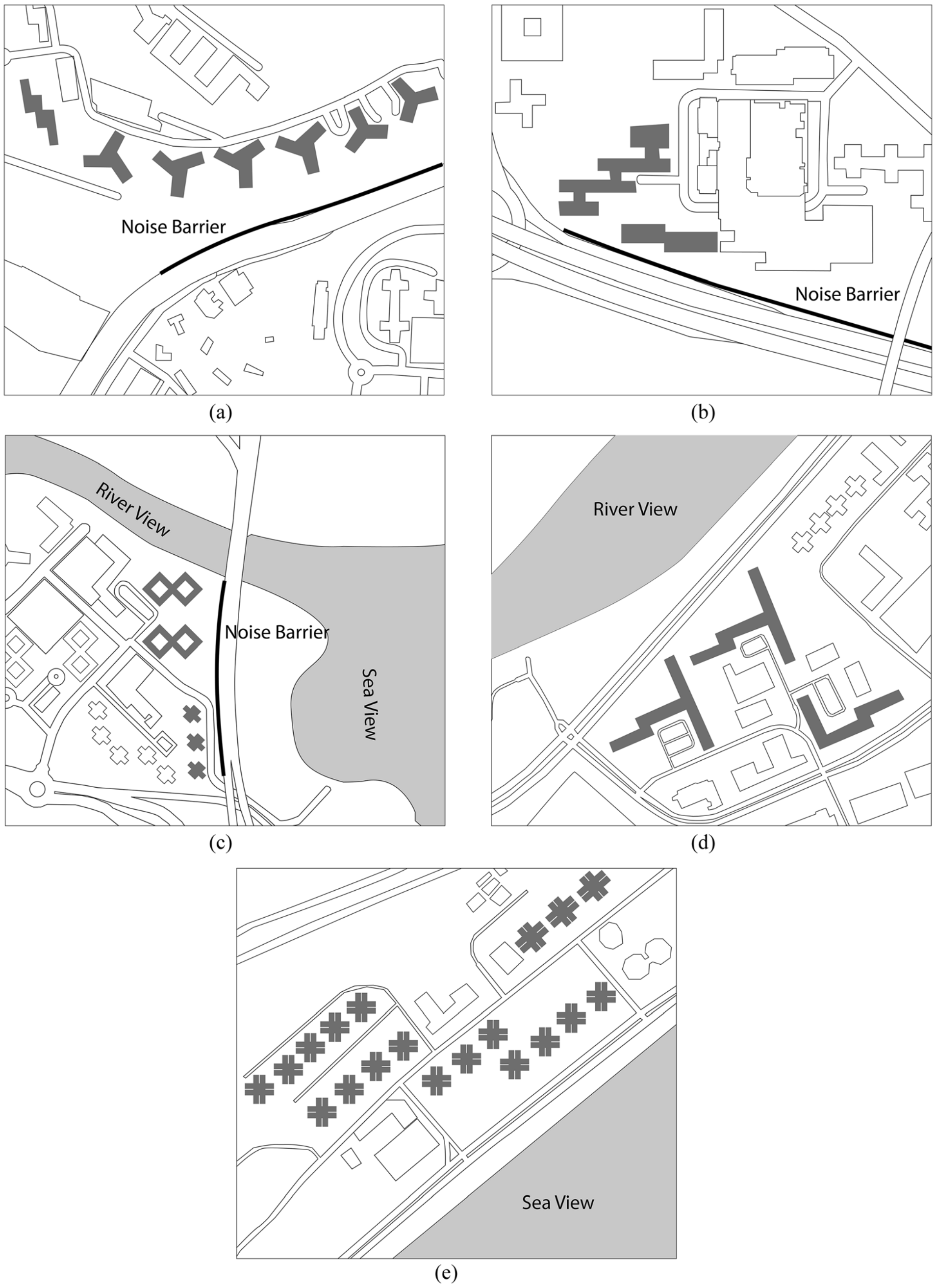

FIG. 1. (a) Site configuration of Kwun Tong (KT). (b) Site configuration of Sheung Shui (SS). (c) Site configuration of Tai Po (TP). (d) Site configuration of Shatin (ST). (e) Site configuration of Tsuen Wan (TW).

individuals who stayed at home for a long time during daytime on weekdays. Respondents were approached in a random manner. A respondent would only be invited to participate in the questionnaire survey if he/she indicated that he/she was living in the survey residential estate. Upon successful completion of the questionnaire survey, each respondent would be given a McDonald's cash coupon of HK\$10 (∼US\$1.3) as a reward.

