# Effect of traffic noise on perceived visual impact of motorway traffic

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**Abstract**

Visual impact is one of the major environmental impacts of motorways and requires adequate assessment. This study investigated the effect of traffic noise on the perceived visual impact of motorway traffic by comparing impact with sound to impact without sound. Computer visualisation and edited audio recordings were used to simulate different traffic and landscape scenarios, varying in four traffic conditions, two types of landscape, and three viewing distances. Subjective visual judgments on the simulated scenes with and without sound were obtained in a laboratory experiment. The results show that motorway traffic induced significant visual impact. In both sound conditions, increases in traffic volume led to higher visual impact and changes in traffic composition changed the impact significantly when traffic flow was low. Visual impact was significantly higher in the natural landscape and the increment was largely constant and independent from the effect of traffic condition in both sound conditions. The effect of viewing distance was also significant and there was a rapid-to-gentle decrease of visual impact by distance both with and without sound, but the decrease with sound was less rapid and the decrease pattern less clear. Overall, introduction of traffic noise increased the visual impact by a largely constant level which did not show clear dependence with noise level, traffic condition, landscape type, or viewing distance, although there was a possible effect of viewing distance on the increase. It suggests that the additional impact caused by traffic noise should be considered in visual impact assessment of motorway projects.

Keywords: traffic noise; visual impact; motorway traffic; landscape

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## 1. Introduction

Visual impacts are changes in visual landscape quality brought about by developments in association with human experience of the changes, and are required to be assessed as an essential component of the Environmental Impact Assessment by EU regulations (The Landscape Institute and Institute of Environmental Management and Assessment, 2013).

A considerable amount of research has been done to develop methods for visual impact assessment (VIA) of various developments. Many of the studies attempted to quantify visual impact by developing objective indices (e.g., Torres-Sibille et al., 2007; Rodrigues et al., 2010;, Chamberlain & Meitner, 2009; Domingo-Santos et al., 2011), while some others investigate human response to the visual effect of developments (e.g., Bishop and Miller, 2007; Cloquell-Ballester et al., 2012; Tempesta et al., 2014). Objective indices can be helpful in reflecting changes in the physical properties of the visual landscape, however, how viewers respond to the changes is also very important in measuring visual impact, as visual landscape quality is determined by the interaction of the physical properties of the landscape and the perception of human viewers (Daniel, 2001).

While great effort has been made to understand the relationship between human perception of the visual landscape and the visual landscape settings (e.g., Shafer, 1969; Anderson & Schroeder, 1983; Palmer, 2004; Dramstad et al., 2006; Ode et al., 2009), which is helpful and essential in achieving more reliable VIAs where human response is associated, findings in studies involving multisensory environmental perception have shown that sound also plays an important role in visual landscape perception. Carles et al. (1999) studied the interaction of image and sound in the perception of general landscape quality, and found that natural sounds increased the perceived pleasantness of both urban and natural images, while man-made sounds degraded the appreciation of natural landscapes. Anderson et al. (1983) found similar results for natural sites where natural sounds were shown to have enhancing effect on the aesthetic evaluation whereas mechanical sounds had detracting effects, however, in the downtown areas the effect of sounds were relatively neutral. In regards to the specific effect of traffic noise, Mace et al. (1999) found that helicopter noise had negative influences on visitor experience in national parks including decreasing the perceived scenic beauty of the landscape. In a later expended study, Benfield et al. (2010) showed that aircraft and road traffic noise decreased ratings in scenic evaluation of natural landscape especially for scenes of high scenic beauty. Using similar landscape evaluation procedure and aesthetic indicators, Weinzimmer et al. (2014) investigated the effect of noises of propeller planes, motorcycles, and snowmobiles in national parks. The results indicated that all the three motorised noises detracted from the evaluation of landscape quality and the motorcycle noise had the most detrimental impact. Contrasting to these cases, however, Anderson et al. (1983) observed that road traffic noise turned to have an enhancing effect on the aesthetic evaluation of urban streets.

The effect of traffic noise on visual landscape perception is of particular importance for VIA of motorway projects, as the visually intrusive motorway traffic induces high level noise as well. However, while there are a lot of studies on the effect of visual settings on traffic noise perception (e.g., Joynt & Kang 2010; Maffei et al., 2013a; Watts et al. 1999), much fewer effect has been made to investigate the effect of noise on traffic visual impact perception. In an evaluation of visual impact of rural road and traffic in Lake District, Huddart (1978) used composite cine films both with and without sound to show controlled combinations of road projects and background sites for subjective assessment, and concluded that traffic noise had no significant effect on the assessment. However, it should be noted that traffic volume on the rural roads in that study were much lower than that of motorways today, and scenes with generally far distances to traffic were used due to the restriction in video simulation using composite cine films. In a study that specifically focused on the visual impact of moving traffic, Gigg (1980) also compared the subjective ratings given to filmed video scenes of moving traffic with and without sound, and found that traffic noise had a dominant effect on the visual assessment. In this study, while traffic volume was still relatively low, viewpoints close to the traffic (about 5 m-45 m) were selected.

The contradictory results of the two studies might be ascribed to the very different stimuli used. A possible hypothesis could be that traffic noise has significant effect on the perceived visual impact of moving traffic but only from short viewing distances. However, it is hard to draw any further conclusions regarding the changes of this effect with different traffic conditions in different background landscapes. Moreover, these two studies failed to achieve a full-factorial experiment design with accurate variable control and a more thorough understanding of the perceived visual impact of moving traffic itself is thus also needed, based on which the effect of traffic noise on the visual impact can be studied.

Therefore, the aim of this study is to first have a more systematic investigation on the perceived visual impact of motorway traffic in different traffic and landscape conditions, and then explore the effect of traffic noise on the perceived visual impact. Using computer visualisation, four traffic conditions, varied in traffic flow and composition, from three viewing distances, were simulated according to UK motorway traffic statistics; two background landscapes, natural and semi-rural residential landscapes, which are typical along the motorway corridors, were modelled based on a real site, as well as a baseline scenario without motorway and traffic for each landscape. Traffic noise was recorded at the real site where the visualisation was based and edited to match the simulated scenarios. Subjective responses to the visual effect of motorway traffic in the simulated scenes in both with- and without-sound conditions were obtained in a laboratory experiment. The effect of traffic noise was explored by comparing results from the two sound conditions.

## 2. Method

### 2.1. Visual stimuli

This study used computer visualisation to create visual stimuli for subjective assessment since computer visualisation is more advantageous in scenario creation and experimental control (Bishop & Miller, 2007). The validity of using computer visualisation in visual landscape research was supported by studies which examined the degree of realism of virtual landscape visualised using updated computer and GIS technologies (Appleton & Lovett, 2003; Bishop & Rohrmann, 2003; Lange, 2001). While the result of these studies showed that computer visualisation still could not be used with full confidence as a surrogate of real landscape or photograph for visual landscape assessment, generally reliable responses could be achieved.

Figure 1. The base site for computer visualisation.

