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Combined acoustical and visual performance of noise barriers in mitigating the environmental impact of motorways

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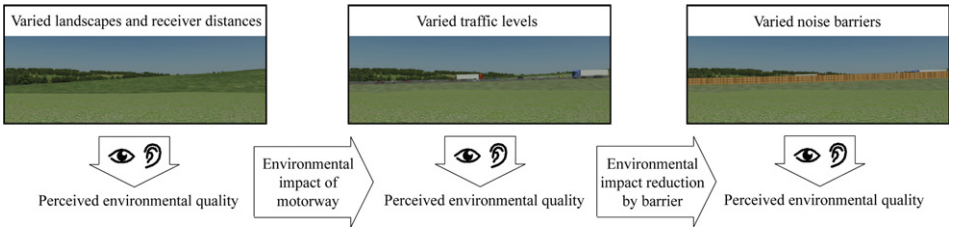
HIGHLIGHTS

- Noise barriers were assessed combining their acoustical and visual performances.
- Barrier performance was compared in varied traffic, distance and landscape scenarios.
- Barriers had beneficial or insignificant effect, largely similar to that of tree belt.
- Taller opaque barrier performed better at far distance but not when getting closer.
- Barrier performance correlated positively with aesthetic preference in residential scenarios.

GRAPHICAL ABSTRACT



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ABSTRACT

This study investigated the overall performance of noise barriers in mitigating environmental impact of motorways, taking into consideration their effects on reducing noise and visual intrusions of moving traffic, but also potentially inducing visual impact themselves. A laboratory experiment was carried out, using computer-visualised video scenes and motorway traffic noise recordings to present experimental scenarios covering two traffic levels, two distances of receiver to road, two types of background landscape, and five barrier conditions including motorway only, motorway with tree belt, motorways with 3 m timber barrier, 5 m timber barrier, and 5 m transparent barrier. Responses from 30 participants of university students were gathered and perceived barrier performance analysed. The results show that noise barriers were always beneficial in mitigating environmental impact of motorways, or made no significant changes in environmental quality when the impact of motorways was low. Overall, barriers only offered similar mitigation effect as compared to tree belt, but showed some potential to be more advantageous when traffic level went high. 5 m timber barrier tended to perform better than the 3 m one at the distance of 300 m but not at 100 m possibly due to its negative visual effect when getting closer. The transparent barrier did not perform much differently from the timber barriers but tended to be the least effective in most scenarios. Some low positive correlations were found between aesthetic preference for barriers and environmental impact reduction by the barriers.

1. Introduction

The growing concern about noise pollution has increased the use of noise barriers along major transport infrastructures (Kotzen and English, 2009). Noise barriers come in various sizes, forms, placements and materials and can reduce noise up to about 15 dBA realistically in practice (Kotzen and English, 2009). Evaluation of noise barriers

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requires however more than the measurement of noise reduction. Studies on perceived effectiveness of noise barrier have shown influences of factors other than acoustical performance, e.g., before-barrier sound levels (May and Osman, 1980), engagement in the barrier design (Hall, 1980, Joynt, 2005), social and economic effects, e.g., changes in property value and risk of crime (Perfater, 1979).

Among the influential factors, visual factor is a major one and many studies have investigated the effect of it. Aylor and Marks (1976) studied the perceived loudness of noise transmitted through barriers of different solidity in "sight + sound" and "sound only" conditions. The results showed lower perceived loudness when the sight of the noise source was partially obscured; but higher perceived loudness when the sight of noise source was completely obscured. Similar results were found in Watts et al. (1999) where the effect of vegetation on traffic noise perception was investigated both on site and in laboratory. It was shown that perceived noisiness was higher where the level on visual screening of the sound source by vegetation was higher. In their laboratory experiment, a willow barrier and a metal barrier of the same dimension were also included in the assessment. While participants rated the willow barrier more attractive than the metal one, similar perceived noisiness behind the two barriers was reported. Joynt and Kang (2010) conducted a more dedicated and detailed study on the effect of barrier aesthetics. The study compared perceived effectiveness of four motorway noise barriers and a deciduous hedgerow in a laboratory experiment. The results showed a strong negative correlation between aesthetic preference and the perceived noise attenuation of the barriers. The study also investigated the effect of preconception of barrier effectiveness on the perceived noise attenuation and found positive correlation between them. Lower perceived loudness behind the opaque barriers was found in this study which was contradictory to that in Watts et al. (1999) and Aylor and Marks (1976). Maffei et al. (2013) studied the effect of barrier aesthetics and noise source visibility through barriers on the perceived loudness and annoyance of railway noise. The results was more in line with Watts et al. (1999) and Aylor and Marks (1976), that perceived loudness was lower for transparent barriers than for opaque barriers, and remained largely the same for barriers of different aesthetics. Noise annoyance was perceived lower for transparent barriers as well, and for barriers with higher aesthetics. The effect of visual characteristics increased as noise level increased.