TABLE I. Types of features that could be perceived from the survey sites.

	Sites				
	KT	SS	TP	ST	TW
1 Greenery	√	√	√	√	√
2 Sea			√		√
3 Urban river			√	√	
4 Noise barrier	√	√	√		
5 Road traffic	√	√	√	√	√
6 Building	√	√	√	√	√

The questionnaire was divided into three main sections and the entire survey was conducted in Cantonese. The first section aimed at identifying the types and proportions of features that would be visible from respondents' apartments. The proportions of a particular type of visible environmental features were elicited using a five-point verbal scale in Chinese ("*Not at all,*" "*Little,*" "*Moderate,*" "*Considerable,*" and "*Predominant*"). The wordings used in the verbal scale had been tested in our pilot studies with a number of laypersons with an aim to remove any ambiguities. Meanwhile, questions relating to views of a specific type of environmental feature were included only if that type of feature was present in the survey site. More specifically, questions relating to views of noise barriers were only included for sites KT, SS, and TP while questions relating to views of water space were only included for sites TP, TW, and ST.

The second section of the questionnaire aimed at eliciting the noise annoyance ratings induced by road traffic noises. Respondents were asked to assign their annoyance ratings using an 11-point scale (0–10; where "0" denotes "*Not annoyed at all*" and "10" denotes "*Extremely annoyed*"), following the recommendations laid down in ISO Standard 15666 (2003).

In the third section, apartment details and personal characteristics of respondents including their gender, age, education level, monthly income, time spent at home, health status, and noise sensitivity were asked. Specifically, they were required to indicate the location, orientation, floor level of their apartments with the aid of a given site map which outlined the locations and orientations of all housing blocks located within the survey estates. In addition, respondents were asked to report the periods they normally stayed at homes each day (i.e., *00:00–06:00, 06:00–12:00, 12:00–18:00, and 18:00–24:00*), and they could indicate more than one period. The entire day was broken into four periods, which was a compromise between the level of information required and the ability to match the daily life patterns of Hong Kong people. Additionally, respondents would indicate their self-rated noise sensitivity using a five-point verbal scale ("*Not sensitive at all,*" "*Slightly sensitive,*" "*Moderately sensitive,*" "*Very sensitive,*" and "*Extremely sensitive*"). Similarly, all the verbal scales included in this section had been tested in our pilot studies.

D. Model formulation

Ordered logit model was formulated to analyze the noise annoyance data collected from the questionnaire surveys. The McFadden's ρ^2 was applied to estimate the maximum likelihood of the final model (Louviere *et al.*, 2000). McFadden's ρ^2 is analogous to R^2 commonly applied in linear regression in that the log likelihood of the intercept model can be regarded as the total sum of squares while the log likelihood of the full model can be regarded as the sum of squared errors. The ratio of the likelihoods gives the level of improvement over the intercept model offered by the full model. High McFadden's ρ^2 value indicates a higher likelihood in model prediction (Kleinbaum and Klein, 2010).

As high noise annoyance response is a major concern of our study, the original ratings of 11-point scale were regrouped into three categories of responses, i.e., low/medium/high, before model formulation. The general form of ordered-logit model used to estimate the latent variable Z as a linear function of independent variables (Hamilton, 2006) is

$$Z = \sum \beta_i x_i + \varepsilon, \tag{1}$$

where x_i represents the independent variables such as the perceived proportion of views of sea, noise level in the apartment, and self-rated noise sensitivity; β_i represents the coefficients of the independent variables; and ε is a logistically distributed error.