A site along a segment of the M1 motorway near Ecclesfield (Sheffield), UK, covering an area of 2500 m × 2500 m, was chosen as the base site for visualisation (Figure 1). The dimensions of cross-section components for rural motorway mainline provided by Highway Agency (Highway Agency, 2005) was used to model the motorway, of which the detailed information can be found in Figure 2. With DTM data of the site from Ordnance Survey, the motorway and its surrounding landscape were modelled in Autodesk 3ds Max Design. Modelled landscape features included trees and buildings, for which the geo-data was obtained from Ordnance Survey's MasterMap. All the buildings were site-typically textured using images captured from Google Street View.

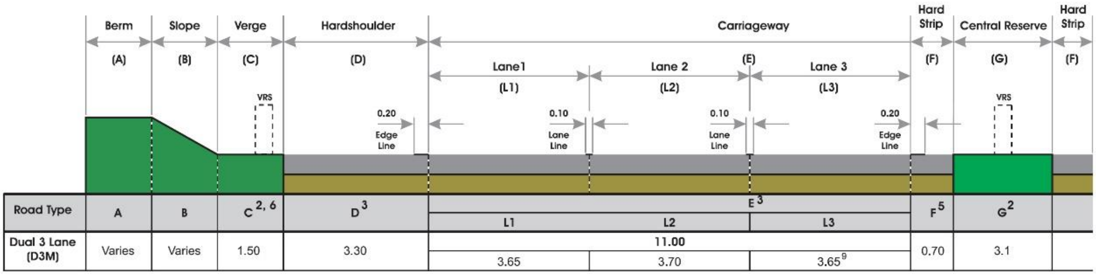


Figure 2. Dimensions of cross-section components for the simulated motorway, reproduced based on the Figure 4-1a in Highways Agency (2005).

Based on this 3D model of the existing landscape, the natural landscape scenario was simulated by removing all the buildings and replacing the original draped satellite image with a satellite image of grassland captured near the base site; the semi-rural residential landscape scenario was simulated by adding more buildings at some suitable positions where there are spacious open areas but not too close to the motorway. Trees were added and/or removed for both scenarios to avoid or mask conflict feature combinations after the alterations. To create the baseline scenarios, the modelled motorway was deleted and the land was draped with an altered satellite image in which the existing motorway was masked by grassland. For each scenario, the land in the foreground was textured with a bitmap of grassland since the draped satellite image blurs when getting close to the camera.

Three viewing distances were assigned for each landscape scenarios. According to the Federal Highway Administration, views of three distances were defined for road project VIA (Federal Highway Administration, 1981): foreground views (0 to 400-800 m), middle ground views (400-800 m to 4.8-8 km), and background views (4.8-8 km to infinite). Roads and traffic in foreground views are most potential to induce visual impact (Jones et al. 2006), while those in background views are unlikely to have an effect (Federal Highway Administration, 1981; Highways Agency, 1993). Field observation on the study site suggests that even from a distance of about 300 m, the visibility of the road and traffic has declined to a level that they only form a small element in the view. So distances (from road central line to the viewpoint) of 100 m, 200 m and 300 m, which covered the most affected area, were used for the three distance levels. Each viewpoint was set 1.6 m above the ground and with a view angle perpendicular to the road. The finished visualisations of the two landscapes as well as their baseline scenarios over the three distances are shown in Figure 3.

Four traffic conditions, varied with two levels of both traffic flow and percentage of heave good vehicle (HGV), which were shown to be predictive for the visual impact in Hopkinson & Watson (1974) and Gigg (1980), were designed for moving traffic simulation. The exact values of traffic flows and percentages of HGV were determined based on the annual traffic count of UK motorways (Department for Transport, 2014; Highway Agency, 2004). The general criteria was to make adequate variations while keep them representative and reasonable for a motorway like M1. A summary of the four traffic conditions can be found in Table 1.

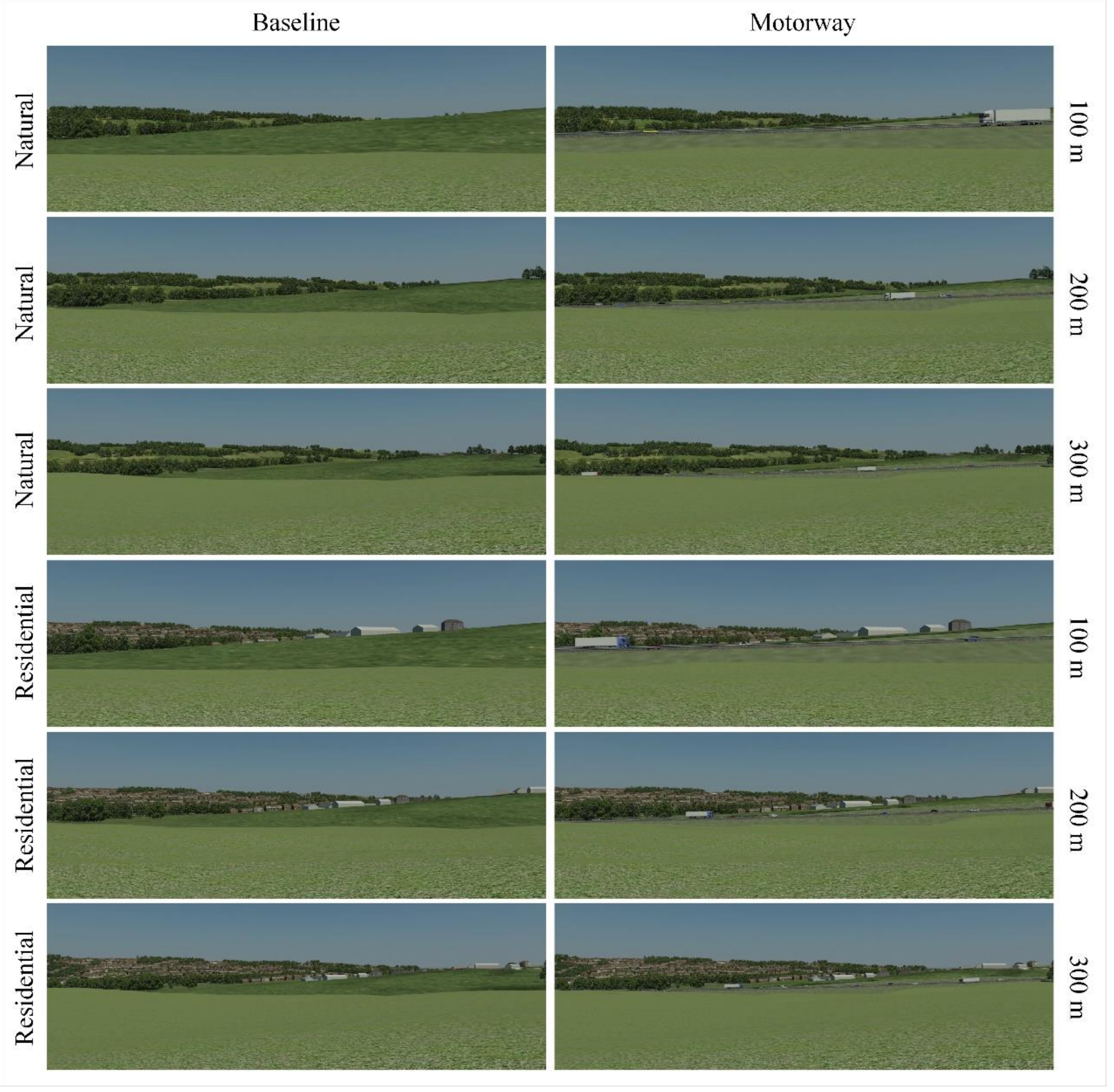


Figure 3. Computer visualisation of the two landscapes over the three distances.

