# Comparing the Effects of Visibility of Different Neighborhood Greenery Settings on the Preference Ratings and Noise Annoyance Responses to Road Traffic Noises

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## ABSTRACT

The impact of visual environment on human noise perceptions has always been under scrutiny. Two consecutive sets of laboratory experiments were performed for studying the effect of visual perceptions of different percentages of sea, greenery, and/or road views on noise-induced annoyance responses as well as preference ratings. Both experiments were carried out in a room purposely constructed inside an anechoic chamber to mimic the living room setting of a dwelling in Hong Kong. Video clips were projected consecutively onto the exterior window panel of the living room to simulate neighborhood views containing different percentages of sea, greenery and road. 82 and 58 participants were successfully administered in two experiments. Each participant was presented with 11 video clips and requested to respond to a series of questions regarding perceived noise annoyance and view preferences after presentation of individual clips. The responses collected from each experiment were employed to formulate ordered logit models to predict the probability of evoking a high annoyance response. Findings indicated that participants tended to prefer the presence of sea rather than that of either mountain or trees in views containing a trafficking road. Views containing sea would produce an attenuating effect on noise annoyance while views containing road would produce an aggravating effect. However, the size of the effects did not vary between 0% and 30% sea, or between 30% and 60% road contained in a view. Views containing dense greenery at a close distance would aggravate noise annoyance irrespective of form. However, when the percentage of greenery increased from 30% to 60%, the noise annoyance attenuating effect increased in the case of wooded mountain but decreased in the case of the more transparent tree clumps.

*Keywords: Natural features, Noise annoyance, Soundscape, Audio-visual interactions*

## 1. Introduction

Inhabitants in compact cities endure unwanted environmental sounds. In particular, a substantial body of research focusing on public health and well-being has acknowledged noise annoyance caused by road traffic sources is associated with adverse effects including sleep disturbance (Björk et al., 2006), disruption of activities (Abo-Qudais & Abu-Qdais, 2005), deficits in recall memory (Stansfeld et al., 2005; Hygge, et al., 2013), and deprivation of the capacity to cope with concurrent stressors (Wallenius, 2004). When acting as a stressor, road traffic noise contributes to the dysregulation of the hormonal response system (Ising & Ising, 2002). Epidemiology studies suggest higher risks of hypertension (Bodin et al., 2009; Babisch et al., 2012) and myocardial infarction (Babisch et al., 2005) among people who are continuously exposed to road traffic noise at levels above 55 dB(A).

Although many abatement schemes are targeted at the reduction of sound level (Klæboe et al., 2000; Ellebjerg, 2007) or population exposure (Murphy et al., 2009), the overall aim at improving soundscape while attenuating noise annoyance and its adverse health effects has drawn much attention in recent research on urban noise problems (Torija et al., 2013; Andringa & Lanser, 2013). Critics have called into question the versatility of the engineering approach to setting out mitigation measures (Murphy & King, 2010). The concept of soundscape, introduced as the acoustic equivalent to landscape into urban research and design, offers an alternative approach to exposure management in assessing urban sound and its impact in the much wider context of multi-sensory perceptions and interactions (Schafer, 1994; Carles, et al., 1992; Payne, et al., 2009; Brown, et al., 2015). Studies have repeatedly showed that while the appreciation of urban sound affects the experience of urban environment (Aletta, et al., 2018), the judgement of urban soundscape is to a certain degree influenced by the evaluation of landscape (Maffiolo et al., 1999) and the way people appreciate the environment (Steffen et al, 2017; Bild, et al., 2018b).

Noise annoyance is far from a function of attributes associated solely with the acoustic stimulus. Numerous studies have found that non-acoustical factors may influence annoyance responses induced by environmental noise, while there is well-documented evidence to indicate that neither noise exposure nor sound pressure level is as strong a predictor of noise annoyance as anticipated (Kastka et al., 1995; Job, 1988, 1996). In addition, other contextual factors that intervened the exposure conditions such as access to a quieter place inside or outside dwelling, and availability of green space nearby have reportedly affected noise annoyance responses (Öhrström, et al., 2006; Gidlöf-Gunnarsson & Öhrström, 2010; Dzhambov & Dimitrova, 2015).

Noise annoyance is a multi-sensory concept as the response to the audible stressor is seldom in isolation, but often involves cross-modal integration of co-occurring environmental stimuli (Ittelson, 1973; Sun et al., 2018). The perceptual organization in one modality influencing perception in another has been reported in many experimental studies (Vroomen & de Gelder, 2000; Driver & Spence, 2004). Studies reported that unsightly wind turbines or a shunting yard visible to dwellers contributed to annoyance in communities exposed to such synthetic sources (Janssens, et al., 2011; Miedema & Vos, 2004). By contrast, natural scenes have been shown to possess the capability of enhancing acoustic comfort (De Coensel et al., 2011; Li et al., 2010; Chau et al., 2018; Ren and Kang, 2015).

Previous studies suggested that the type and setting of natural features contained in a view were likely to evoke a noise annoyance rating lower than that under the baseline condition (Leung et al., 2017b). The likelihood of an attenuating effect on noise annoyance was associated with the presence of natural features such as greenery and sea within an eyeshot. Dwellers having a view to sea were less likely to feel annoyed by road traffic noise (Li et al., 2012). Views of greenery were shown to have stronger attenuation capability than views of water space (Li et al., 2010). Even for the same type of natural feature, auditory perceptions differ with natural setting. A stronger attenuating effect was found for green views in wetlands than in urban parks (Li et al., 2010), while the strength of urban river views in attenuating noise annoyance was relatively small compared with those of sea views (Leung et al., 2017b). The degree of attenuation also varied if the transparency of the vegetation was different (Watts et al., 1999), However, these past attempts fell short of pinpointing the particular type and setting of the natural feature that viewers would translate its attenuating effects on noise annoyance responses into high preference ratings.

In addition, auditory perceptions were influenced by the perceived amount of natural features contained in a view. Conceivably, the higher the percentage of greenery perceived, the stronger the noise annoyance attenuation capability (Li et al., 2010). The prevalence of being moderately annoyed was found to be lower with a higher percentage of greenery seen through the window (Van Renterghem and Botteldooren, 2016). Studies also uncovered that the percentage area taken by natural features in a photograph or within view of the visitor on site also affected the assessment of perceived tranquility of the place (Pheasant et al., 2008, 2010; Watts et al., 2011, 2013; Watts and Pheasant, 2015).

