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The influence of preconceptions on perceived sound reduction by environmental noise barriers

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Abstract

The paper presents research that answers three main questions: (1) Do preconceptions held about the constituent materials of an environmental noise barrier affect how people perceive the barrier will perform at attenuating noise? (2) Does aesthetic preference influence the perception of how a barrier will perform? (3) Are barriers, which are deemed more aesthetically pleasing, more likely to be perceived as better noise attenuators? In a virtual reality setting with film to improve the contextual realism of the intersensory interaction test, participants were required to compare the perceived effectiveness of five standard 'in-situ' noise barriers, including concrete, timber, metal, transparent acrylic and a vegetative screen. The audio stimulus was held at a constant sound pressure level (SPL), whilst the visual stimulus changed, as the influential factor. As the noise levels projected during the study were held constant, it was possible to attribute the participant's perception of noise attenuation by the barriers, to preconceptions of how the varying barrier material would attenuate noise.

There was also an inverse correlation between aesthetics and perception of how a noise barrier would perform. The transparent and deciduous vegetation barriers, judged most aesthetically pleasing, were judged as the least effective at attenuating noise.

Keywords (Noise Barriers; Intersensory; Perception; Materials; Acoustics; Environment)

The Influence of Preconceptions on Perceived Sound Reduction by Environmental Noise Barriers

1. Introduction

Changes in legislatively driven programs under the European Directive on the Assessment and Management of Environmental Noise (European Parliament, 2002) are likely to lead to an increase in the use of noise barriers as a means of mitigating road traffic noise.

This paper presents research that answers three main questions: (1) Do preconceptions held about the constituent materials of a noise barrier affect how people perceive the barrier will perform at attenuating noise? (2) Does aesthetic preference influence the perception of how a barrier will perform? (3) Are barriers, which are deemed more aesthetically pleasing, more likely to be perceived as better noise attenuators?

The basis of the research stemmed from an assertion found both in the literature and primary research (Joynt, 2005, Aylor and Marks, 1976, Watts *et al*, 1999, MD-Taha, 1999), that residents rarely, if ever, are given the 'before' and 'after' installation 'objective' values of noise attenuation levels by noise barriers. Consequently, their opinions are formed largely on a subjective perception.

This subjective perception has been found to be influenced by many factors beyond the actual objective noise reduction. One of which being the engagement in the design of the barriers by those to be affected by it prior to construction. This factor alone has been shown to radically alter the resident's perception of noise reduction (Cohn, 1981, Cohn, and Bowlby, 1984, Hall. 1980, Joynt, 2005), and in some cases warrant the removal of the barrier altogether (Orsman, 2003). Equally according to Bailey and Grossardt, (2006), 'subject to a minimum sound attenuation capacity, noise walls must present a pleasing visual aspect to their user communities including residents, commuters, and others '.

Additionally, research has found that noise barriers that instil a perception of increased risk of crime, through vandalism or potential concealment of criminals, are also evaluated as less effective (Perfater, 1979).

This is a particularly salient fact when decisions are made over the type of material a noise barrier is constructed from, as it would be logical to choose a material that both incites particular confidence of noise attenuation and reduces the perception of other non-auditory risks, such as perceived increase in crime and vandalism (Perfater,1979).

The outcome of this research aims to indicate to what extent preconceptions held about varying materials used in noise barrier design impact on perceived noise reduction. The research design extends the number of barriers tested from that used in previous research to five standard noise barrier materials available in the UK. The laboratory style test enabled a controlled assessment of the barriers in practice by a sample of randomly selected volunteers. The novel experimental approach, using film and audio projections aims to introduce a new method for illustrating a range of barrier designs and materials in practice, offering a new technique to be used to improve public engagement with communities during the design stage of a noise barrier's development. The research also aimed to determine whether auditory and visual intersensory interaction influenced the respondents' perception of noise attenuation by the noise barriers, which was assessed by keeping the audio stimulus at a constant sound pressure level (SPL), whilst the visual stimulus was changed.

Following this introduction section, Section 2 reviews the existing literature and experimental approaches adopted by previous researchers. Section 3 sets out the methodology, which draws on previous research and incorporates the use of virtual reality techniques. Section 4 presents the findings, and answers the main research questions. Section 5 compares the findings with previous research. The final section reflects on the findings in the context of previous research and practical implications for barrier choice and use.

2. A review of previous intersensory research on noise barriers

The perception of noise and the complexities of intersensory interactions using many different experimental approaches has been widely reported in the literature of Psychology, . Despite this, a common potential risk is that controlled experimental designs limit contextual realism and do not truly illustrate the impact of intersensory interactions.