Table 1. The four traffic conditions and their sound pressure levels (dBA) at the three distances.

| | Hourly traffic flow | No. of vehicle in 25s* | Percentage of HGV | No. of HGV in 25s* | PCU** in 25s* | SPL 100m | SPL 200m | SPL 300m |
|---|---|---|---|---|---|---|---|---|
| **Traffic condition 1** | 5464 | 38 | 10% | 4 | 46 | 69.6 | 65.0 | 62.7 |
| **Traffic condition 2** | 5464 | 38 | 20% | 8 | 54 | 70.9 | 66.3 | 63.9 |
| **Traffic condition 3** | 10928 | 76 | 10% | 8 | 92 | 72.6 | 68.0 | 65.7 |
| **Traffic condition 4** | 10928 | 76 | 20% | 15 | 106 | 73.9 | 69.3 | 66.9 |

*25s is the length of each scene with traffic.
** PCU: passenger car unit, car = 1; HGV = 3.

Changes in vehicle speed were not considered in this study because introducing various speeds would make the experiment design over complicated, and it was assumed that traffic flow is fairly consistent on motorways and vehicles move at a speed around the speed limits. So 110 km/h was assigned to cars and 90 km/h assigned to HGVs according to the UK motorway speed limits (GOV.UK, 2014). Vehicles for the four traffic conditions were added into the 3D model in Autodesk 3ds Max Design for animation rendering. Colour and other detailed attributes of individual vehicles were excluded as they were beyond the scope of this study.

The resolution of the rendering output was 1800 × 600 pixels, which was much wider than most of the standard frame sizes but was thought to be suitable and preferred for road project which extends transversely in the view (Landscape Institute, 2011). To avoid distortion of distance perception, the camera and rendering in 3ds Max were set in such a way that the vertical field of the widened view remained the same as the vertical field that a 3 × 2 image captured by a 35 mm format camera fitted with a 50 mm lens would have from the same distance.

Each scene of moving traffic lasted 25 seconds, which was thought to be long enough for making judgment yet not too long to avoid boredom. The frame rate was set at 30 fps to ensure smooth movement of the vehicles. The scenes of baseline scenarios were still images and each was 8 seconds in length which is a proper exposure time for visual landscape assessment using images (Daniel & Boster, 1976). In total, 24 scenes of moving traffic covering four traffic conditions, three viewing distances, two landscapes, plus 6 scenes of corresponding baseline scenarios, were compiled for the experiment.

## 2.2. Audio stimuli

Audio recording of the M1 traffic noise was made on site using a digital recorder Sound Devices 722 and a pair of DPA 4060 Miniature Omnidirectional Microphones, but only from a distance of about 230 m due to the limited accessibility. Estimated based on the simultaneous video recording, the traffic flow during recording was about 6300/h with a 14% HGV rate at speeds around 80-110 km/h, and was generally consistent. The recording was made on 24th October 2013. The weather was dry and the wind speed was very low at about 2.2 m/s. The temperature during the recording hour was about 12 ℃.

A 25-second audio recording sample was extracted from the full audio recording for reproduction. To calibrate the recording sample, the playback system (see Section 2.4), was first calibrated by playing back a calibrator signal recording (94 dB/1 kHz) and adjusting the setting-ups according to the sound pressure level (SPL) read on a sound level meter (SOLO Black 01dB) placed at the participant head position. The recording sample was then played back using the system with the same setting-ups. The received SPL of the recording sample was 70.4 dB(A).

In order to produce the traffic noise of the simulated moving traffic that would be received at the viewpoints of the three distances, SPLs for the three receiver positions in each of the four traffic conditions were predicted using the noise prediction software CadnaA. In Cadna A, 3D models for the two landscape scenarios were built using the same terrain and land cover data as used for the 3D modelling in 3ds Max. The absorption coefficient of the ground, which was grassland in this study, was set as 0.5. The UK CRTN model was used to calculate the noise levels (Department of Transport, 1988) and the obtained $L_{A10,18h}$ levels were further converted to $L_{Aeq,18h}$ levels (Abbott & Nelson, 2002)). The results showed that change of land cover in the background of the two landscape scenarios did not make the predicted SPLs any different. The SPLs for each traffic conditions are shown in Table 1. The original recording sample was then edited using Adobe Audition CS6, either by increasing or by decreasing the level, to produce traffic noise files of the needed SPLs.

For baseline scenarios where there would be no traffic, bird song was thought to be suitable for the soundtrack to be added, as it was the main background sound at the base site and was also contained in the extracted traffic noise recording sample. So audio recording of bird sound was obtained in a quiet park in Sheffield and an 8-second sample was extracted and attached to each of the baseline images. The played-back SPL of the bird song sample was 47.8 dB(A).

In total, 12 sound files of moving traffic for the four traffic conditions at three viewing distances, and 1 sound file of bird song for all the baseline scenarios, were produced for the experiment.

### 2.3. Combining visual and audio stimuli

Two copies of the 30 visualised scenes were made, one for the without-sound condition; and the other were matched up and combined with the sound files for the with-sound condition; The total 60 video clips were put together in a random order to create a single long video, with the scene number (Scene 1 to Scene 60) appearing for 4 seconds before each scene and an 8-second blank interval for the participants to do the rating after each scene. The overall length of the video was 35 minutes. To eliminate the possible bias in judgment that would induced by the showing order of the scenes, another video was made with scene showed in an inverse order. The two videos were equally but randomly assigned to the participant sessions. Correlation between ratings given to the two videos was tested after the experiment and a significantly high correlation was found (Pearson's $r = 0.953$, $p < 0.001$), which means that the inter-group agreement was high and the bias in judgment caused by showing order can be ignored.

**2.4. Participants and the experiment procedure**

To decide the sample size needed for the 4×3×2 within-subject design in this study, a power analysis was conducted using G*Power 3.1 (Erdfelder et al. 2007). With an effect size $f = 0.25$, an $\alpha = 0.05$, and a power = 0.95. The result suggested that a sample of 12 participants was needed. For this study, thirty participants (14 male and 16 female), aged 18-47 (Avg. = 24.2, S.D. = 6.2), with normal hearing and normal or adjusted to normal vision, were recruited via email invitation in the university and other online social media. Each participant received five pounds cash as compensation for their time.