The predicted probabilities of invoking a particular type of annoyance response depends on the value of Z and cut points μ_n. They were computed by

$$\Pr(\text{Annoyance} = \text{“Low”}) = \Pr(Z \le \mu_1) = \frac{1}{1 + e^{(Z-\varepsilon-\mu_1)}}, \tag{2}$$

$$\Pr(\text{Annoyance} = \text{“Medium”}) = \Pr(\mu_1 < Z \le \mu_2) = \frac{1}{1 + e^{(Z-\varepsilon-\mu_2)}} - \frac{1}{1 + e^{(Z-\varepsilon-\mu_1)}}, \tag{3}$$

$$\Pr(\text{Annoyance} = \text{“High”}) = \Pr(\mu_2 < Z) = 1 - \frac{1}{1 + e^{(Z-\varepsilon-\mu_2)}}. \tag{4}$$

III. RESULTS

Full-scale questionnaire surveys were carried out between 2012 and 2014. In total, 2033 questionnaire responses were successfully administered. As a quality assurance procedure, a response would be discarded if it contained conflicting information between neighborhood views and apartment details. Table II shows the summary statistics in surveys.

Ninety four percent of the respondents reported that they could perceive views of water space, greenery, or noise barrier from their apartments. About 27% of the respondents could perceive views of sea and 15% could perceive views of urban rivers at homes. Eighty nine percent could perceive views of greenery while 27% could perceive views of noise barriers. Noise levels of the five sites laid within a range between 46 and 75 dBA with a mean value and a standard deviation value of 63.85 and 5.06 dBA, respectively. Mean noise annoyance rating in five sites was 4.25 (on an 11-point scale, i.e., 0–10). About 8% of the respondents indicated that they were highly annoyed by road traffic noises (i.e., noise annoyance rating >7).

Upon further data analysis, only moderate correlation was found to exist between noise level and annoyance response (Pearson coefficient = 0.276, *P-value* < 0.001). This suggested that it is necessary to incorporate more variables for portraying annoyance responses. The initial model formulation was based on the responses from the original scales of subjective variables such as views of greenery/noise barrier/water space, age, education, health status, and duration of stay at home. Due to unsatisfactory results, the scales were combined and only dichotomized scales were formulated for these variables. The split points for the dichotomized scales were determined from subsequent analysis of the collected data rather than determined beforehand. They were generally determined based on 50% values of the surveyed population and the splits were confirmed to be significant by independent t-tests. Table III lists the coding assigned for the categorized variables used for model formulation.

A. Model for predicting annoyance responses

A stepwise approach was employed for formulating multivariate models. Environmental factors (e.g., view of greenery,

TABLE II. Summary statistics in surveys.

Survey Site Characteristics	
Site	**Number of respondents**
KT	413
ST	258
SS	211
TP	318
TW	833
Total	2033
Types of features	
Water space	
Could not perceive any	1178
Sea	549
Urban river	306
Greenery	
Yes	1805
No	228
Noise barrier	
Yes	549
No	1484
Site	**Noise level**
KT	46.00–73.50 *[Mean:64.04 (7.80[a])]*
ST	53.13–70.21 *[Mean:63.80 (2.83[a])]*
SS	46.30–75.05 *[Mean:63.80 (7.21[a])]*
TP	52.00–71.89 *[Mean:63.07 (4.06[a])]*
TW	54.00–74.48 *[Mean:64.11 (3.17[a])]*
Personal Characteristics	**Number of respondents**
Gender	
Male	960
Female	1073
Educational Level	
Primary or Below	294
Secondary	1020
Tertiary Education or Above	693
Others	26
Age [Mean:40.75 (27.5[a])]	
Below 45	1415
Above 45	618
Self-rated Noise Sensitivity [Mean:3.04 (0.89[a])]	
Sensitive	571
Non-noise sensitive	1462
Self-rated Health Status [Mean: 3.34 (0.82[a])]	
Healthy	849
Not so healthy	1184

[a]*Standard deviation*

sea/urban river, and noise barrier), personal factors (e.g., gender, age, health status, noise sensitivity, occupation) as well as noise levels were input into the model in a stepwise manner. An examined variable would be included into the model if all the following three criteria were satisfied: (i) the variable was significant at 95% level; (ii) inclusion of the variable would significantly improve the McFadden's ρ^2 value; and (iii) inclusion of the variable would not alter the significance of other variables. Results showed that there would be a significant increase in ρ^2 value by including acoustical, environmental, and personal factors (cf. ρ^2 values of the model containing acoustical factor only, acoustical and environmental factors, and acoustical, environmental, as well as personal factors were 0.044, 0.087, and 0.130, respectively).