Intersensory interaction occurs when experimental situations are designed to allow only one, or more than one, modality to receive information (such as eyes and/or ears). Warren *et al* (1983) indicated that ‘intersensory interaction has not occurred, if the addition of a second sensory modality does not change a perception. Often, however, the perception does change when information is available to a second modality, and in such a case it is claimed that intersensory interaction has taken place’.

Several authors have concentrated specifically on the perception of noise through environmental noise barriers, with the aim of determining the most appropriate design. Two of the earliest authors to undertake this were Aylor and Marks (1976), whom devised. an experiment using human observers to measure perceived loudness of noise as it was transmitted through outdoor barriers. This experiment used a selection of four noise barriers, positioned around the circumference of a circle, with a swivel chair for the respondent to sit in, in the centre. The experiment was under free-field conditions and used a sound source projected from speakers behind each of the barriers as a stimulus. The respondents recorded their perception of the noise reaching them, by allocating a value proportional to the perceived value and in association to the other noise incidences heard.

Aylor and Marks (1976) revealed that visual shielding by a barrier dramatically affected the perception of sound transmitted through the barrier, but the direction of this effect was not simply related to shielding. ‘As long as the source of sound can be seen, reduced visibility of the source is accompanied by a reduction in apparent loudness’ (Aylor and Marks, 1976, p.400). However, when the sight of the source was completely obscured by the barrier, this effect completely reversed, i.e. the apparent loudness increased.

Aylor and Marks (1976) discovered strong audio-visual interactions; however, visual information did not necessarily affect auditory judgement in a linear way. Aylor and Marks (1976) related this to a phenomenon uncovered by Kryter (1968, p.293-297), where it was indicated that 'noises heard indoors are judged slightly more acceptable than noises heard outdoors, but not nearly as much as would be expected from the sound attenuation produced by a building'. Aylor and Marks believed that the effect of a solid barrier on perceived loudness might hinge on peoples' expectations of the barrier's effectiveness. They presented the phenomenon as an analogy between their findings and the 'size-weight illusion', whereby a pound of lead feels heavier than a pound of feathers'(Stevens and Rubin, 1970 cited in Aylor and Marks 1976). Thus, if this reasoning is comparable, then 'when a sound source is occluded visually, one expects its loudness to be diminished. Therefore, sounds coming from behind barriers appear surprisingly loud and hence is overestimated relative to sounds coming from open space' (Aylor and Marks, 1976, p.400).

Viollon (2003, p.1) offered the following conclusion in the context of an experiment to determine audio-visual interactions in an urban context: 'visual information were not neutral but indeed influenced the auditory impression: the more urban the visual setting, the more contaminated the auditory judgements and the more pleasant the noise barrier, the more beneficial the effect in auditory judgement of stress'. Viollon (2003) also revealed similar results when road traffic noises were used as an auditory stimulus projected from behind a wooded visual setting. The wooded visual setting did not exercise a positive influence on auditory judgement, and the explanation for this was that the auditory expectations were not fulfilled, and the sound of road traffic noise was a disappointment (Viollon 2003, p.1). These assertions were highlighted in Joynt (2005, p.183) who reviewed a community's perception of a noise barrier's effectiveness following its installation adjacent to their properties. The review found that the community reportedly perceived little or no benefit from the noise barrier installation. Representatives of the Highways Agency, who were responsible for the barriers installation, attributed these perceptions to the high and unrealistic expectations of noise reduction held by the residents. Consequently, two factors emerged with regard to perceived noise reduction. The first one is that preconceptions and skewed perceptions of how different materials will attenuate noise, influence actual perceived noise attenuation. The second one is the importance of realistic expectations being instilled in those people the noise barrier is built to protect (Joynt 2005, p.153).

Neither Viollon (2003) nor Aylor and Marks (1976) reported which noise barrier material impacted most upon the perceived noise attenuation. There has been some research in the field of auditory perception of barrier effectiveness by Watts *et al* (1999), who tested the perception of noise reduction through a variety of screens both in-situ and under laboratory conditions. The screens used were a willow noise barrier, a metal noise barrier, a row of conifer trees and an open space. Different noise levels were played from behind the barriers throughout the course of the test. In the in-situ experiments, it was the density of vegetation that was varied, by taking the respondents to a range of roadside locations displaying varying traffic flows, and altering degrees of concealment of the road by vegetation. A limitation to this method is that the respondents may have lost some clarity of thought on which barrier performed better during the change of location, consequently resulting in a perception based on memory recall rather than real spontaneous reactions.

Watts *et al* (1999) concluded that any difference in the sensitivity of people to noise depended on the degree of visual screening obscuring the noise source. This phenomenon was found to be largely independent of the noise exposure levels; thus listeners were more sensitive to noise where the screening was highest. These findings concurred with those of Aylor and Marks (1976), Viollon (2003), and Nilson (2008).