Despite the evidence of noise annoyance attenuation facilitated by a higher visible nature and the possibiity of an optimised visual composition for a state of being perceptually quiet in outdoor space, there is little evidence to suggest that the attenuation capability varies in a direct proportion with the percentage of a environmental feature within the field of vision. Furthermore, it is not clear whether multiple environmental features will interact with each other as well as with attributes presented in the acoustical mode. Few have analyzed whether the attenuation capability will vary with the spatial arrangement of environmental features in terms of the depth of view, for example, whether greenery in proximity or at a distance fares better. Even with the same type and same amount of natural features, the perceived outcomes might be quite different (Parsons, 1995). Moreover, it is unclear whether different settings and forms of green features such as wooded mountain and tree clumps exert attenuating effects on annoyance response in different manners, and how those effects differ. Accordingly, the primary objective of this study is to quantify the effect of different settings and percentages of greenery, and different percentages of sea and road contained within a view on noise annoyance responses and preference ratings. The ultimate objective is to construct multivariate models to predict how noise annoyance responses vary quantitatively with the type of environmental features, form of greenery, composition and spatial arrangement of neighborhood scenes as well as characteristics of sound sources.

## 2. Methodology

The present study sought to investigate whether the two forms of green features, namely wooded mountain and trees clumps, would lead to different preference ratings and noise annoyance responses under the same as well as different acoustic and visual conditions. In order to avert a lengthy presentation of all the audio-visual combinations to each participant and the risk of incomplete responses, two separate sets of experiments were conducted for collecting evaluation data per green feature. In each experiment, the same combinations of visual compositions of greenery, sea and road, sound types and sound pressure levels in the neighborhood scenes were studied.

While there are many studies examining greenery as an restorative attribute such as naturalness afforded by the place (Hadavi, et al., 2015) or landscape setting of a park (Gatersleben & Andrews, 2013) or trail (Chiang et al., 2014), very few have focused directly on the form of green features presented as one of the visual components in a neighborhood view. Our study aimed to bridge this research gap with questionnaires administered in two experimental set-ups.

*2.1.1. Participants*

A group of 85 participants was recruited for *Experiment I*, while a smaller group of 60 participated in *Experiment II*. Table 1 summarizes the personal characteristics of the participants.

**Table 1**

**Summary statistics of the personal characteristics of the participants**

| | ***Experiment I*** | ***Experiment II*** |
|---|---|---|

| Description | | Number of counts | Number of counts |
|---|---|---|---|
| Gender | Male | 18(22%) | 26(45%) |
| | Female | 64(78%) | 32(55%) |
| Age | 19 or below | 24(30%) | 13(22%) |
| | 20-29 | 56(68%) | 44(76%) |
| | 30-39 | 2(2%) | 1(2%) |
| | 40 or above | 0 | 0 |
| Noise Sensitivity | Very insensitive | 0 | 0 |
| | Insensitive | 2(2%) | 4(7%) |
| | Fair | 30(37%) | 21(36%) |
| | Sensitive | 49(60%) | 32(55%) |
| | Very sensitive | 1(1%) | 1(2%) |

### *2.1.2. Experimental set-up*

The setup for *Experiment II* was identical to that of *Experiment I*, except that all those videos containing mountain greenery were replaced with dense clumps of trees. The baseline scene for both experiments was composed of the sky only.

A 2.4m (w) x 3.5 m (l) x 3.5 m (h) semi-anechoic chamber was constructed for carrying out the experiments inside the testing facility for building acoustics in the Hong Kong Polytechnic University. The setting of the chamber was purposely designed as a living space of a dwelling about three stories above ground in a public housing block in Hong Kong (Figs. 1–3). Fig. 3 shows the layout floor plan of the living room inside the anechoic chamber. Videos of composite scenes were projected on a 2.2m (w) x 1.7 m (h) mock-up window panel for participants to watch as though they could see the outside neighborhood scenes through the window. Sounds were reproduced from behind the panel by two loudspeakers placed at a separate room. During the experiment, one window panel was kept opened. Participants were informed that road traffic and sea sounds were transmitted from the outdoors to the living room through the open window panel. More details of the experimental set-up can be found in Chau et al. (2018).

**Fig. 1. The living room exterior**

**Fig. 2. The living room interior**

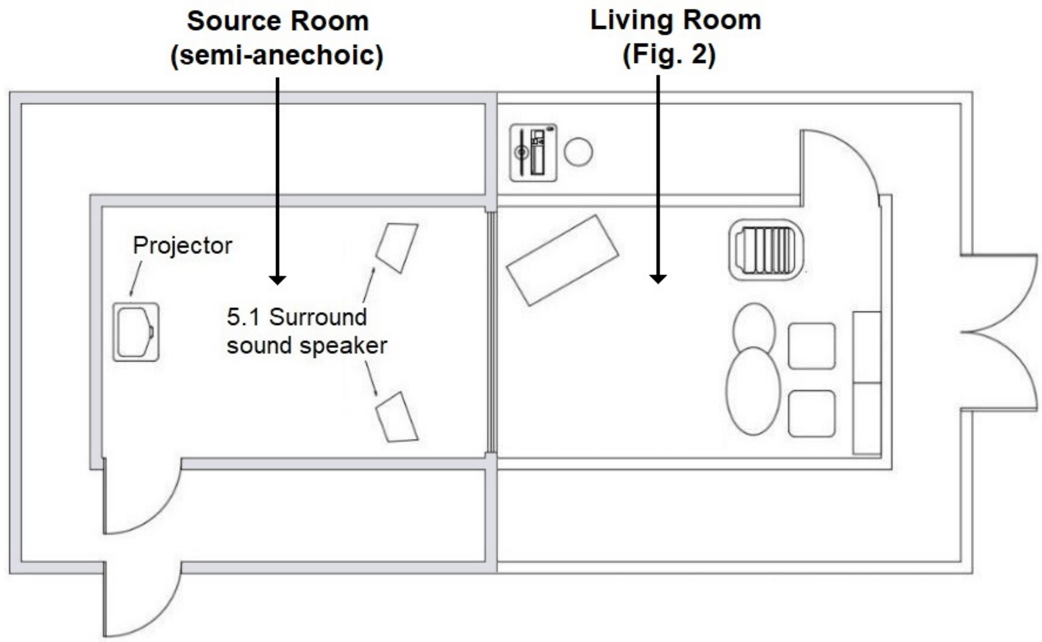



**Fig. 3. Layout plan of the test room setup**

*2.1.3. Preparation of Visual and Audio Stimuli*

The experiments aimed at studying greenery, sea and a trafficked two-lane trunk road. Each of these environmental features contributed to 0, 30%, or 60% of the total view area in a composite neighborhood scene. The percentage of an environmental feature was measured by the ratio between the pixels of the feature and the pixels of the framed view. Footages and images of residential areas in Hong Kong were modified to generate 17 types of composite scenes using the software “Adobe Photoshop CS6” and “Adobe After Effects”. Cuttings of moving vehicles were keyed into the video and synced with the vehicular sound synthesized from clips recorded on site after adjustments for receiver-source distances (Tam et al., 2012).