The experiment was carried out in a 3.5 m ×3.5 m ×2.3 m anechoic chamber equipped with a playback system which consisted of a Dell Studio 1535 laptop, a RME BabyFace USB Audio Interface, a pair of Genelec 8030B loudspeakers which are self-powered, and a Genelec 7060B subwoofer. Loudspeakers and subwoofer were preferred as it reproduces sound contribution of traffic noise at low frequencies better than headphones (Maffei et al. 2013b). The video was projected via a Hitachi ED-X33 LCD projector onto a 203cm ×152cm Duronic floor stand projector screen about 2.2 meters away from where the participants were seated (Figure 4).

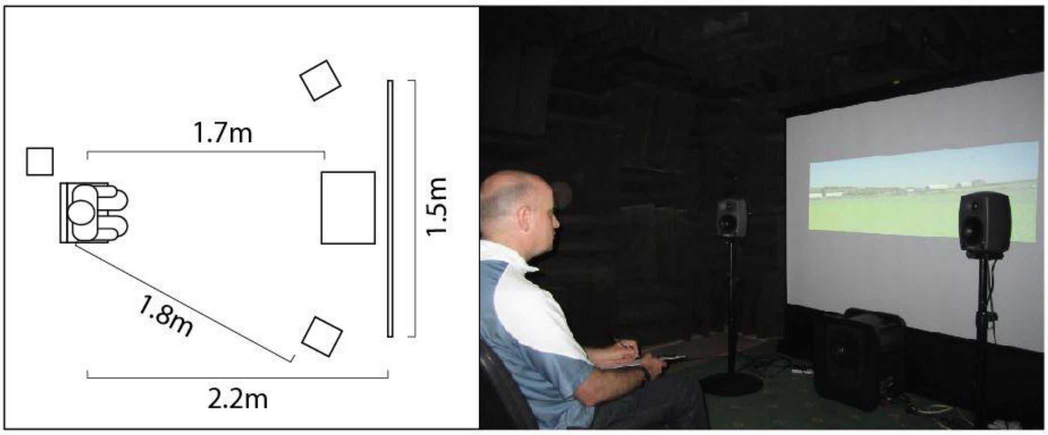


Figure 4. The layout of the anechoic chamber.

In the experiment, participants were asked to rate the visual pleasantness of each scene using visual analogue scale, that is, by marking a "×" on a bar which was 100 mm long on the printed questionnaire and had only "low pleasantness" and "high pleasantness" labelled at the two ends. Before start, participants were reminded that visual pleasantness in this study could be understood as visual landscape quality or scenic quality of the scenes, and there were no clear criteria for the rating, and they could draw upon whatever value judgements they deemed necessary. However, the purpose of this study was not mentioned. During the experiment, some participants did the rating before each scene finished, while the others waited for the 8 or 25 seconds. Since the content within each scene was very consistent throughout the scene length in this experiment, errors caused by variation in rating time would be minimal. At the end of each participant session, a short interview was carried out asking about participants' rating criteria. It was also attempted to ask the participants to rank the importance of the factors he/she mentioned but some found it very difficult. Participants were also asked to give comments on the experiment, e.g. the quality of the visualisation and sound playback, the length of the experiment, and the rating instrument used.

**2.5. Data analysis**

Visual pleasantness score was measured on questionnaires as the length from the low-pleasantness end of the visual analogue scale bar to the marked "×" on the bar in millimetre. For example, if the length is 60 mm, then the visual pleasantness score is 60. So possible visual pleasantness scores would range from 0 to 100. The perceived visual impact of traffic in each scene with traffic was calculated by subtracting visual pleasantness score of the scene from visual pleasantness score of the corresponding baseline scene. Possible visual impact values would thus range from -100 to 100, where a negative value means the traffic enhances the visual pleasantness whereas a positive value means the traffic decreases the visual pleasantness, the larger the absolute value the higher the degree of impact.

The significances of visual impact in each scenario was tested using *t*-test. A $4 \times 3 \times 2 \times 2$ within subjects ANOVA was run to analyse the effects of traffic condition, viewing distance, landscape type and sound condition on the visual impact. All the statistical analysis was carried out using IBM SPSS Statistics 21.

**3. Results**

**3.1 An overall analysis of the results**

The *t*-test was applied to test if there were significant changes in visual pleasantness when motorway traffic was introduced as compared with the baseline scenes. In total, 48 *t*-tests were run and the results show that changes in visual pleasantness were highly significant in all the traffic-landscape-distance-sound scenarios ($t$ = 4.339 to 19.559, df = 29, $p < .001$), which means the introduction of traffic induced significant visual impact in all the scenarios. Table 2 shows visual pleasantness of the baseline scene and visual impact of traffic averaged across the 30 participants for each scenario. All the visual impact values are positive, ranging from 14.9 to 46.6 with an average value of 30.9 in the without-sound condition, and from 29.1 to 58.2 with an average value of 42.5 in the with-sound condition. Given that the average visual pleasantness of the baseline scenes is 73.6 and 77.4 in the without- and with-sound condition respectively, the visual impact values indicate substantial deteriorations in perceived visual quality of the views caused by motorway traffic in both sound conditions.

A 4 × 3 × 2 × 2 within subject ANOVA was carried out for an overall analysis of the effects of traffic condition, viewing distance, landscape type and sound condition on the perceived visual impact of motorway traffic. The result shows that all the four factors had significant effect (Greenhouse-Geisser correction was applied where assumption of sphericity was violated), traffic condition: F = 50.193, df = 2.175, 63.082, $p < .001$, $\eta^2_p = .634$; viewing distance: F = 32.919, df = 1.426, 41.359, $p < .001$, $\eta^2_p = .532$; landscape type: F = 24.763, df = 1, 29, $p < .001$, $\eta^2_p = .461$; sound condition: F = 44.496, df = 1, 29, $p < .001$, $\eta^2_p = .605$, but none of their interactions was significant. The values of partial eta squared indicate that the effect of sound condition was even stronger than the effects of viewing distance and landscape type. Marginal mean comparisons show that differences between traffic condition 1 and 2, and between traffic condition 2 and 3 were highly significant ($p = .001$ and $p < .001$ respectively). The difference between traffic condition 3 and 4 was also significant but at a lower level ($p = .019$). As for the viewing distance, difference was significant between 100 m and 200 m ($p < .001$) but not between 200 m and 300 m.

The results indicate that all the studied factors played an important role in perceived visual impact of motorways. More detailed analysis is presented in Section 3.2 and Section 3.3.