The experiment by Watts *et al* (1999) confirmed that it was the visual screening of the source of sound, not the other factors connected to the presence of vegetation, which had the greatest influence. Similar findings were also previously affirmed by Mulligan *et al* (1987) and Kragh (1981).

In addition, Watts *et al* (1999) asked the respondents which of the four barriers under consideration was the most aesthetically attractive on a 0-9 scale. This was determined as being the willow barrier, which they concluded, ‘enforced the impact of appearance on the perception of noise attenuation’ (Watts *et al,* 1999, p.55).

The studies highlighted in the above literature review lead to similar conclusions; that some concealment of the sound source is beneficial to the perception of the attenuation of noise, but completely obscuring it increases the perceived loudness of sound. Key to this research is the fact that noise barriers are developed not on the principle of the interruption by 'line of sight' or 'obscuring' in visual terms, but by maximising 'path difference' in terms of the UK statutory method 'Calculation of Road Traffic Noise', or analogous calculations in noise models used in other countries, as a consequence much of the research on audio-visual interaction tends to be not yet fully reflected in official methods or current practice.

3. Methodology

3.1 Sample of volunteers

A random sample of respondents was selected from the University of Sheffield population through advertising for volunteers. Each volunteer was compensated for their time with five pounds sterling. Due to restricted time availability and physical spaces in the RAVE facility, the sample was limited to that which could be assessed during a two day period. The nature of the experiment meant that participants had to attend at specific times and in a particular location. The opportunity to volunteer was not restricted to students, and was open to academic and non-academic University staff alike, although the relatively large commitment of time required to participate made it more appealing to students than those in employment.

The sample was made up of 9 males and 14 females with a mean age of 23 years old, ranging from 18-30 years old. The respondents were a mix of Undergraduates, Postgraduates and Postdoctoral researchers. The sample size and demography were similar to those used by Holm and Mantyla (2007) and Verbruggen and De Houwer (2007), in a similarly controlled laboratory experiment testing perceptions of stimuli.

The respondents were tested in groups of no more than seven people at any one time. To ensure that the respondents all had 'normal hearing', they undertook a hearing test at different frequencies and SPLs and all were found to have a normal range of hearing.

3.2 Site recordings

Recording of audio-visual data from behind the noise barriers was gathered using a video camcorder in locations throughout the UK. The barriers were chosen as they represented some standard style types commercially available. The material types analysed were concrete, timber, metal, transparent acrylic and a hedgerow of deciduous vegetation, as shown in Figures 1 to 5, respectively. The deciduous hedgerow was included because a natural looking barrier such as a willow barrier could not be found in-situ.The lack of willow barriers availability. was allegedly a result of their removal alongside motorways and trunk roads, following problems stemming from both the irrigation requirements and disease (Gramm Barriers, UK).

Insert figure 1-5

The recording was designed so that the view would represent the passage of traffic visible from a ground floor property, adjacent and approximately level with the barrier. Care was taken to position the camera so that low vehicles.were not visible, such as cars passing by, were visible, for the opaque barriers. This was important as the sound recording had to be matched as closely as possible with each of the five visual recordings. Had the cars been visible as well as the high sided vehicles, then the match of the audio and visual recordings would have been much more difficult, and could have potentially reduced the contextual realism and consequently undermined the test. A 12-minute recording of the traffic was taken at each site to give enough data to manipulate the recordings for the laboratory tests.

3.3 Digital manipulation and laboratory design

To test the participants' perception of the noise barriers' effectiveness, several trial methods were devised. The original experiment involved superimposing a noise barrier photograph on top of a moving videoed image of a motorway. This method was abandoned due to questionable contextual realism. The alternative was to digitally manipulate the visual recordings so that a sample audio recording of traffic passing a barrier was matched to each of the films, thereby, giving the impression that the audio and visual sequences had been recorded simultaneously, although in fact the audio stimulus was controlled. This was a labour intensive method, but guaranteed that the respondents were tested on their reaction to the visual stimulus alone. The recordings of the barriers were played back using the Adobe Premier 6.0 and Cool Edit Pro 2.0 software. The audio sample was chosen from a 23-second recording at the location of the concrete noise barrier. The sample was chosen as it included a frequent flow of large trucks, which could be clearly heard. Each visual recording was then analysed in turn, and sections of the audio sequence, which appeared to match, i.e. a truck passing behind the rear of the barrier on the visual recording, were matched with the sound of a truck passing on the audio recording, and the audio recording was pasted onto the clip. The end result was five visual recordings with the same audio sequence synchronised and attached.

The experimental design of this investigation used the RAVE- Reconfigurable Advanced Virtual Environment suite, known as the REFLEX studio at the University of Sheffield. The five films were projected in succession on to a large screen, and the audio sequence was played on four large speakers on either side and behind the screen. The layout of the room was constructed similar to a cinema, with chairs at an equal distance facing the projection screen, as shown in Figure 6. Foam absorbers were attached to the walls of the laboratory, reducing sound reflections. The reverberation time (RT) of the room was less than 0.2-0.3s at high and middle frequencies, and less than 0.4s at low frequencies.