A 30-second clip was prepared for each composite scene. The clips for Road traffic sound (*RTS*) was extracted from disturbance-free binaural recordings taken from the roadsides of a local residential area. Sea sound (*SS*) was purchased from a website (www.prosoundeffects.com) specialized in audio effects. Software Audacity 2.0.5 was employed to mix RTS with SS for the mixed-source clips. Sound levels of the clips were calibrated using Bruel & Kjaer 4128C "Head and Torso Simulator" (HATS) and analysis software "PULSE LabShop". Figure 4 illustrates the A-weighted band levels of *RTS* and *SS*, each with an equivalent sound pressure level of 65 dBA.

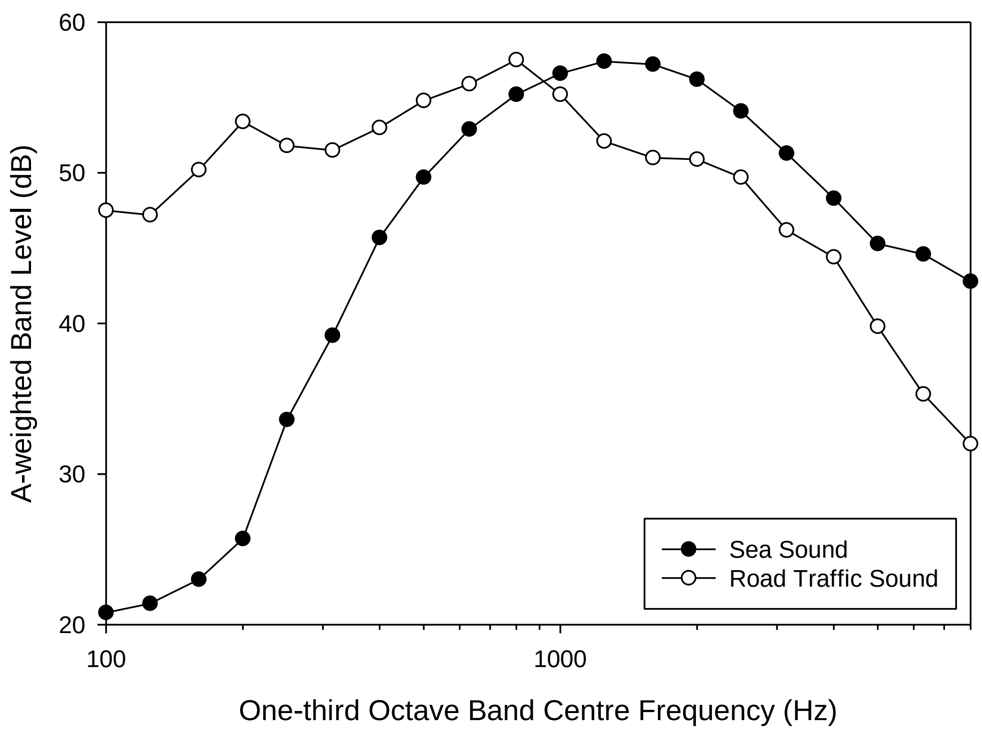



**Fig. 4 A-weighted band levels of *Road traffic sound* and *Sea sound* (65 dBA)**

Acoustic stimuli of single sound source and mixed sound sources were prepared for the experiments. For both single-source and mixed-source clips, the sound pressure level (*SPL*) of *RTS* and *SS* were set to either 55, 60, or 65 dBA. The signal-to-noise ratio (*SNR*) of the two types of sound sources increased 3 dB for each step from –6 to 9 dB *SNR* is the difference in *SPL*s between sea and road traffic. A negative *SNR* value denotes that the *SPL* of *RTS* is higher than that of *SS*, and vice versa (Table 2).

**Table 2 Scenarios containing both road traffic and sea sounds**

| ***SPL* of Road Traffic (dBA)** | ***SNR* (dB)** | | | | | |
|---|---|---|---|---|---|---|
| 55 | –6 | –3 | 0 | 3 | 6 | 9 |
| 60 | –6 | –3 | 0 | 3 | 6 | 9 |
| 65 | –6 | –3 | 0 | 3 | 6 | 9 |

**Note**: Positive sign of signal-to-noise ratio (SNR**)** denotes that level of sea sound is higher than that of road traffic sound; negative sign of SNR denotes that the level of sea sound is lower than that of road traffic sound.

The total number of combinations presented to each participant was reduced by way of an efficiency design to avoid the massive number of composite scenarios, which would have degraded the response quality. With the aid of software SAS, the efficiency design reduced the total 198 combinations to 36 based on the *D*-efficiency value of 0.9421 (see Appendix) for minimizing the parameter estimates (NIST/SEMATECH, 2013). The 36 composite audio-visual scenarios were further divided into 3 groups in a random manner.

Only one group of the video clips would be presented to each participant in one set of experiments.

*2.1.4. Questionnaire design*

The structure and format of the questionnaires for eliciting responses from participants in *Experiment I* and *Experiment II* were essentially the same. The questionnaires were presented in Chinese. During the first section, participants were asked to report their self-assessed noise sensitivity and other personal information such as gender and age. Throughout the following sections, participants were asked to relax as if they were undertaking leisure activities at homes. They were required in the second section to give an acoustic comfort rating to each sound clip using a 21-point scale (where "–10" denotes "*Extremely uncomfortable and annoyed*", "0" denotes "*Neutral*", "10" denotes "*Extremely comfortable*") when exposed to 2 types of single sound source separately (i.e. *RTS* and *SS*) at different *SPLs*. The adoption of a 21-point scale would render an 11-point scale on the annoyed and uncomfortable side (0 to -10) and an 11-point scale on the comfortable site (0 to 10). A total of 6 single source sound clips were presented consecutively to participants while they were looking at the baseline neighborhood view (i.e. the sky). In the third section, participants were asked to give a noise annoyance rating to each scene of different combinations visual and aural cues using an 11-point verbal scale (where "0" denotes "*Not annoyed at all*", "5" denotes "*Moderately annoyed*", and "10" denotes "*Extremely annoyed*"). They also needed to assign a rating to indicate the level of dominance of a particular sound source they perceived via a 11-point scale (where "0" denotes "*Water sound dominant*", "5" denotes

"*No dominant sound*", "10" denotes "*Traffic noise dominant*"). The final section of the questionnaire aims at revealing the participant's visual preference of neighborhood scenes viewed from the living room setting. They ranked on an 11-point scale their order of preference for each of the 11 composite neighborhood scenes projected on the mock-up window panel (see Figures 5 and 6). The scores of "0" denoted the "*Least preferred*" and "10" the "*Most preferred*".