Table 2. Visual pleasantness of the baseline scene and visual impact of traffic in each scenario (visual pleasantness: 0 for lowest pleasantness and 100 for highest pleasantness; visual impact: decrease in visual pleasantness).

| | | | Natural | | | | Residential | | | | Mean | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | **100m** | **200m** | **300m** | **mean** | **100m** | **200m** | **300m** | **mean** | **100m** | **200m** | **300m** | **mean** |
| **Without sound** | **Baseline visual pleasantness** | | 80.7 | 83.8 | 84.3 | 82.9 | 64.4 | 63.0 | 65.3 | 64.2 | 72.6 | 73.4 | 74.8 | 73.6 |
| | **Visual impact** | **Traffic condition 1** | 34.0 | 27.8 | 24.6 | 28.8 | 31.4 | 16.9 | 14.9 | 21.1 | 32.7 | 22.4 | 19.8 | 24.9 |
| | | **Traffic condition 2** | 41.7 | 30.4 | 29.3 | 33.8 | 30.1 | 22.7 | 20.0 | 24.3 | 35.9 | 26.6 | 24.7 | 29.0 |
| | | **Traffic condition 3** | 46.6 | 38.9 | 31.4 | 39 | 33.5 | 26.7 | 22.6 | 27.6 | 40.1 | 32.8 | 27.0 | 33.3 |
| | | **Traffic condition 4** | 46.3 | 40.1 | 35.3 | 40.6 | 41.0 | 30.2 | 24.6 | 31.9 | 43.7 | 35.2 | 30.0 | 36.3 |
| | | **mean** | 42.2 | 34.3 | 30.2 | 35.5 | 34.0 | 24.2 | 20.5 | 26.2 | 38.1 | 29.2 | 25.3 | 30.9 |
| **With sound** | **Baseline visual pleasantness** | | 81.0 | 84.7 | 90.0 | 85.2 | 68.7 | 70.4 | 70.0 | 69.7 | 74.9 | 77.5 | 79.9 | 77.4 |
| | **Visual impact** | **Traffic condition 1** | 44.8 | 36.4 | 40.0 | 40.4 | 38.2 | 32.1 | 29.1 | 33.1 | 41.5 | 34.3 | 34.5 | 36.8 |
| | | **Traffic condition 2** | 50.7 | 43.4 | 40.8 | 45.0 | 41.2 | 34.0 | 29.7 | 35.0 | 45.9 | 38.7 | 35.3 | 40.0 |
| | | **Traffic condition 3** | 56.8 | 45.9 | 47.3 | 50.0 | 47.7 | 38.6 | 36.6 | 41.0 | 52.3 | 42.3 | 41.9 | 45.5 |
| | | **Traffic condition 4** | 58.2 | 50.0 | 49.5 | 52.6 | 52.3 | 39.4 | 38.0 | 43.2 | 55.3 | 44.7 | 43.8 | 47.9 |
| | | **mean** | 52.6 | 43.9 | 44.4 | 47.0 | 44.9 | 36.0 | 33.4 | 38.1 | 48.7 | 40.0 | 38.9 | 42.5 |

### 3.2. Effects of traffic condition, viewing distance and landscape type

Corresponding to Table 2, Figure 5 compares visual impact for traffic condition, viewing distance and landscape type in the two sound conditions. While the results in the with-sound condition might be of more interest, since in real situations visual impact of motorways almost always occurs in the presence of traffic noise, the results in the without-sound condition can provide a useful comparison for understanding how effects of the examined factors might change when presence of noise is considered, which would help better interpretation and utilisation of findings from many of the visual impact studies that have been conducted without consideration of present noise.

In the without-sound condition, Figure 5-a shows that visual impact increased from traffic condition 1 to 4 and decreased by distance. The rates of decrease by distance kept largely the same across the four traffic conditions, and were faster between 100 m and 200 m than between 200 m and 300 m. Figure 5-b shows that visual impact in natural landscape was higher than that in residential landscape, and again the rates of decrease by distance were largely the same in the two landscapes. A similar trend is shown in figure 5-c where visual impact in natural landscape remained consistently higher than that in residential landscape across the four traffic conditions. The similar patterns of lines within each sub-figure indicate that the effect of each of the three factors on visual impact was largely independent from the others two.

In the with-sound condition, overall, visual impact increased from traffic condition 1 to 4, decreased by distance, and was higher in natural landscape than in residential landscape. However, although the ANOVA shows no significant interaction between any of the three factors in association with sound condition, patterns of lines within each sub-figure with sound are not as similar to each other as in the case without sound, and decrease by distance became smaller and less clear between 200 m and 300 m. Figure 5-d shows that visual impact decreased by distance between 100 m and 200 m at similar rates as those in the without-sound condition for the four traffic conditions, but remained largely unchanged from 200 m to 300 m except for traffic condition 2 where visual impact kept dropping. A noticeable difference in decrease by distance is also shown between the two landscape types in Figure 5-e. The two lines drop parallel from 100 m to 200 m, however, while visual impact in the residential landscape kept decreasing at a less rapid rate, that in the natural landscape increased and became slightly higher at 300 m than at 200 m. The minor decrease and no decrease in the with-sound condition can explain the overall insignificant difference between distances of 200 m and 300 m in the ANOVA result. No clear possible interaction is shown between traffic condition and landscape type in Figure 5-f.

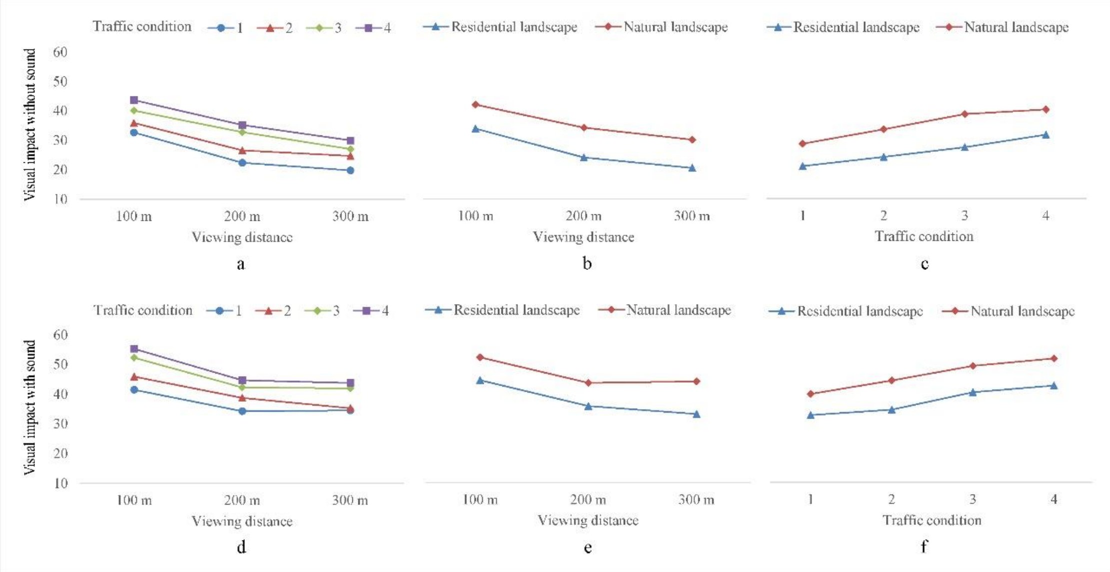


Figure 5. Comparisons of visual impact for traffic condition, viewing distance and landscape type in the two sound conditions (visual impact is the decrease in visual pleasantness which ranges from 0 to 100, 0 for lowest pleasantness and 100 for highest pleasantness).