Besides the main effects, it is also of interest to reveal whether interaction effects exist between major variables. Due to data limitation, we only attempted to verify our hypothesis that interaction effects existed between environmental features and personal characteristics (i.e., greenery × duration of stay at home; greenery × age; water space × duration of stay at home; water space × age; noise barrier × duration of stay at home; noise barrier × age), between environmental features (i.e., greenery × water space; greenery × noise barrier; water space × noise barrier), and between personal characteristics (i.e., age × duration of stay at home). The same set of criteria was applied to assess whether to include or exclude the interaction terms. As a result, interaction terms including water space × noise barrier, water space × duration of stay at home, and age × duration of stay at home were added.

The final multivariable ordered logit model form used to predict high annoyance responses is

$$Z = \beta_{WV}WV + \beta_{BA}BA + \beta_{GR}GR + \beta_{A}A + \beta_{EDU}EDU + \beta_{LS}LS + \beta_{H}H + \beta_{NS}NS + \beta_{NL}NL + \beta_{BA\times WAV}BA \times WV + \beta_{LS\times WV}LS \times WV + \beta_{A\times LS}A \times LS + \varepsilon \quad (5)$$

and the descriptions explaining the abbreviations in the model are given in Table IV.

The McFadden's ρ^2 value obtained for the model was 0.14, which suggests that the model reasonably fit the collected survey data. The McFadden ρ^2 value of 0.2–0.4 represents an excellent fit (McFadden, 1973). Therefore, the overall model fit could be considered as acceptable (Zhang *et al.*, 2015). Table V shows the coefficient estimates for individual variables. A positive sign suggests that annoyance rating increases with the value of the variable. While a negative sign suggests that annoyance rating increases inversely with the value of the variable. According to the results, a higher noise annoyance response would be invoked when views of noise barriers were perceived at home. Lower noise annoyance would be resulted if views of greenery/sea/urban river were perceived at home. Initially, a site-specific dummy variable was added to the model specification for each survey site. However, all these dummy variables were found to be insignificant (*P-value* > 0.05) and subsequently dropped from the final model formulation. This suggests that all the incorporated variables are adequate for portraying the influences of major site characteristics on annoyance responses. In addition, the cut points (i.e., at $Z = 5.608$ and 9.082) determined for the model can be considered as benchmarks for categorizing different types of annoyance responses, i.e., low/medium/high. This in turn can provide valuable information for policy makers to identify which options are available for tipping residents from one annoyance response category to another.

B. Types of neighborhood views

With the formulated model, it is suggested that a significant relationship existed between noise annoyance and views of different types of environmental features. Of particular

TABLE III. The coding of categorized variables used in the models.

Code / Regrouped variables	0	1	2
Annoyance	Low (0 ≤ original annoyance rating ≤ 3)	Medium (3 < original annoyance rating ≤ 7)	High (original annoyance rating > 7)
Greenery	Not at all;	Little; Moderate; Considerable; Predominant	
Noise barrier	Not at all; Little	Moderate; Considerable; Predominant	
Water space	Not at all	Sea view	Urban river view
Age	Below 45	Above 45	
Education	Below Undergraduate	Undergraduate degree or above	
Health status	Very poor; Poor; Moderate	Good; Very good	
Noise sensitivity	Not sensitive at all; Slightly sensitive; Moderately sensitive	Very sensitive; Extremely sensitive	
Duration of stay at home	Stay at home for less than or equal to 12 h a day	Stay at home for more than 12 h a day	

interest is to determine whether noise annoyance moderation capability varies with type of views. The probability value of invoking a high noise annoyance response (i.e., probability value hereinafter) for a view containing a specific type of environmental features was computed by varying the values of variables pertaining to the environmental features while keeping all the other variables at their mean values based on Eqs. (4) and (5). The noise annoyance moderation capability of a specific type of view was revealed by comparing its probability value against the probability value of the baseline condition (for which residents could not perceive any view of greenery, water space, or noise barrier). A view containing a particular type of environmental features was said to have noise annoyance moderation capability if its probability value was lower than that of the baseline condition.