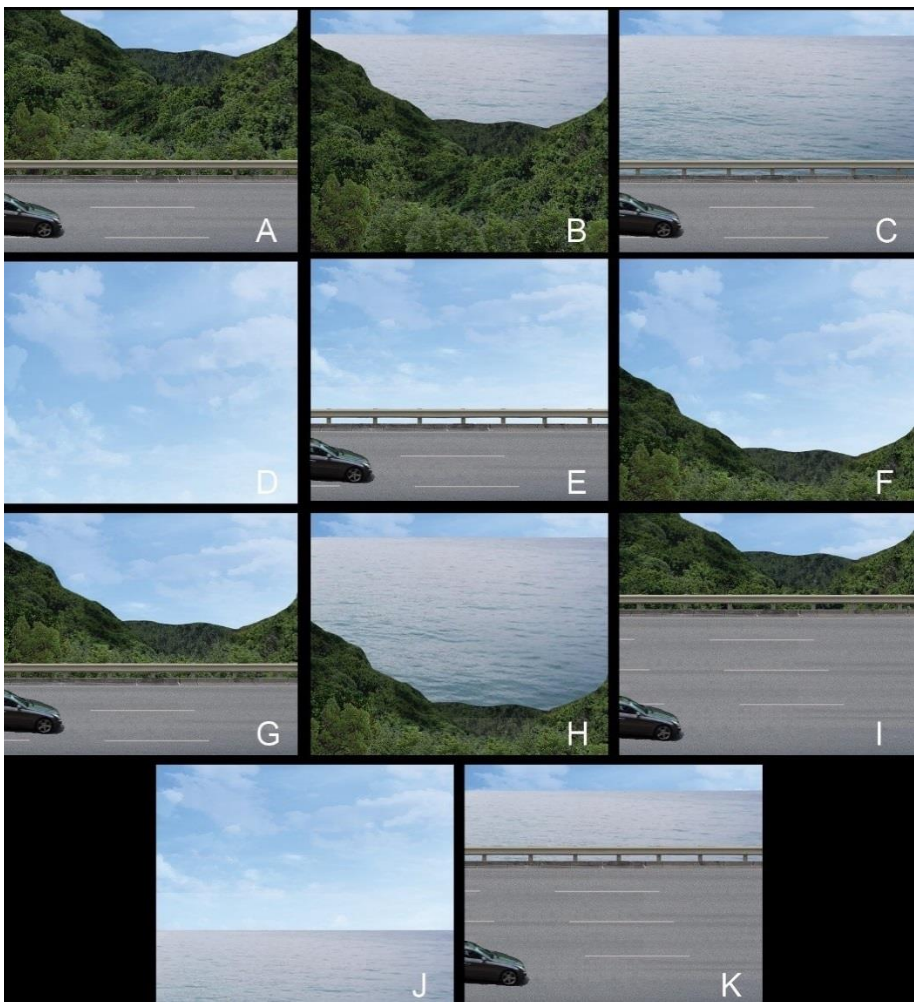



**Fig. 5 Composite neighborhood scenes presented in *Experiment I***


**Fig. 6 Composite neighborhood scenes presented in *Experiment II***

*2.3. Preliminary analysis*

As a preliminary analysis, the mean preference and annoyance ratings computed for different video scenes (i.e. *Scene A* to *Scene K*) perceived by the participants at different *SPL*s for *Experiments I* and *II* (i.e. mountain greenery and tree clumps). Independent t-tests were performed for each type of neighborhood scenes at 55, 60 and 65 dBA to compare whether there were significant differences in their mean values in their preference and annoyance ratings ($\mu$). This preliminary analysis would help to understand whether individual environmental features should be included into the later ordered logit models.

### *2.4. Model formulation*

When formulating the models, it was hypothesized that acoustical perceptions would vary with visual and aural cues in the environment. In addition, it was hypothesized that there might be some potential interaction effects between different natural and urban features in the neighborhood scenes. To facilitate model formulation, the 11-point noise annoyance ratings were re-categorized into one of three groups, i.e. low (0, original rating 0-2), medium (1, original rating 3-6), and high annoyance responses (3, original rating 7-10). In addition, independent variables that took on more than two values were also regrouped (See Table 3). Due to the ordinal nature of the annoyance ratings, ordered logit models were formulated to analyze the noise annoyance response data collected from *Experiments I* and *II*.

The general form of ordered-logit model used to estimate the latent variable *Z* as a linear function of independent variables (Hamilton, 2006) is:

$$Z = \sum \beta_i x_i + \varepsilon \quad (1)$$

where $x_i$s are the independent variables such as percentage of sea views, percentage of greenery views, percentage of road view, sound levels in the dwelling and self-rated noise sensitivity; $\beta_i$s' are the coefficients of the independent variables; and $\varepsilon$ is a logistically distributed error.

Given the major focus of this study is on high annoyance responses, only the probabilities of evoking a high annoyance response were computed and presented. The probability of evoking a high annoyance response, which depends on the value of $Z$ and cut point, $\mu_2$ was computed by:

$$Pr(Annoyance = "High") = \Pr(\mu_2 < Z) = 1 - \frac{1}{1+e^{(Z-\varepsilon-\mu_2)}} \quad (2)$$

The McFadden's $\rho^2$ was employed to evaluate the goodness-of-fit of the logit model. The McFadden statistics was applied to estimate the maximum likelihood of annoyance response in the final model. McFadden's $\rho^2$ is analogous to $R^2$ applied in linear regression commonly referred to as the log-likelihood chi-square, while the log-likelihood of the full model can be regarded as the sum of squared errors. The ratio of the likelihoods indicates the improvement offered by the predictors in the full model over and above the intercept-only model. The log-likelihood statistics for model comparison is expressed as $LL\chi^2 = -2(LL_1 - LL_0)$, where $LL_0$ plays the role of the residual sum of squares in linear regression. High McFadden's $\rho^2$ value indicates a higher likelihood in model prediction (Kleinbaum and Klein, 2010).

## 3. Results

For *Experiment I*, 85 participants successfully completed our laboratory experiments. However, as a quality assurance procedure, 3 responses were excluded from our data analysis due to missing information or conflicting responses. For *Experiment II*, 60 participants were successfully administered with 2 participants being excluded from the data analysis for irrational responses. Table 1 summarizes the personal characteristics of the participants who took part in the experiments. 22% and 45% of the participants in *Experiments I* and *II* were males, respectively. Most of them were undergraduate students whose age was between 20 and 29 years old. Most of them rated their noise sensitivity "*Fair*" or "*Sensitive*".