### 3.3. Effect of traffic noise

The ANOVA in Section 3.1 shows a significant difference between the two sound conditions. Figure 6 illustrates the difference. Generally, traffic noise increased the perceived visual impact in all the traffic-landscape-distance scenarios and the increases were relatively constant across the scenarios with an average of 11.6. The relatively constant increases reflect the insignificant interactions between sound condition and the other factors reported by ANOVA.

Specifically, Figure 6-a compares the effect of traffic noise over the four traffic conditions. Increases in visual impact by traffic noise remained largely the same in the four traffic conditions, despite the different noise levels associated with them. Similar noise effect was found in Figure 6-b where increases in visual impact by traffic noise were nearly identical in the two landscapes. Figure 6-c, however, shows potential changes in noise effect with viewing distance, where increases in visual impact by traffic noise was slightly higher at the distance of 300 m. This has also been mentioned in the analysis of the effect of viewing distance. Overall, it can be concluded that the effect of traffic noise on visual impact was not affected very much by traffic condition, landscape type, or viewing distance, but there is a potential interaction with viewing distance.

To test the possible dependence of noise effect on SPL at receiver position, Pearson's correlation analysis was carried out for each of the two landscapes respectively. However, the results were not significant either.

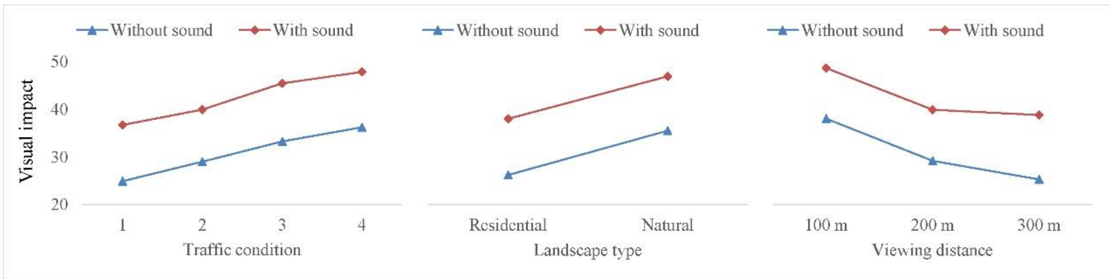


Figure 6. Differences in visual impact between the two sound conditions (visual impact is the decrease in visual pleasantness which ranges from 0 to 100, 0 for lowest pleasantness and 100 for highest pleasantness).

## 4. Discussion

### 4.1. Implications for visual impact assessment.

The results of this study show that motorway traffic induced significant visual impact, and the higher the traffic volume, the higher the impact. In Huddart (1978), passenger car unit (PCU), as the index of traffic volume, was used as an independent variable to predict the visual impact of roads and traffic, whereas in Hopkinson & Watson (1974) and Gigg (1980), traffic flow and percentage of HGV were used to reflect not only changes in traffic volume, but also changes in traffic composition, which is analogous to the prediction of traffic noise. In this study, comparisons of the marginal mean of visual impact of each traffic condition indicate that traffic composition made highly significant difference on visual impact when traffic volume was low, and less significant difference when traffic flow was high. Figure 7 shows the increase of visual impact by traffic volume which is measured in PCU (car = 1, HGV = 3). In both sound conditions, visual impact increased rapidly when PCU increased by only 8 from 46 to 54 but with the number of HGVs doubled. The increase of visual impact was much slower from PCU 54 to 92 where the number of HGVs remained the same. From PCU 92 to 106, visual impact increased at a rate more similar to that from PCU 54 to 92 despite the doubled number of HGVs. It suggested that simply calculating or measuring PCU for visual impact assessment may be sufficient for projects where traffic volume is high enough, but may not be a proper method when traffic volume is low since the extra effect of HGVs would be eliminated.

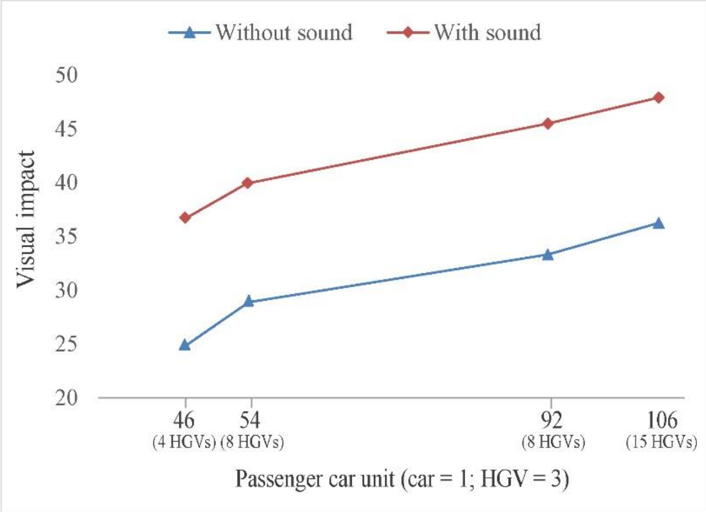


Figure 7. Increase of visual impact by traffic volume measured in PCU (car = 1, HGV = 3) (visual impact is the decrease in visual pleasantness which ranges from 0 to 100, 0 for lowest pleasantness and 100 for highest pleasantness).

It had been expected that the pattern of the increase of visual impact by traffic condition would be different in the two landscapes, given different sensitivities to visual intrusion of different landscapes. In Huddart (1978), equations using PCU as the predictor were developed for different landscapes and larger slopes of the linear regression equations were found for the more visually pleasant sites. However, the result in this study shows that whether with sound or not, the pattern of increase by traffic condition did not change significantly with landscapes, although with the same traffic, visual impact did tend to be higher in the natural landscape. The finding of this study indicates that it is possible to simplify the VIA of motorway projects as the effect of landscape seems to be rather independent from the effect of traffic condition. However, studies covering a wider range of landscape types are still needed.

Independent effect on visual impact was also found of viewing distance. However, the effects were slightly different in the two sound conditions. While visual impact generally decreased by distance, the decrease from 200 m to 300 m in the with-sound condition was very small. Specifically, visual impact at 300m was even slightly higher than at 200m in the natural landscape. This might be explained by that traffic noise and traffic visibility decline at different rates by distance, in this case the decline of traffic noise was less rapid and thus the intensification effect of it became more obvious at further distances. Also, the negative effect of traffic noise would be stronger in the more vegetated landscape (Anderson et al., 1984; Mulligan et al., 1987). However, on the other hand, no significant interaction between sound condition and distance or between sound condition and landscape, or among the three factors, was reported in this study. Further studies are needed to better understand the complex decrease of visual impact by distance when noise is present. The possible effect of noise would require a different approach for studying the visual impact of motorway project. Conventional visual impact research only focuses on the effect of visual stimuli when studying visual perception related to visibility or distance issues (Shang & Bishop, 2000; Bishop, 2002; Bruce Hull IV & Bishop, 1988). In the case of motorways where noise impact is severe, the effect of noise should be addressed and visual threshold for visual impact at a larger distance might need to be considered.