Figure 2 shows the probability values for homogeneous and heterogeneous environments. Homogeneous environment corresponds to an environment containing views of a single type of environmental feature only. Heterogeneous environment corresponds to an environment containing views of more than one type of environmental features, e.g., views of urban rivers and noise barriers. As seen from Fig. 2(a), for a homogeneous environment, views of natural features such as greenery, sea, and urban rivers were found to have noise annoyance moderation capabilities. However, views of noise barrier made the probability even higher than the baseline condition, and thus exert negative influence on the noise annoyance moderation capabilities. Among three types of views of natural features, views of greenery had the strongest noise annoyance moderation capability followed by views of sea and in turn by views of urban rivers. Heterogeneous environments are much more complicated. As seen in Fig. 2(b), a heterogeneous environment containing views of sea or urban

TABLE IV. The descriptions of variables used in Eq. (5).

Symbol	Descriptions
WV	A view of water space
BA	A view of noise barrier
GR	A view of greenery
A	Age group of respondents
EDU	Education level of respondents
LS	Daily duration of stay at home
H	Self-rated health status
NS	Self-rated noise sensitivity
NL	Predicted noise level of the apartment
BA × WV	The interaction effect between views of noise barrier and water space (coded as "1" if both noise barrier and water space could be perceived, and otherwise "0")
LS × WV	The interaction effect between daily duration of stay at home and view of water space (coded as "1" if the respondents stayed at an apartment which was exposed to water space for more than 12 h a day, and otherwise "0")
A × LS	The interaction effect between age and daily duration of stay at home (coded as "1" if the respondents aged above 45 stayed at an apartment for more than 12 h a day, and otherwise "0")

TABLE V. Estimated coefficient values of the ordered logit model.

Model fitting information		
McFadden ρ^2		0.140
Parameter	Coefficient Value (β)	P-value
WATERVIEW		
Sea view	−1.0320[a]	<0.001
Urban river view	−0.5413[a]	<0.001
BARRIER	0.6519[a]	<0.001
GREENERY	−1.1608[a]	<0.001
AGE	0.3130[a]	<0.01
EDU	1.1752[a]	<0.001
LONGSTAY	0.5738[a]	<0.001
HEALTH	−0.2247[b]	<0.05
SENSITIVITY	0.6144[a]	<0.001
NOISE	0.0941[a]	<0.001
BARRIER × WATERVIEW	0.9078[a]	0.001
LONGSTAY × WATERVIEW	0.6164[a]	<0.001
AGE × LONGSTAY	0.6496[a]	<0.01
Cut Points		
μ_1	5.608	
μ_2	9.082	

[a]Significant at 0.01 level;
[b]Significant at 0.05 level

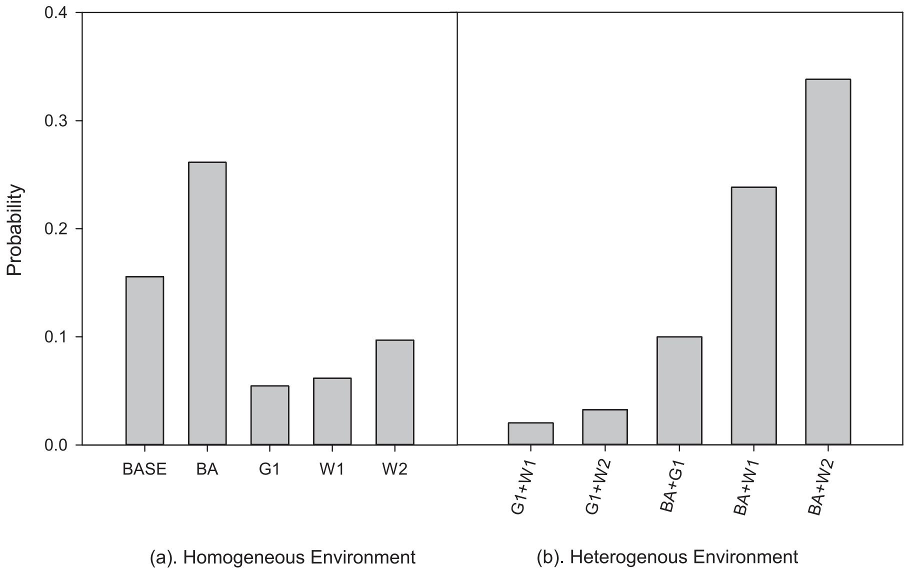

FIG. 2. The probability values induced by the perceptions of different types of neighborhood views - BASE: Baseline condition; BA: Views of noise barrier; G1: Views of greenery; W1: Views of sea; W2: Views of urban river.