The ratings assigned in the second section of the questionnaire revealed the acoustic comfort ratings assigned by individual participants when exposed to two specific sound sources. Fig. 7 shows the mean acoustic comfort ratings for different types of single source sound clips at different levels. As expected, the acoustic comfort rating lowered as *SPL* was higher. The mean acoustic comfort ratings for road traffic sound tended to be moderately annoying even at low *SPLs*, and decreased with increasing dB level. On the contrary, a majority perceived sea sound to be "comfortable" at all three sound levels, but the acoustic comfort ratings lowered with increasing dB level.

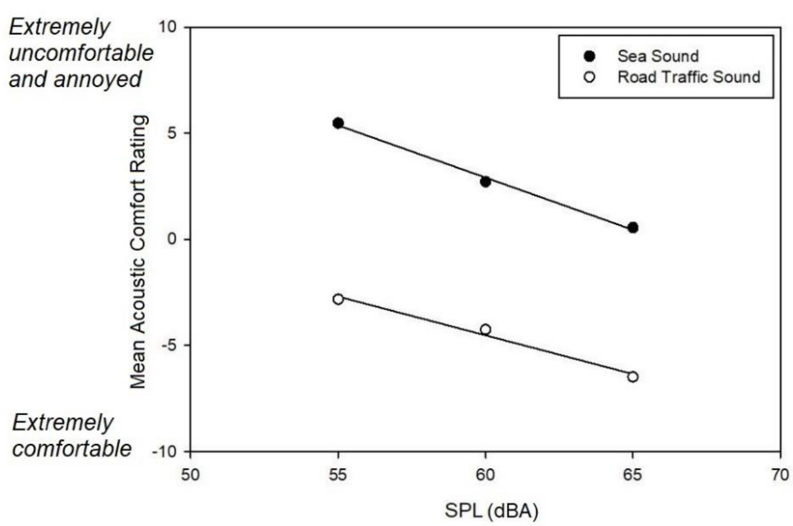


**Fig. 7 The mean acoustic comfort ratings for sea and road traffic sounds of single source sound clips at different *SPL*s**

Two ordered logit models were formulated using the valid responses obtained from the questionnaire surveys in *Experiment I* and *Experiment II,* respectively. The interaction term '*Green*×*Road*' was successfully introduced to the model specification. Stepwise approach was adopted in the model formulation with an input sequence following the order of main effect variables, interaction terms, and individual's characteristics and perceptions. An independent variable would be included in the model only if all the following three criteria had been met: i) it was significant at 95% level; ii) its inclusion would significantly increase the McFadden $\rho^2$ value without causing any multi-collinearity effects; and iii) its inclusion would not alter the statistical significance of other variables (i.e. rendering other significant variables insignificant after the inclusion of a particular variable). Multi-collinearity tests had also been performed among all the variables in order to provide more comparable predictions and avoid undesirable influences on the model coefficients. No strong multi-collinearity effects had been observed between variables in the final model (with all tolerance values > 0.40).

Finally, the following common form for the 2 ordered logit models has been formulated to predict the probability of evoking a high annoyance response (Eq. (3)). Table 3 lists the description of all the coded variables in the model.

$$\mathrm{Z} = b_{SPL} \cdot \mathrm{SPL} + b_{SNR1} \cdot \mathrm{SNR1} + b_{SNR2} \cdot \mathrm{SNR2} + b_{Dom} \cdot \mathrm{Dom} + b_{G1} \cdot \mathrm{Green1} + b_{G2} \cdot \mathrm{Green2} + b_{S1} \cdot Sea1 + b_{S2} \cdot Sea2 + b_{R1} \cdot \mathrm{Road1} + b_{R2} \cdot \mathrm{Road2} + b_{Green \times \mathrm{Road}} \cdot \mathrm{Green} \times \mathrm{Road} + b_{SS} \cdot SS + \varepsilon \quad (3)$$

**Table 3**

**Description of the coded variables in the two models**

| **Variables** | **Description** |
|---|---|
| ***<u>Sound Characteristics</u>*** | |
| ***SPL*** | Sound pressure level of road traffic in dBA |
| ***SNR1*** | Signal-to-noise ratio between sea sound and road traffic sound; coded as “1” if SNR equals to 6 or 9 dB; “0” if SNR equals to 3, 0, –3 or –6 dB |
| ***SNR2*** | Signal-to-noise ratio between sea sound and road traffic sound; coded as “1” if SNR equals to 9 dB; “0” if otherwise |
| ***<u>View Characteristics</u>*** | |
| ***Green1*** | Percentage of greenery in a view from the window; coded as “1” if the percentage equals to 30; “0” if the percentage equals to 0 or 60 |
| ***Green2*** | Percentage of greenery in a view from the window; coded as “1” if the percentage equals to 60; “0” if the percentage equals to 0 or 30 |
| ***Sea1*** | Percentage of sea in a view from the window; coded as “1” if the percentage equals to 30; “0” if the percentage equals to 0 or 60 |
| ***Sea2*** | Percentage of sea in a view from the window; coded as “1” if the percentage equals to 60; “0” if the percentage equals to 0 or 30 |

| | |
|---|---|
| ***Road1*** | Percentage of road in a view from the window; coded as “1” if the percentage equals to 30; “0” if the percentage equals to 0 or 60 |
| ***Road2*** | Percentage of road in a view from the window; coded as “1” if the percentage equals to 60; “0” if the percentage equals to 0 or 30 |
| ***Green×Road*** | Interaction term between view of greenery and view of road from the window; coded as “1” if there is an interaction effect, otherwise “0” |
| ***<u>Personal Characteristics and Perceptions</u>*** | |
| ***Dom*** | Sound dominance ratings assigned by participants (0-10); coded as “0” if participants assigned “5”; “–1” if participants assigned “0-4”; “1” if participants assigned “6-10” |
| ***SS*** | Coded as “1” if the participant perceived sea sound to be very comfortable (i.e. acoustic comfort ratings > 3 for all the single sea sound clips), otherwise “0” |

The variables *Green*, *Sea*, *Road* and *SNR* were regrouped and expressed as dummy variables *Green1*, *Green2*, *Sea1*, *Sea2*, *Road1*, *Road2*, *SNR1* and *SNR2* for better model fit. *SNR1* was coded as “1” if the *SNR* equals to 3 or 6 dB, “0” if otherwise. *SNR2* was coded as “1” if *SNR* equals to 9 dB, “0” if otherwise. Similarly, *Green1* was coded as “1” if the percentage of greenery equals to 30, “0” if otherwise. *Green2* was coded as “1” if the percentage of greenery equals to 60, “0” if otherwise. *Sea1*, *Sea2*, *Road1* and *Road2* were coded based on the similar principle (See Table 3).