While traffic noise was found to have an overriding effect on visual assessment in Gigg (1980) but did not significantly affect the ratings in Huddart (1978), the result in this study suggests something in between. It shows that traffic noise had a considerable effect which however was constant and did not show clear dependence with noise level, traffic condition, landscape type, or viewing distance, although there was a possible increase in the effect by distance. So traffic noise significantly increased the perceived visual impact, but the variation in visual impact with sound was still largely determined by visual stimuli. One possible reason for this constant effect might be the high but small-ranged level of noise applied in this study (62.7 - 73.9 dBA). In this study, the contrast between with and without sound was sharp, but noise levels in the with-sound condition might not have varied widely enough to significantly diversify participants' responses. At a lack of more improved knowledge from further studies, findings in this study suggests that the effect of traffic noise can be accounted for in VIA of motorway projects by adding on a constant level of additional impact to the visual impact which is evaluated based on visual factors. This may not offer more useful information than when noise effect is ignored for comparing alternative plans within the issue of visual impact, but it will give more accurate weight on visual impact when balancing it with other environmental impacts of motorways, and also enable more cooperative and efficient measures for mitigations of visual and noise impacts.

### 4.2. Possible effects of vehicle speed and colour on perceived visual impact

Some participants mentioned the effect of vehicle speed on their judgment and gave lower visual pleasantness rating when the speed was “higher”. While speed was fixed in this study, the movement of vehicle did look faster from shorter distances, which is also the case in Gigg (1980) using filmed scenes of real traffic. It implies that higher visual impact of traffic being expected from a shorter distance may not only be because the traffic forms a larger element in the view but also because it appears to be faster than traffic passing the viewers at the same speed from longer distances. It also reveals the potential effect of speed which was not addressed in this study and would require further investigation.

Colour has also shown an effect in this study. Some participants mentioned that the colour contrast between the white lorry cargos and the greenery background detracted from the visual pleasantness. This inclination is consistent with findings or emphasis in research that addressed the effect of colour in landscape perception (Bishop, 1997; Garcia et al, 2003; Groß, 1991). While these findings can be useful in minimising visual impact of new constructions in sensitive areas, they are hardly applicable to moving traffic of which the colour cannot be defined in the proposal of development. However, awareness should be raised that traffic consisting of brighter-coloured vehicle is likely to have higher visual impact.

## 5. Conclusions

This study aimed to have a systematic investigation on the perceived visual impact of motorway traffic in different but controlled traffic and landscape conditions, and examine the effect of traffic noise on the perceived visual impact by comparing with- to without-sound conditions. Using computer visualisation, four traffic conditions, two types of landscape, three viewing distances were simulated, and a sample of motorway traffic noise recording was edited and added for the with-sound condition. Subjective responses to the simulated scenes of motorway traffic both with and without sound were gathered in a laboratory experiment.

The results of this study show that motorway traffic induced significant visual impact, and the higher the traffic volume, the higher the impact. Specifically, when traffic flow was low, the composition of the traffic could change the impact dramatically; while when traffic flow was high, the composition made no significant changes, implicating that different concerns on traffic composition might be needed for VIA of motorway projects with different traffic volumes.

Consistently higher visual impact was found in the natural landscape than in the residential landscape, indicating a significant effect of landscape types. However, this effect seemed to be largely independent from the effect of traffic condition, which suggested that it might be possible to simplify VIA of motorway projects.

The effect of viewing distance was also significant and largely independent, and there was a rapid-to-gentle decrease of visual impact by distance. However, the decrease was less rapid and the decrease pattern less clear at further distance in the with-sound condition. Further studies are needed to address this issue and different approaches in deciding visual threshold might be required for VIA of motorway projects where loud traffic noise is present.

Comparing visual impact with sound to without sound, this study shows significant effect of traffic noise on the perceived visual impact of traffic. Generally, the effect of noise was consistent and increased visual impact by a relatively constant level despite the changing noise levels, traffic conditions, landscape types, and viewing distances. There was a possible effect of distance on noise effect but would require further studies to draw more confident conclusions. At this stage, findings in this study suggest to add on a constant level of additional impact to visual impact evaluated based on visual factors to account for the effect of traffic noise in the VIA of motorway projects.

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**References**

Abbott, P., G. & Nelson, P. M. (2002). *Converting the UK Traffic Noise Index $L_{A10,18h}$ to EU Noise Indices for Noise Mapping*. Project Report PR/SE/451/02. TRL Limited.

Anderson, L.M., Mulligan, B.E., and Goodman, B.E. (1984). Effects of vegetation on human response to sound. *Journal of Arboriculture, 10*(2): 45-49.

Anderson, L.M., Mulligan, B.E., Goodman, B.E., & Regen, H. Z. (1983). Effects of sounds on preferences for outdoor settings. *Environment and Behavior, 15*(5): 539-566.

Anderson, L. M. and Schroeder, H. W. (1983). Application of wildland scenic assessment methods to the urban landscape. Landscape Planning, *10*(3): 219-237.

Appleton, K. & Lovett, A. (2003). GIS-based visualisation of rural landscapes: defining 'sufficient' realism for environmental decision-making. *Landscape and Urban Planning*, *65*(3): 117-131.

Benfield, J. A., Bell, P. A., Troup, L. J., & Soderstrom, N. J. (2010). Aesthetic and affective effects of vocal and traffic noise on natural landscape assessment. *Journal of Environmental Psychology*, *30*(1): 103–111.

Bishop, I. D. (1997). Testing perceived landscape colour difference using the Internet. *Landscape and Urban Planning*, *37*(3-4): 187-196.

Bishop, I. D. (2002). Determination of thresholds of visual impact: the case of wind turbines. *Environment and Planning B: Planning and Design*, *29*(5) 707-718.

Bishop, I. D. & Miller, D. R. (2007). Visual assessment of off-shore wind turbines: The influence of distance, contrast, movement and social variables. *Renewable Energy*, *32*(5): 814-831.

Bishop, I. D. & Rohrmann, B. (2003). Subjective responses to simulated and real environments: a comparison. *Landscape and Urban Planning*, *65*(4): 261-277.

Bruce Hull IV, R. & Bishop, I. D. (1988). Scenic impacts of electricity transmission towers: the influence of landscape type and observer distance. *Journal of Environmental Management, 26*: 000-000.

Carles, J. L., Barrio, I. L., & de Lucio, J. V. (1999). Sound influence on landscape values. *Landscape and Urban Planning 43*(4): 191-200.