Insert Figure 6

3.4 Test methods

The test approach was developed to minimise the possibility of respondents forgetting how they had perceived the previous barrier. The video-audio clips were incorporated into a computer program, which enabled the clips to stream seamlessly which reduced the distraction to the respondents (Meredith, 2003). Previous studies investigating the phenomenon of intersensory effects on the perception of soundscapes and noise barriers have used a variety of rating scales, many opting for the use of worded scales such as relaxing/ stressful etc. This investigation, in light of the fact that it was not the actual characteristic of the noise that was varying, but the barriers, used a numbered scale.

Test 1 analysed predetermined assumptions about barrier attenuation, where the visual stimulus was played without the auditory stimulus. The respondents were told to predict how well each barrier would reduce the traffic noise by assigning a value of between 1 and 5 to each barrier type, with 1 representing the best, namely the most effective in attenuating noise. Table 1 shows the response sheet. **(Insert Table 1)**

Test 2 investigated the perception of noise attenuation of five standard barrier types with a constant noise stimulus. In total five sets of the video and audio sequences were run, each set comprised of the five barrier types presented in a random order. The audio sequence of the first test was set at the base noise level of 71.6dBA. This was equivalent to the measured SPL at 10m from the noise source on site. The sound level was then increased by 5dBA at the beginning of each subsequent set, and was held constant at this SPL whilst each visual image of the noise barriers was played; this was used to invoke a sense of change, when in fact the noise levels in each set were kept constant. The incremental rises at the beginning of each set tested whether trends in the data were consistent on repetition of the experiment and at increasing SPL. The respondents watched the clips, and were allowed 5 seconds to record their response (Table 2). An alternative to this approach would have been to use a sound stimulus such as a tone, played at the beginning of the recordings, without a visual stimulus being played, which could provide a more effective auditory stimulus for the respondents to make a comparison to, as illustrated by Mulligan *et al,* (1987) and Nilson *et al* (2008).

Insert Table 2

The sequence that the materials were presented in, were devised to reduce the possibility of ordering (Dénes and Keedwell, 1991; Watts *et al*, 1999). The recording sheet used a Latin square function, as shown in Table 2, contained columns for each material with a space to record the participant response. The first column of each set was completed with the value 5; this was the reference level that all the proceeding noise levels were to be judged against. This method was preferred over a ranking system as it enabled parametric tests to be carried out on the data and reduced ill-considered responses (Watts *et al*, 1999). The internal consistencies of the scales were tested for reliability, and all demonstrated Cronbach's Alpha Coefficient values of between 0.70 and 0.76, ensuring that the scales were reliable (Pallant, 2001)

Test 3 determined the aesthetic qualities of each barrier. It required the respondents to judge the barriers in order of preference, based purely on aesthetics. This was then correlated with the results of the acoustic perception, and the prediction data to see whether perception of aesthetics had any link to preconceptions of how a barrier would perform and perception of the barriers' ability to attenuate noise. The results were recorded using a 5 point ranking system with 1=most to 5= least attractive.

The following information was also given to the participant's to aid their understanding of the test;

The test consists of 3 sections, the first shows a set of video clips with no accompanying sound and you are asked to make a prediction of how well the barriers will attenuate noise by raking them from best (1) to worst (5). Test 2 involves you seeing five sets of films, each set containing five video clips of traffic passing some noise barriers, and you will be asked to judge how much noise you can hear from behind each barrier.

This is the main test and you will see and hear the noise barriers in action. You will see that the first barrier to appear is accompanied by the value 5 in the answer table, please give a value relative to this for all the other barriers in that group.

For example if you think all the other barriers allow higher noise levels through give them each values above 5, if you think they are the same you can give them the same value and if you think they are letting less through give them a lower value. Each group of five clips should be judged independently to all the other sets. The values you give must be between 0 – 9, and must be whole numbers.

4. Results

4.1 Preconceptions without audio stimulus

Figure 7 illustrates the mean values of the ranking in Test 1. It can be seen that, without actually hearing any audio stimulus, the respondents predicted that concrete would be the most effective, followed by timber, metal, vegetation and transparent barriers. A Friedman's Test showed significant differences between the barriers, with Chi-square=31.4; df=4; $p<0.0005$. This suggests that there are significant differences in preconceptions of how each of the barriers would perform.