A McFadden's $\rho^2$ values of 0.253 and 0.203 was obtained for *Model I (from Experiment I)* and *Model II (from Experiment II)*, respectively, suggesting an excellent goodness-of-fit of the models formulated from the responses elicited in the two experiments. Specifically, McFadden $\rho^2$ value of 0.2 to 0.4 represents an excellent fit (1973), which is analogous to a range of values between 0.7 and 0.9 in $r^2$ value for a linear regression model. Table 4 lists the estimated coefficient values and odds ratios of all the statistically significant variables in the models. For continuous variables, a positive coefficient sign indicates that the probability of evoking a high annoyance response increases with the value of the variable, given all the other variables in the model being held constant. A negative coefficient sign indicates that the probability of evoking a high annoyance response lowers when the value of the variable increases. For categorical variables, the coefficient value shows the increase/decrease in the probability value when the variable changes from the "baseline level" (usually the first group of this variable, coded as "0") to the studied level (coded as "1").

The findings in *Model I* and *Model II* are similar. Same signs were obtained for the same variables in both *Experiment I* and *II*, e.g. positive signs obtained for road views, and negative signs obtained for sea views. The findings suggest that similar effects on noise annoyance were obtained for the same types of natural and urban views.

**Table 4**

**Estimated coefficient values for the variables in the final models in *Experiment I and Experiment II***

| | ***Experiment I (Model I)*** *N* = 82 | | | ***Experiment II (Model II)*** *N* = 58 | | |
|---|---|---|---|---|---|---|
| **McFadden's $\rho^2$** | **0.253** | | | **0.203** | | |
| **Variable** | **Coefficient (*b*)** | **Standard Error** | **Odds Ratio** | **Coefficient (*b*)** | **Standard Error** | **Odds Ratio** |
| ***Sound Characteristics*** | | | | | | |
| ***SPL*** | 1.662** | *(0.114)* | 5.27 | 1.502** | *(0.129)* | 4.49 |
| ***SNR1*** | –0.627** | *(0.243)* | 0.53 | –0.533* | *(0.268)* | 0.59 |
| ***SNR2*** | –1.760** | *(0.103)* | 0.17 | –1.267** | *(0.278)* | 0.28 |
| ***View Characteristics*** | | | | | | |
| ***Green1*** **(Mountain-Greenery)** | 0.826** | *(0.282)* | 2.28 | – | – | |
| ***Green2*** **(Mountain-Greenery)** | 1.016** | *(0.187)* | 2.76 | – | – | |
| ***Green1*** **(Tree-Clumps)** | – | – | | 0.857* | *(0.347)* | 2.36 |
| ***Green2*** **(Tree-Clumps)** | – | – | | 0.625* | *(0.321)* | 1.87 |
| ***Sea1*** | –0.563* | *(0.160)* | 0.57 | –0.598* | *(0.252)* | 0.55 |
| ***Road1*** | 0.563* | *(0.185)* | 1.76 | 0.609* | *(0.312)* | 1.84 |
| ***Green×Road*** | –1.211** | *(0.270)* | 0.30 | –0.912* | *(0.451)* | 0.40 |
| ***Personal Characteristics and Perceptions*** | | | | | | |
| ***Dom*** | 0.432** | *(0.103)* | 1.54 | 0.762* | *(0.233)* | 2.14 |
| ***SS*** | –0.322** | *(0.147)* | 0.74 | 0.857* | *(0.401)* | 2.36 |
| **Cut points 1** | –2.263 | *(0.308)* | – | –0.884 | *(0.627)* | – |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Cut points 2** | 2.333 | *(0.318)* | – | 3.419 | *(0.496)* | – |

Note: ** *p*-value ≤ 0.005; * *p*-value ≤ 0.05

It was hypothesized that the probability of evoking a high noise annoyance response (hereinafter called the probability) would be varied by exposing dwellers to combined sounds and compositions of neighborhood views. Results from the models showed that the probability was determined by the sound attributes, i.e. *SPLs* and sound composition. As expected, the probability value drastically increased with road traffic sound level. In addition, the probability was also determined by the *SNR* of road traffic and sea sounds. The highest probability values were obtained in both models when *SNR* was equal to 9 dB ("baseline"). This is not surprising as the total sound level was the highest when *SNR* was equal to 9 dB. Regarding individual environmental features, a view to trunk road would increase the probability of evoking a high noise annoyance while a view to sea would lower the probability. These results are basically in line with our hypothesis. Contrary to our original expectation, views containing nearby mountain greenery or tree clumps, were found to evoke a higher probability than those containing no mountain greenery or tree clumps in general. Upon closer investigation, it was found that the magnitude of coefficient *Green2* (with a value of 1.016) was larger than that of *Green1* (0.826) in *Experiment I* while the opposite was found in *Experiment II* (0.625 for *Green2* and 0.857 for *Green1*). This suggested that the probability value would be higher when the proportion of mountain greenery occupying the scene increased. On the contrary, the probability value would become lower if the proportion of tree-clumps in the scene increased. Meanwhile, the negative sign of the coefficient estimated for the interaction term *Green×Road* suggested that the probability value would decrease when both greenery, no matter whether it was mountain greenery or tree clumps, and road were presented in the scene.

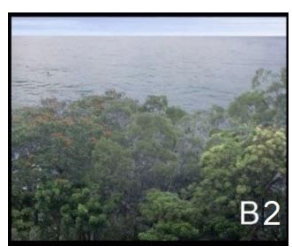
Of paramount interest in this study is to determine the types of composition and spatial arrangement of the components in the views would affect the probability of evoking a high noise annoyance level, given all other variables in the model are held constant. The high-annoyance-response probability for specific composition and spatial arrangement of views containing different combinations of environmental features were computed by adjusting the values of variables relating to particular types of environmental features while keeping all the other variables at their mean values. A summary of estimated high-annoyance probability values ($Pr$) for specific percentages of the view features is provided in Table 5.

In the presence of a 2-lane trunk road occupying 30% of the scene, a view containing 60% of sea in the scene would produce a lower probability value of evoking high annoyance than a scene with 30% trunk road and 60% greenery ($Pr_{C1} = 0.17$ vs $Pr_{A1} = 0.23$; $Pr_{C2} = 0.16$ vs $Pr_{A1} = 0.21$ ). Interestingly, the situation was found to be different when 60% trunk road occupied the scene. In such a scene, participants exposed to 30% mountain greenery tended to be less annoyed than those exposed to 30% sea ($PrI1 = 0.20$ vs $PrK1 = 0.27$). When the 30% greenery was tree-clumps, individuals would have similar annoyance levels to the case that the greenery was replaced with sea ($PrI2 = 0.25$ vs $PrK2 = 0.26$).