river together with greenery made the total moderation capability stronger than a homogeneous environment. In contrast, a heterogeneous environment containing views of noise barriers and urban rivers would even induce a higher probability of invoking a high noise annoyance response than a homogeneous environment containing only views of noise barriers. This was due to the existence of an interaction effect between noise barrier and water space.

C. Personal characteristics and daily life patterns

In addition to the above site characteristics, personal characteristics and daily life patterns also played a role on the annoyance responses. A high annoyance response would be more likely to be invoked for individuals who considered themselves highly noise sensitive or not so healthy. Based on the analysis of the collected responses, individuals who were older than 45 yr, or were degree holders were found to be more likely to be highly annoyed. Additionally, an interaction effect was found between age and duration of stay at home. Individuals who were older than 45 yr and staying at home for more than 12 h were more likely to be highly annoyed by road traffic noise. Meanwhile, some interaction effects were also observed between an individual's daily life patterns and site characteristics. Individuals staying at homes with daily exposure to water space for more than 12 h were found to have higher probabilities of being highly annoyed. The effects of having or not having views of the sea or urban rivers on noise annoyance responses for people staying at homes for more than 12 h were different. Individuals staying at home for more than 12 h daily and perceived views of the sea ($probability = 0.118$) were found to have lower probability than those did not perceive views of water space ($probability = 0.168$). However, the probability would be higher if they perceived views of an urban river ($probability = 0.179 > 0.168$).

IV. DISCUSSIONS AND CONCLUSION

In contrast with a majority of findings of similar studies obtained from laboratory studies employing simulated settings of still images or videos and sound recordings (e.g., Joynt and Kang, 2010; Maffei *et al.*, 2013; Viollon *et al.*, 2002), the findings arising from this study were derived from the questionnaire responses obtained from field survey studies. Given that many factors are difficult to control within field survey studies, our site selection strategy should be carefully planned to ensure that meaningful results can be obtained by minimizing the number of confounding variables. Additionally, there are at least two other benefits that can be brought by field surveys: (i) the collected responses should better mimic those given in the real life situations as all the invited respondents actually lived near the trunk roads of the survey sites; (ii) the collected responses portrayed their long-term instead of short-term noise annoyance responses. Furthermore, to our best knowledge, this study should be one of the pioneering studies that can reveal the individual and combined effects of neighborhood environment containing views of multiple environmental features on noise annoyance responses within a single study. Of equal importance is that the formulated multivariate model enables one to not only to predict annoyance responses due to perceptions of different types of neighborhood views, but also to compare their noise moderation capabilities.

Noise annoyance moderation capability of views of an environmental feature has often been explained by resorting to its restorative power. The stronger the restorative power, the stronger moderation capability of an environmental feature is, and vice versa (Gidlöf-Gunnarsson *et al.*, 2007). Our findings are generally in line with earlier evidence reporting on restorative power of natural features (Karmanov and Hamel, 2008; White *et al.*, 2010; Nordh *et al.*, 2009), and noise moderation capability (Li *et al.*, 2010; Li *et al.*, 2012).

Nevertheless, few studies have compared the restorative power or noise annoyance moderation capability of greenery and water space. Greenery has been confirmed to have annoyance moderation capability and its details were discussed in Li *et al.* (2010). In contrast, divergences in conclusions were found on the restorative power of water space. Although Van den Berg *et al.* (2003) and Ulrich *et al.* (1991) did not find water space to have restorative power, White *et al.* (2010) and White *et al.* (2013) confirmed the restorative power of water space. In fact, our study revealed that views of water space had annoyance moderation capability but their annoyance moderation capability was found to be weaker than that of greenery. This was in contradiction with the findings from White *et al*. (2010) that water space had a stronger restorative power than greenery. Given that different settings of greenery and water space were examined in different studies, small differences observed in values are considered to lay well within boundaries of errors. More studies are needed for determining whether views of greenery or water space has a stronger noise annoyance moderation capability.