Insert Figure 7

4.2 Perceptions with audio and visual stimulus

Insert Figure 8

Figure 8 gives an overview of the findings from Test 2, where the baseline barrier, to which all the other barriers were judged in each set, can be seen as a constant of 5. The other values within each set are the total mean under each of the different conditions and the standard deviation about the means is also shown. As the first barrier in each set was used as a base level, to which all other barriers were to be judged, there is no standard deviation. The graphs illustrate that there was not much tendency to rate the noise levels below the base value despite the respondents being informed that they could do so. It can be seen that the respondents did perceive the noise attenuation properties of each material differently. The use of increasing SPL helped to distract from the fact that each noise source within each set was the same, and there was some variance in ordering relative to the noise level increases. The respondents confirmed that the technique had been an effective means of making them believe that the noise levels were altering, when asked post assessment.

A one-way repeated measure ANOVA test was undertaken, as the data were made up of 'one group of subjects' measured on the same scale, under five different conditions, and one independent categorical variable (i.e. the noise barriers), and one continuous dependant variable (i.e. the rating of the noise level for each barrier). Each set was tested individually, to determine any significant differences between how the barriers were rated, and to see if any potential patterns were consistent at increasing noise level. The results demonstrate that the proportion of variance of the dependent variable that is explained by the independent variable is greatest at the lower noise levels, not statistically significant for 81.6dBA and then moderately influential at 86.6 and 91.6dBA:

- Noise level 71.6dBA- Wilk's Lambda = .288, $F_{(4,19)}$= 11.76, $p< .0005$, multivariate eta squared = .712
- Noise level 76.6dBA- Wilk's Lambda = .225 $F_{(4,19)}$ = 16.33, $p<.0005$ multivariate eta squared = .775
- Noise level 81.6dBA- Wilk's Lambda = .783 $F_{(4,19)}$ = 1.32, $p<.30$ multivariate eta squared = .217
- Noise level 86.6dBA - Wilk's Lambda = .466 $F_{(4,19)}$ = 5.45, $p<.004$ multivariate eta squared = .534
- Noise level 91.6dBA Wilk's Lambda =.410$F_{(4, 19)}$ = 6.8, $p<.001$ multivariate eta squared = .590.

The lower SPL values are more representative of what a person standing 10m from a carriageway edge, with free flowing traffic, would be exposed to; thus, the improved contextual realism can explain the statistical relationship at lower SPL.

In set 1 and 2, namely at 71.6 and 76.6dBA, concrete and metal consistently received a low rating, representing the perception of greater noise attenuation by these barrier types. The vegetation consistently had the highest or equal highest mean ranking at all the SPLs with an average rating over all of 6.36, as compared to the average value awarded to concrete of 5.46. This suggests that the perception of a purpose built barrier did invoke a greater perception of noise reduction, despite this being based purely on its visual attributes rather than a real reduction in SPL.

The perception of the transparent barrier's inefficiency at attenuating noise was illustrated by the fact that in all of the tests showing significant differences between 71.6dBA–86.6dBA, the transparent barrier was always ranked less effective than the concrete, metal and timber barriers with an average rating of 5.98. It is noted that in set 5 the transparent barrier is deemed more effective than the rest. This could be influenced by the fact that it was presented as the base value of 5, and therefore the judgements could have been more influenced.

4.3 Influence of preconceptions on the perceptions of the barrier performance

Insert Figure 9

To determine how the respondents' preconceptions influenced their perceptions of the barriers abilities to attenuate noise, the findings of Test 1 were compared to those in Test 2, and their correlations are shown in Figure 9, where the data from all the tests are combined and the reference value data in each test are removed. The correlation coefficient is R^2= 0.57. The direction of the trend indicates that the barriers predicted to be more effective prior to the audio stimulus introduction were also perceived as being more effective at attenuating noise in the sound perception exercise. These preconceptions can be assumed to have influenced the respondents' perception of the noise reduction, as the audio stimulus was held constant. Should these findings be applicable to the wider population, then it can be assumed that timber and concrete would provide the most effective materials for noise barriers based purely on preconceptions, which influence perception of noise reduction.

4.4 Aesthetic influences

Insert Figure 10

Figure 10 shows the results of the aesthetic preference test. It can be seen that the respondents rated vegetation as their most preferred barrier based purely on aesthetics. The Friedman's test undertaken on the data showed that there is a significant difference between the respondents' aesthetic preference (Chi-square=29.6; df=4, p=<0.0005), with the choices in descending order of popularity being, vegetation, timber, transparent, concrete and least popular metal.

No correlation was found between aesthetic preference and predicted noise attenuation (i.e. preconceptions) with the R^2 value being equal to 0.06, indicating that barriers perceived as more attractive are not also predicted to be more effective at reducing noise.

Insert Figure 11

There is, however, a fairly strong correlation between the aesthetic preference and the perceived noise attenuation, as shown in Figure 11, where the data from all the tests are combined and the reference value data in each test are removed. With R^2=0.43, the graph indicates an inverse relationship between aesthetic preference and perceived noise reduction, implying the barriers assessed as being most aesthetically pleasing were not perceived as the most effective noise attenuators.