Our results showed that wooded mountain and tree clumps performed differently in attenuating noise annoyance responses in a view containing a trunk road. When comparing Scene *A2* with Scene *I2* ( $Pr_{A2} = 0.21, Pr_{I2} = 0.25$ ), the effect of noise annoyance attenuation rendered by planted trees was evident as the probability in the view containing the larger clumps of trees (60%) behind the narrower road (30%) was about 80% lower than the view containing the smaller clumps (30%) accommodating the wider road (60%). On the contrary, an aggravating effect was found in Scene *A1* as the probability was higher ($Pr_{A1} = 0.23$) in the view featuring the looming mountain taking up a larger proportion (60%) than those ($Pr_{I1} = 0.20$) in the view outlining the mountain ridge at a distance (30%). The results indicated that individuals were more likely to be highly annoyed when exposed to the combination of 60% wooded mountain and 30% road rather than 30% mountain and 60% road. However, individuals exposed to the 60-30 combination of trees and road were less likely to be highly annoyed than exposed to 30-60 combination of trees and road. Comparing *I1* with *I2* and *A1* with *A2* also reveals some interesting findings. For a scene containing 60% road and 30% mountain greenery, the probability of evoking high annoyance was lower than the scene containing 60% road and 30% tree-clumps. However, the opposite would be found for a scene containing 30% road and 60% greenery. In addition, for a view containing 30% sea, the probability was found considerably lower in the view covered by a large swath of trees ($Pr_{B2} = 0.26$) than those in the view dominated by a chunk of sloping woods ($Pr_{B1} = 0.36$). However, the probability values were found to be similar for 60% sea combining with 30% mountain greenery or tree-clumps.

**Table 5**

**Estimated probability values of evoking high-annoyance responses for specific view compositions containing road and greenery in *Model I (Wooded Mountain) and Model II (Tree Clumps)***

| *Experiment I (Model I)* | | *Experiment II (Model II)* | |
|---|---|---|---|
| **Scene Composition** | **Predicted Probability ($Pr$)** | **Scene Composition** | **Predicted Probability ($Pr$)** |
| **Mountain-Greenery**<br>Green: 30%; Sea: 0; Road: 0<br>Green×Road = 0<br> | **0.32** | **Tree-Clumps**<br>Green: 30%; Sea: 0; Road: 0<br>Green×Road = 0<br> | **0.31** |
| **Mountain-Greenery & Sea**<br>Green: 60%; Sea: 30%; Road: 0<br>Green×Road = 0<br> | **0.36** | **Tree-Clumps & Sea**<br>Green: 60%; Sea: 30%; Road: 0<br>Green×Road = 0<br> | **0.26** |
| **Mountain-Greenery & Sea**<br>Green: 30%; Sea: 60%; Road: 0<br>Green×Road = 0 | | **Tree-Clumps & Sea**<br>Green: 30%; Sea: 60%; Road: 0<br>Green×Road = 0 | |


**0.21**


**0.20**

**Mountain-Greenery & Road**

Green: 30%; Sea: 0; Road: 60%
Green×Road = 1

**Tree-Clumps & Road**

Green: 30%; Sea: 0; Road: 60%
Green×Road = 1


**0.20**


**0.25**

**Mountain-Greenery & Road**

Green: 60%; Sea: 0; Road: 30%
Green×Road = 1

**Tree-Clumps & Road**

Green: 60%; Sea: 0; Road: 30%
Green×Road = 1


**0.23**

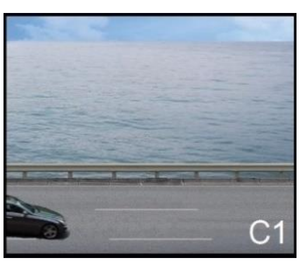

**0.21**

**Road & Sea**

Green: 0; Sea: 60%; Road: 30%
Green×Road = 0

**Road & Sea**

Green: 0; Sea: 60%; Road: 30%
Green×Road = 0




**0.17**


**0.16**

**Road & Sea**

**Road & Sea**

Green: 0; Sea: 30%; Road: 60%
Green×Road = 0


**0.27**

Green: 0; Sea: 30%; Road: 60%
Green×Road = 0


**0.26**

## 4. Discussions and Conclusion

The aim of the present study was to investigate the influence of spatial arrangement of neighborhood scenes and compositions of environmental features on view preference ratings and high annoyance responses induced by exposures to sea and road traffic sounds. Our results regarding neighborhood view preferences revealed that greenery, whether in the form of mountain or clumps of trees, did not always render a positive effect on scenic attractiveness. Untrimmed growth of tree lines and imposing, bushy hills can be unwelcoming obstructions to vistas. The greenery presented in the two experiments, especially for the mountain or trees that dominated the scene composition, was too close to the viewing participants for eliciting a high preference rating. The results have confirmed the findings that views containing close-by mountain greenery could aggravate, rather than attenuate noise annoyance (Chau et al., 2018). However, the high ratings on sea views were consistent with the findings that suggested perceived restorative power of blue space (White et al, 2010) as well as attenuating effects of water on noise annoyance (Li et al, 2012).

Noise annoyance attenuation capability of views containing an environmental feature has often been linked directly to its potential to restore stress (Dzhambov et al., 2017; von Lindern et al., 2016). The useful conclusion drawn from previous studies is that noise annoyance attenuation capability tended to increase with restorative potential of a natural feature available to dwellers exposed to urban noise (Gidlöf-Gunnarsson et al., 2007). In turn, restorative potential has been believed to be directly linked to degree of naturalness, which can be proxy by the type, setting and/or visible amount of an environmental feature (Abdulkarim and Nasar, 2014; Berto, 2005; Leung et al., 2017a; Nordh et al., 2011, 2009; van den Berg et al., 2007).

Our study revealed that the noise annoyance attenuation capability of a scene with built and natural features did not necessarily increase with the proportion of natural components. The model results indicated that there were no significant differences in the probability values of evoking a high annoyance response between 30 and 60% road view. Only 60% sea view was found to produce an attenuating effect while 30% sea view did not produce any effect. Such differences would probably help explain the divergences in earlier findings on whether sea view could attenuate noise annoyance (White et al., 2013).

In addition to the type and composition of environmental features, our findings indicated that the spatial arrangement of environmental features within views did play an important role on noise annoyance perceptions in the presence of natural features of low permeability. Dense mountain greenery and tree clumps were both found to produce an aggravating effect on noise annoyance in the models. The notion of probability of evoking a high annoyance response increased with the percentage of greenery in a view (i.e. 60% > 30% > 0% greenery view) was found in wooded mountain but not in tree clumps.