Unlike greenery or water space, the presence of noise barriers would induce a higher probability of invoking a high noise annoyance. The significant interaction effect between noise barriers and water space made the moderation capability of the environment more complicated to predict. Conceivably, the presence of an urban river and noise barriers would lead to a more compact and urbanized view, which made the auditory and restoration judgment more contaminated for individuals.

The above findings should provide valuable insights for urban planners and building designers in formulating strategies to moderate the noise annoyance responses of residents living near a heavily trafficked road by making use of human visual perceptions. Views of greenery, the sea, or urban rivers can always benefit residents by moderating their noise annoyance responses. Although views of the sea could have stronger noise annoyance moderation capability than views of urban rivers, rivers had a higher potential to benefit more nearby residents compared to natural seashores since urban rivers can be relatively easier to be mingled with urban fabric than natural seashores. However, we also need to note that it would be better to avoid constructing noise barriers along rivers or seacoasts due to the interaction effect.

Similar to other studies, our results showed that personal characteristics like age, education level, and self-rated noise sensitivity would affect an individual's noise annoyance response. According to the survey, residents older than 45 yr were more likely to be highly annoyed by traffic noise. Although the split point of 45 yr was not closely in line with conventional elderly classification, it agrees with the finding reported in an earlier study that middle-aged people were more annoyed by traffic noise (Emin MARAŞ and Uslu, 2015). Further investigations are needed to reveal the relationship between respondent's age and noise annoyance. Interaction effects were also found to exist between neighborhood views and individual daily life patterns. In particular, an individual's duration of stay at home interacted with the perception of views of water space on influencing the probability of invoking a high annoyance response. A view of water space would raise the probability if an individual stayed at home for a long period. However, such an interaction effect was not found to exist between views of greenery and duration of stay at home. These findings in fact bridged the knowledge gap on whether visual settings should be paired with data of time spent on them in order to generate a more precise measure of visual exposure to green and blue spaces (Nutsford *et al*., 2016). Even though it is difficult for individuals to alter their daily life patterns, the results from this study help gain better understandings of the interaction effect between daily life patterns and visual environment so as to facilitate residential neighborhood planning to reduce the chance of being highly annoyed by road traffic. For instance, the interaction effect between staying at home for a long time and views of urban rivers should be taken into consideration when planning a residential building estate or nursing home for the elderly who stay a long time at home.

Finally, there were also a number of limitations inherent in this study. First, attitudes towards natural and built features in visual environment of individuals were not included in the scope of this study. However, preferences towards various types of features in visual environment may have some influences on noise annoyance responses. Second, our current analysis is confined in a way that only dichotomized scales were formulated for subjective variables such as views of greenery/noise barriers. Further investigations on the data segmentation method can help reveal the influences of different levels of these variables. Third, due to the site constraints, the types and proportions of greenery are not differentiated in our model formulation. Fourth, the applicability of the model is limited in a way that the subjective judgment of the respondents rather than objective information on the proportions of visible environmental features was used in the formulation of model. Also, the model is only applicable to the environment containing views of three types of environmental features, i.e., with a combination of large proportions of greenery, water space, and noise barriers. Of particular interest is to explore whether there is a limit in the maximum total number of features that can be visible in large proportions within an environment. Fifth, the time period breakdown in the survey did not fully match the daily variations of noise levels after compromises made between the daily life patterns of Hong Kong people and the level of information required. This may not help reveal the type of noise annoyance responses given during a specific time period. Finally, noise barriers were the only type of built feature investigated in this study, while views of other built features such as buildings were not considered. Despite this, the results arising from this study should be able to provide valuable insights on how the environment containing views of multiple environmental features affects noise annoyance responses.

ACKNOWLEDGMENTS

The authors would like to acknowledge the Research Grant Council in Hong Kong for the funding support through the General Research Grant No: 512112.

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