5. Discussion

The vegetative, transparent and timber barriers were the most aesthetically pleasing, but they were deemed less effective at reducing noise than the less attractive options of concrete and metal. This further enforces the fact that although aesthetics are important, they are not incremental in the judgement of a barrier’s ability to attenuate noise.

The finding that the transparent barrier was perceived as more inefficient at attenuating noise, is somewhat in contrast to that of Watts *et al* (1999), and Aylor and Marks (1976) and Mulligan *et al* (1987) who discovered that when the respondents could see the sound source through the barrier, they actually overestimated its ability to attenuate noise. Previous research attributed this phenomenon to false expectations: when a sound source is visually screened, a listener expects its loudness to be significantly diminished.

In Viollon’s study (2003) it was found that vegetation had a distinct effect on noise annoyance. This was attributed to noise being heard in the wrong context, such as traffic noise in a wood, where the respondents found it more disturbing than in a realistic environment such as alongside a road. Although such reactions could equally be related to further factors beyond lack of congruence. For example, the trigger of primeval anxieties associated with the 'fight or flight' response.

With the vegetation test in our research, although the respondents were not watching a visual stimuli out of context per-se, the fact that the vegetation was present next to the motorway, and it was evident that the recording had been made in a field, could have yielded more negative responses, as the presence of traffic noise close to an area of vegetation was deemed inappropriate.

While the evaluation of the subjects under laboratory conditions might be different from that of actual residents in their living environments, the results of this investigation hold particular relevance when consideration is given to previous work in the field (Cohn, 1981; Cohn and McVoy, 1982; Golding, 1986; Golding, 1986; Hall, 1980; Joynt, 2005; Pendakur and Pyplacz, 1984), all of which have proven that strong negative perceptions of a noise barrier's effectiveness can be held by residents adjacent to a barrier they find visually inappropriate. Consequently, in practice if a material is chosen for a barrier, which is not perceived as being effective, then the resultant perception of the barrier's ability to attenuate noise could be compromised, regardless of its measured objective reduction.

It is particularly important to undertake this type of assessment for individual communities, as variations in perceived effectiveness have been found in groups of different ethnic backgrounds (Md-Taha, 1999). Further research using samples drawn from a wider group, and reflecting greater differences in both ethnic and socio-economic background would be a useful addition to the literature and would give greater statistical confidence to the assertions made.

6. Conclusions

Key to this research was the introduction and test of a new method to determine the impacts of intersensory interactions using moving stimuli, which improved the contextual realism. This enabled a more accurate understanding of the perception of noise barriers.

The results showed that regardless of which noise barrier was presented to the respondents, that preconception of the materials' ability to attenuate noise was embedded. Based purely on preconceptions, the concrete barrier was predicted to be the most effective noise attenuator, followed by metal and timber. These preconceptions also influenced the actual perception of the barriers effectiveness at attenuating noise. When the respondents were exposed to a visual stimulus which was altered and a constant audio stimulus, the intersensory interaction made the respondents perceive greater noise reduction by the more solid and opaque purpose built barriers and less effectiveness by the transparent and vegetative screens. This trend was found to be stronger at the lower sound pressure levels.

An inverse relationship between aesthetics and perception of noise attenuation was found in this research. The results showed that the transparent and deciduous vegetation barriers, judged most aesthetically pleasing, were judged as the least effective at attenuating noise. The findings of were also contrary to the findings of previous research undertaken in a similar vein, which found that where the sound source was partially obscured by a barrier that the perceived noise reduction was more effective than barriers that completely hid the sound source, given the same sound levels. This research therefore supports the current rationale by noise barrier designers to use opaque materials to block the line of sight between the source and the receiver of road traffic noise, to achieve the greatest perception of noise attenuation. In practice, barrier designers should gauge an understanding of whether preconceptions can be addressed prior to the ultimate decision on barrier material type being made. Bailey and Grossardt (2006) also support this notion. This could be done by undertaking an assessment of the preconceptions a specific community has about various material types using a similar method to the one outlined in this research. The procedure could also be used to complement the Highways Agency initiative to develop ‘virtual reality images to aid public involvement in appearance of roads and bridges’ (Wallsgrove and Barlow 2001).

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References

Aylor, D. E., and Marks, L. E. (1976). Perception of noise transmitted through barriers. *Journal of Acoustical Society of America, 59,* 397-400.

Bailey, K., and Grossardt, T. (2006). Structured public involvement in context-sensitive noise wall design using casewise visual evaluation. *Transport Research Record: Journal of the Transportation Research Board*, *1984*, 112-120.

Cohn, L. (1981). *Highway noise barriers: National co-operative highway research program synthesis of highway practice 87.* Washington DC Transportation Research Board, National Research Council.