The difference between mountain as a backdrop in landscape and a natural feature in the foreground was reflected in the probabilities as well as coefficient values estimated in *Model I*. The distinction between greenery as thickets on a slope and greenery as clustered planting was also suggested in the differences in probabilities predicted by the variables associated with view-proportion in the two models. Upon closer examination, it was attributed to the limiting effect of nearly impermeable greenery on the depth of view, especially in the case of a wooded mountain. With sufficiently dense thickets located at a close distance to the window view, the restorative effect of greenery is expected to be weakened or even reversed, as nature has become more of a menace than a refuge (Herzog and Chernick, 2000).

This postulation was supported by examining the coefficient value of the interaction term '*Road x Green'*. If a view contained both road and greenery, the probability value of evoking a high annoyance response would be lowered by at least 20% for a view containing 30% mountain greenery or tree clumps plus 60% road when compared with those views to the same 30-60 combination of close-by thickets on a mountain or in clumps with environmental features other than road. The results appear to be logical for greenery being placed on the roadside with a separation distance incurred less blockage of views than those being put directly in the foreground. The openness of view suggested a buffering effect that compromised or even outweighed the attenuating effect of greenery on noise annoyance responses if wooded mountains were placed in close proximity to the viewer. Our results are consistent with the findings that landscape with blocked lines of sight was likely to not only undermine the restorative potential (Gatersleben & Andrews, 2013; Hauru, et al., 2012) and perceived beauty of the overall view (Ruddell, et al., 1989) but also invoke the human predisposition to feel negatively toward spatially enclosed environment (Ulrich, 1993).

The negative psychological effect produced by lack of open views to nature is problematic. The effect of openness can be explained by resorting to Prospect and Refuge theory (Appleton, 1996). People prefer environments that can provide prospects for the feeling of security. Although more greenery appeared to be more favorable in residential areas to feel psychologically secured, people feel stressful, insecure and even dangerous when their field of vision is occluded (Gatersleben and Andrews, 2013). For example, dense urban woodlands were likely to be perceived unsafe (Jorgensen, et al., 2002). More effort should be spent on exploring how various types of greenery with different degrees of transparency affect perceived safety in residential neighborhood (van den Berg et al., 2017); and how effective greenery is in stress restoration for dwellers with window views containing closely packed high-rise buildings (Asgarzadeh et al., 2014; Chung et al., 2019).

All in all, our results suggested that a greater attention should be paid to spatial arrangement of scenes and landscaping for viewing in a high-dense urban residential settling where the opportunities for connections to nature are few and far between. Previous studies mainly focused on whether and how much natural features exerted their restorative effect on the viewing experience without specifically considering how they were arranged spatially, bar a few exceptions (Tabrizian et al., 2018). Further studies are needed to reveal the holistic relationships between the mix and proportion of natural features, and their spatial arrangements in neighborhood scenes. From the practical standpoint, designers should consider not only the provision of natural features but also the spatial relationship between natural and built features for the enhancement of both acoustics and visual environment.

There are a number of limitations arising from this study. The results were constrained by the laboratory settings of simulated environments, which restricted sensory experiences compared with the possibilities offered in a field survey. For instance, daylighting and outdoor airflow could not be reproduced in the anechoic chamber. The representation of the ground plane and the horizon in the video was not entirely veridical due to the view angle designed for viewing the scenes three stories above. The models were only applicable to neighborhood views containing three types of environmental features (i.e., greenery, sea and road) that were further confined to only three discrete percentage points (i.e., 0, 30 and 60). In addition, the data collected for noise annoyance, acoustic comfort, preferences, and perceived sound dominance were subject to the semantic spectrum of the translated terms on the rating scales, which operated under the assumption that local participants have a common understanding of those terms. A number of acoustic metrics such as frequency, temporal content, sharpness were not considered in the study. Finally, the findings are only applicable to age group examined. The group size in the two experiments was also not the same. It warrants a larger scale study before the results can be extended to the other age groups. Despite so, the results regarding sea and road largely fell within our expectations; on the other hand, we contend that the findings on mountain-greenery and tree-clumps provided valuable insights into the spatial arrangements of greenery types among the built other natural features that exerted influence on noise annoyance responses.

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## Appendix

**Detailed composition of different groups of composite visual and audio scenarios**

| Group No. | Number of composite scenes | Proportion of environmental features | | | *SPL* of road traffic (dBA) | SNR (dB) |
|---|---|---|---|---|---|---|
| | | Greenery (%) | Sea (%) | Road (%) | | |
| 1 | 1 | 30 | 0 | 60 | 65 | 0 |
| | 2 | 30 | 60 | 0 | 65 | –3 |
| | 3 | 0 | 60 | 30 | 55 | 0 |
| | 4 | 60 | 30 | 0 | 55 | -6 |
| | 5 | 30 | 60 | 0 | 60 | 9 |
| | 6 | 60 | 30 | 0 | 55 | 6 |
| | 7 | 0 | 30 | 60 | 65 | 6 |
| | 8 | 30 | 30 | 30 | 60 | –3 |
| | 9 | 0 | 0 | 0 | 65 | 3 |
| | 10 | 0 | 30 | 0 | 60 | -6 |
| | 11 | 30 | 0 | 60 | 55 | 9 |
| | 12 | 60 | 0 | 30 | 55 | –3 |
| 2 | 13 | 30 | 0 | 60 | 60 | –6 |
| | 14 | 60 | 30 | 0 | 65 | 0 |
| | 15 | 0 | 0 | 30 | 65 | 6 |
| | 16 | 0 | 0 | 0 | 55 | –3 |
| | 17 | 0 | 60 | 30 | 65 | -6 |
| | 18 | 60 | 0 | 30 | 60 | 0 |
| | 19 | 0 | 30 | 60 | 60 | –3 |
| | 20 | 0 | 60 | 30 | 55 | 6 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 21 | 30 | 60 | 0 | 65 | 3 |
| | 22 | 30 | 30 | 30 | 55 | 0 |
| | 23 | 60 | 0 | 30 | 60 | 3 |
| | 24 | 30 | 30 | 30 | 65 | 9 |
| 3 | 25 | 0 | 60 | 30 | 60 | 3 |
| | 26 | 30 | 60 | 0 | 60 | 6 |
| | 27 | 30 | 30 | 30 | 65 | –6 |
| | 28 | 0 | 30 | 60 | 55 | 3 |
| | 29 | 0 | 0 | 0 | 60 | 0 |
| | 30 | 60 | 30 | 0 | 65 | –3 |
| | 31 | 30 | 30 | 30 | 55 | 3 |
| | 32 | 0 | 30 | 60 | 60 | 9 |
| | 33 | 0 | 0 | 0 | 55 | 9 |
| | 34 | 30 | 0 | 60 | 55 | –6 |
| | 35 | 30 | 0 | 0 | 60 | 6 |
| | 36 | 60 | 0 | 30 | 65 | 9 |

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