The above studies show that perceived effectiveness of noise barriers are influenced by noise source visibility and barriers aesthetics in complex ways, requiring the use of aural-visual interaction approaches for the assessment of barriers. While some studies investigated either the effect of visual stimuli on sound environment perception (e.g., Anderson et al., 1984; Liu et al., 2014; Mulligan et al., 1987; Ren and Kang, 2015; Viollon et al., 2002), or audio stimuli on visual environment perception (e.g., Anderson et al., 1983; Benfield et al., 2010; Hetherington et al., 1993), many have focused on their interactive effects on the perception of the overall quality of the environment (e.g., Carles et al., 1999; Hong and Jeon, 2013; Pheasant et al., 2008). Nilsson et al. (2012) argued that assessing the overall environmental quality is easier and more natural than assessing environmental qualities of each individual sensorial modality, which is particularly applicable for the case of noise barriers, as design and installation of noise barriers is also a landscape issue: while they are aimed to be acoustically beneficial, they are often visually intrusive and can restrict sight of desired views (Arenas, 2008; Bendtsen, 1994; Kotzen and English, 2009).

Following this argument, Hong and Jeon (2014) studied the overall preference for noise barriers considering both audio and visual performances. Their results show that vegetated barrier was the most preferable one, followed by concrete and wood barriers, translucent acrylic and aluminium barriers were the least preferred, despite the lower perceived loudness found for transparent and nonsolid barriers in Aylor and Marks (1976), Maffei et al. (2013) and Watts et al. (1999). Preconception of barriers' noise reduction effectiveness was the most affecting factor in determining the overall preference for the barriers when the noise level was relatively low (55 dBA), while aesthetic preference for barriers came to be the most determinant one when noise level was relatively high (65 dBA).

The results of Hong and Jeon (2014) are informative and indicate potential improvement that could be made for the evaluation of noise barriers by evaluating their overall environmental performance. However, one limitation of Hong and Jeon (2014) is the use of static images to present noise barriers for road traffic in their experiment. It failed to present moving traffic which should be visible in some barrier scenarios, while moving traffic has been shown to be influential on perceptions of both sound (Fastl, 2004) and visual (Gigg, 1980; Huddart, 1978) environmental qualities. Moreover, there is a lack of investigations on the effects of background landscape and receiver distance to road on the perceived barrier performance in previous multisensory-based noise barriers studies. Background landscape is not only one of the decisive factors in determining the visual effect that a certain development can have on human viewers (Landscape Institute and Institute of Environmental Management and Assessment, 2013), it is also influential on noise perception (Mulligan et al., 1987; Viollon et al., 2002) and can thus affect the perceived acoustic performance of the barriers. Receiver distance to road is also not only critical for visual impact assessment (Landscape Institute and Institute of Environmental Management and Assessment, 2013), but for the measured net benefit that barriers can have on certain receivers as well (Highways Agency, 2001a). Herman et al. (1997) showed that perceived effectiveness of barriers was also distance-dependant.

Therefore, the aim of this study is to investigate the overall performance of noise barriers in mitigating environmental impact of motorways, taking into consideration their effects on reducing noise and visual intrusions of moving traffic, but also potentially inducing visual impact themselves. Specifically, the study is to answer the following questions: (1) are noise barriers always beneficial in mitigating environmental impact of motorways and how beneficial are they given different traffic levels, receiver distances to road and background landscapes? (2) How do barriers of different acoustical and visual characteristics differ in their performance in the varied scenarios? (3) Do aesthetic preference for barriers and preconception of their noise reduction effectiveness influence the perceived overall performance of them? A laboratory experiment was carried out to obtain subjective responses to computer-visualised video scenes representing different experimental scenarios, including scenes without motorways, scenes with motorways, and scenes with motorways and barriers varying in size and transparency. Performances of barriers were compared in terms of reductions in perceived environmental impact of motorways in different scenarios.

2. Methods

2.1. Design of the experimental scenarios

Three barrier scenarios were designed to represent barriers varying in transparency and size: 3-m-tall timber barrier, 5-m-tall timber barrier, and 5-m-tall transparent barrier. Timber material was preferred over metal, concrete, brick etc. for the opaque barrier because timber barriers are the most commonly used type of barriers for mitigation of road traffic noise in the UK (Kotzen and English, 2009). The height of timber barriers in the UK rarely exceeds 3 m (Kotzen and English, 2009; Morgan, 2010) and there was a general restriction on barrier height of 3 m in the UK to avoid visual intrusion (Highway Agency, 2001b). However, timber barriers are recently increasing in height and those in the Europe can reach 4–5 m tall (Kotzen and English, 2009; Morgan, 2010). So the heights of 3 m and 5 m were used for the two timber barrier scenarios, which are realistic in scale and typical for the visual concerns while offer adequate difference in noise reduction. Transparent barriers can be made from several materials and there is less restriction in their heights. The height of 5 m, the same as the taller timber barrier,