Cohn, L., and Bowlby, W.J. (1984). Minimizing highway noise barrier intrusions. *Journal of Environmental Engineering. 110*, 534-549.

Cohn, L., and McVoy, G. (1982). *Environmental analysis of transportation systems*. USA: John Wiley & Sons.

Dénes, J., and Keedwell, A. D. (1991). *Latin squares: New developments in the theory and applications*. Amsterdam; Oxford: Holland.

European Parliament (2002). *Directive relating to the assessment and management of environmental noise 2002/49/EC.* European Parliament and of the Council.

Golding, S. (1986). Road noise barriers: Experience on western arterial roads in Brisbane. *Transport and Planning, 13,* 264-274.

Gramm Barriers. Personal telephone communication with the author, *September 24 2003.*

Hall, F. L. (1980). *Attitudes towards noise barriers before and after construction*: *Highway noise abatement*. *Transport Research Record: Journal of the Transportation Research Board,* 740.

Holm, L., and Mantyla, T. (2007). Memory for scenes: Refixations reflect retrieval. *Memory and Cognition, 35*, 1664-1674.

Joynt, J. L. R. (2005). *A sustainable approach to environmental noise barrier design.* Unpublished doctoral thesis. University of Sheffield, Sheffield, UK.

Kragh, J. (1981). Road traffic noise attenuation by belts of trees. *Journal of Sound and Vibration, 74,* 235-241.

Kryter, K. D. (1968). *The effects of noise on man.* New York: Academic.

Md-Taha, M. (1999). *Public perception of road traffic noise barriers- UK and Malaysian perspective.* Unpublished doctoral thesis, University of Aberystwyth, Aberystwyth.

Meredith, M. (2003). *Program to incorporate the video and audio clips in one sequence.* University of Sheffield, Sheffield, UK.

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

Nilson, M. E. (2007). A-weighted sound pressure level as an indicator of short-term loudness or annoyance of road-traffic sound. *Journal of Sound and Vibration, 302,* 197-207.

Nilson, M. E. Andéhn, M., and Leśna, P. (2008). Evaluating roadside noise barriers using an annoyance-reduction criterion. *Journal of the Acoustical Society of America,* 124, 3561-3567.

Orsman,B. (2003). Restraints in wall removal. *New Zealand Herald, Auckland.*

Pallant, J. (2001). SPSS survival manual (version 10 and 11). Buckingham: Open University Press.

Pendakur, V. S., and Pyplacz, B. (1984). Urban traffic noise abatement. *Transportation Quarterly, 38,* 471-486.

Perfater, Michael A (1979). Community perception of noise barriers. Volume I. Virginia Transportation Research Council. Charlottesville, Virginia.

Stevens, J. C., and Rubin, L. L. (1970). Psychophysical scales of apparent heaviness and the size- weight illusion. *Perception and Psychophysics, 8,* 225-230.

Verbruggen, F., and De Houwer, J. (2007). Do emotional stimuli interfere with response inhibition? Evidence from the stop signal paradigm. *Cognition & Emotion, 21,* 391-403.

Viollon, S. (2003). Two examples of audio-visual interactions in an urban context. *Euronoise,* Naples, Italy.

Viollon, S., Lavandier, C., and Drake, C. (2002). Influence of visual setting on sound ratings in an urban environment. *Applied Acoustics, 63,* 493-511.

Walsgrove, J., and Barlow, R. (2001) Virtual reality images to aid public involvement in appearance of roads and bridges. *Transport Research Record: Journal of the Transportation Research Board, 1770,* 166-172.

Warren, D. H., McCarthy, T. J., and Welch, R. B. (1983). Discrepancy and nondiscrepancy methods of assessing visual-auditory interaction. *Perception and Psychophysics, 33,* 413-419.

Watts, G. R, Chinn, L., and Godfrey, N. (1999). The effects of vegetation on the perception of traffic noise. *Applied Acoustics, 56,* 39-56.

Watts, G. R., and Nelson, P. M. (1992). The relationship between vehicle noise measures and perceived noisiness. *Journal of Sound and Vibration, 164,* 425-444.