Chamberlain, B. C. and Meitner, M. J. (2009). Automating the visual resource management and harvest design process. *Landscape and Urban Planning*, *90*(1–2): 86-94.

Cloquell-Ballester, V., Torres-Sibille, A., Cloquell-Ballester, V., & Santamarina-Siurana, M. (2012). Human alteration of the rural landscape: Variations in visual perception. *Environmental Impact Assessment Review, 32*(1): 50-60.

Daniel, T. C. (2001). Whither scenic beauty? Visual landscape quality assessment in the 21st century. *Landscape and Urban Planning, 54*(1-4): 267–281.

Daniel, T. C. & Boster, R. S. (1976). *Measuring Landscape Esthetics: The Scenic Beauty Estimation Method*. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station.

Department of Transport (1988). *Calculation of Road Traffic Noise*. London: Her Majesty's Stationery Office.

Department for Transport. Traffic Count. Retrieved April, 2014 from: http://www.dft.gov.uk/traffic-counts/

Domingo-Santos, J. M., de Villarán, R. F., Rapp-Arrarás, Í, and de Provens, E. C. (2011). The visual exposure in forest and rural landscapes: An algorithm and a GIS tool. *Landscape and Urban Planning, 101*(1): 52-58.

Dramstad, W., Tveit, M., Fjellstad, W., & Fry, G. (2006). Relationships between visual landscape preferences and map-based indicators of landscape structure. *Landscape and Urban Planning, 78*(4): 465-474.

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods,39*: 175-191.

Federal Highway Administration (1988). *Visual Impact Assessment for Highway Projects*. Washington, D.C.: U.S. Department of Transportation.

García, L., Hernández, J., & Ayuga, F. (2003). Analysis of the exterior colour of agroindustrial buildings: a computer aided approach to landscape integration. *Journal of Environmental Management, 69*(1): 93-104.

Gigg, M. F. (1980). *The Visual Intrusion of Moving Traffic*, PhD Thesis. University of Sheffield, Department of Civil and Structural Engineering.

GOV.UK. Speed Limit. Retrieved April, 2014 from: https://www.gov.uk/speed-limits

Groß, M. (1991). The analysis of visibility—Environmental interactions between computer graphics, physics, and physiology. *Computers & Graphics, 15*(3): 407-415.

Highways Agency (1993). *Design Manual for Roads and Bridges, Volume 11, Section 3, Part 5: Landscape Effects*. Retrieved from: http://www.dft.gov.uk/ha/standards/dmrb/vol11/section3/11s3p05.pdf

Highways Agency (2005). *Design Manual for Roads and Bridges, Volume 6, Section 1, Part 2: Cross-sections and Headrooms*. Retrieved from: http://www.dft.gov.uk/ha/standards/DMRB/vol6/section1/td2705.pdf

Highways Agency (2004). *Design Manual for Roads and Bridges, Volume 13, Section 4, Part 4: Traffic Input to COBA*. Retrieved from: http://webarchive.nationalarchives.gov.uk/20100304070241/http://www.dft.gov.uk/pgr/economics/software/coba11usermanual/part4trafinputtocobarevis315.pdf

Hopkinson, R. G. & Watson, N. (1974). *Visual Effects of Road and Traffic, Report to the Department of Environment.* London: Her Majesty's Stationery Office.

Huddart, L. (1978). *An Evaluation of the Visual Impact of Rural Roads and Traffic*. Crowthorne: Transport and Road Research Laboratory.

Jones, G. R., Sorey, D. F., & Scott, C. G. (2006). Applying visual resource assessment for highway planning. In L. J. Hopper (Ed), *Landscape Architectural Graphic Standards* (pp. 130-139). New York: John Wiley & Sons.

Joynt, J. & Kang, J. (2010). The influence of preconceptions on perceived sound reduction by environmental noise barriers. *Science of the Total Environment*, *408*(20): 4368-4375.

Landscape Institute (2011). *Photography and Photomontage in Landscape and Visual Impact Assessment*. London: Landscape Institute.

Lange, E. (2001). The limits of realism: perceptions of virtual landscapes. *Landscape and Urban Planning*, *54*(1-4): 163-182.

Mace, B., Bell, P., & Loomis, R. (1999). Aesthetic, affective, and cognitive effects of noise on natural landscape assessment. *Society & Natural Resources: An International Journal*, *12*(3): 225-242.

Maffei, L., Masullo, M., Aletta, F., & Gabriele, M. (2013a). The influence of visual characteristics of barriers on railway noise perception. *Science of The Total Environment*, *445–446*: 41–47

Maffei, L., Iachini, T., Masullo, M., Aletta, F., Sorrentino, F., Senese, V. P., & Ruotolo, F. (2013b). The effects of vision-related aspects on noise perception of wind turbines in quiet areas. *International Journal of Environmental Research and Public Health, 10*: 1681-1697.

Mulligan, B. E., Lewis, S. A., Faupel, M. L., Goodman, L. S., & Anderson, L. M. (1987). Enhancement and masking of loudness by environmental factors: vegetation and noise. *Environment and Behavior, 19*(4): 411-443.

Ode, Å., Fry, G., Tveit, M. S., Messager, P., & Miller, D. (2009). Indicators of perceived naturalness as drivers of landscape preference. *Journal of Environmental Management, 90*(1): 375–383.

Palmer, J. (2004). Using spatial metrics to predict scenic perception in a changing landscape: Dennis, Massachusetts. *Landscape and Urban Planning, 69*(2-3): 201-218.

Rodrigues, M., Montañés, C., and Fueyo, N. (2010). A method for the assessment of the visual impact caused by the large-scale deployment of renewable-energy facilities. *Environmental Impact Assessment Review 30*(4): 240-246.

Shafer, E. (1969). Perception of natural environment. *Environment and Behavior, 1*: 71-82.

Shang, H. & Bishop, I.D. (2000). Visual thresholds for detection, recognition and visual impact in landscape settings. *Journal of Environmental Psychology, 20*: 125-140.

Tempesta, T., Vecchiato, D., & Girardi, P. (2014). The landscape benefits of the burial of high voltage power lines-A study in rural areas of Italy. *Landscape and Urban Planning, 126*: 53-64.

The Landscape Institute and Institute of Environmental Management and Assessment (2013). *Guidelines for Landscape and Visual Impact Assessment, third edition*. Abingdon: Routledge.

Torres-Sibille, A., Cloquell-Ballester, V., loquell-Ballester, V., & Darton, R. (2009). Development and validation of a multicriteria indicator for the assessment of objective aesthetic impact of wind farms. *Renewable and Sustainable Energy Reviews, 13*(1): 40-66.

Watts, G., Chinn, L., & Godfrey, N. (1999). The effects of vegetation on the perception of traffic noise. *Applied Acoustics, 56*(1): 39–56.

Weinzimmer, D., Newman, P., Taff, D., Benfield, J., Lynch, E., & Bell, P. (2014). Human responses to simulated motorized noise in national parks. *Leisure Sciences: An Interdisciplinary Journal, 36*(3): 251-267.