Figure Captions

Figure 1. Concrete noise barrier

Figure 2. Timber noise barrier

Figure 3. Metal noise barrier

Figure 4. Transparent noise barrier

Figure 5. Deciduous vegetation

Figure 6. Diagram of Reflex studio with projection of the metal noise barrier image

Figure 7. Preconceptions of how effective each barrier would be at attenuating noise (1 as most effective - 5 as least effective), where the mean and standard deviation of ranked values are shown

Figure 8. Results of the perception exercise at the five different SPLs (0 as quietest - 9 as loudest), where the mean and standard deviation of ranked values are shown

Figure 9. Correlation between predicted noise attenuation (i.e. preconceptions) and perceived noise attenuation

Figure 10. Results of respondents' preference based on aesthetics alone (1 as most attractive - 5 as least attractive), where the mean and standard deviation of ranked values are shown

Figure 11. Correlation between aesthetic preference and perceived noise attenuation

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

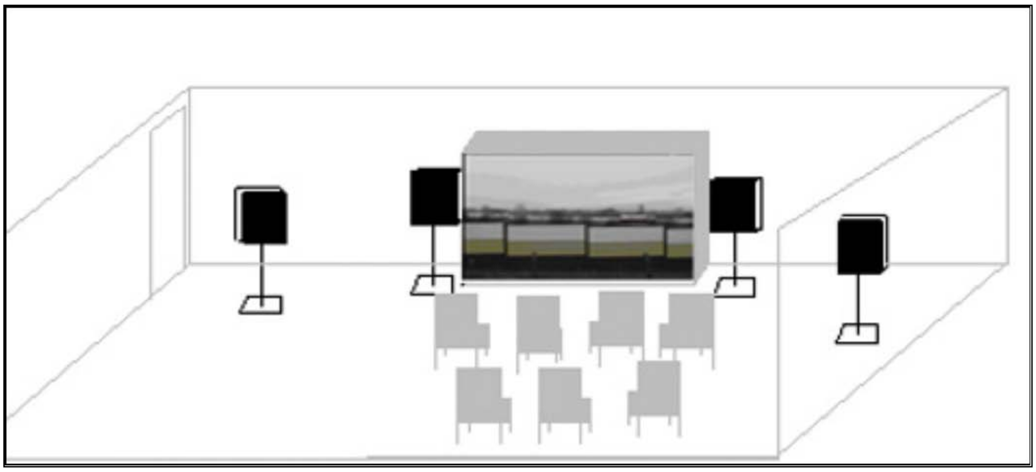

Figure 6

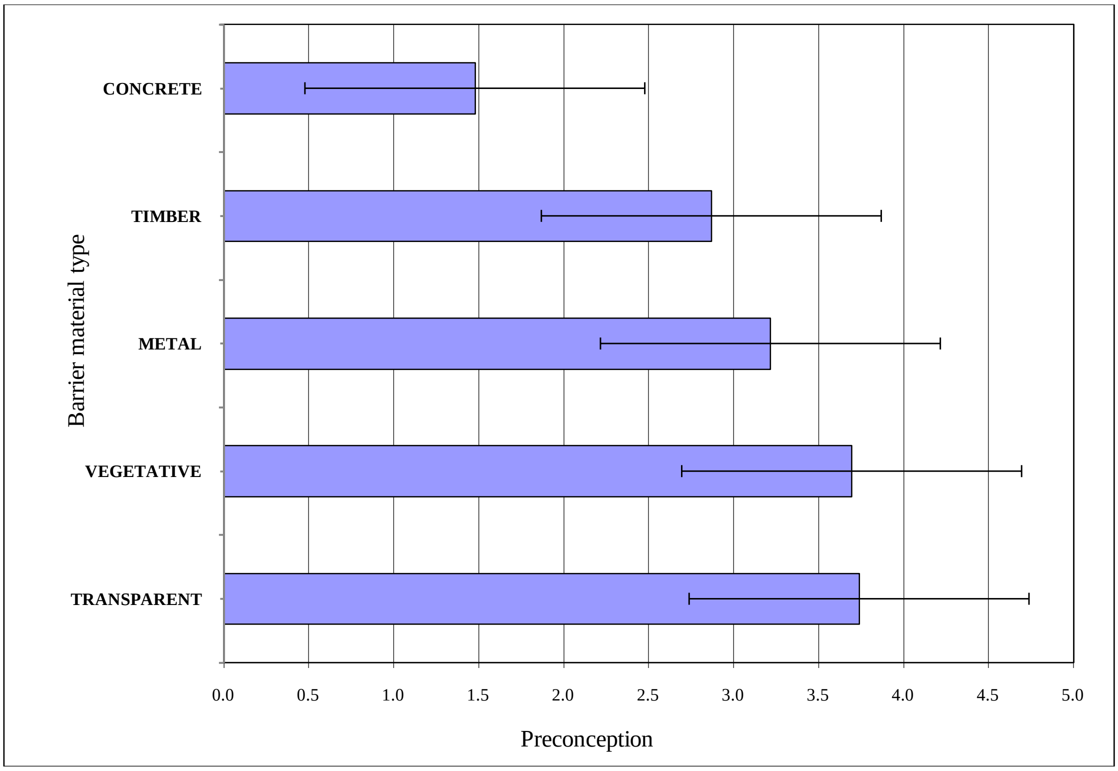
CONCRETE
TIMBER
METAL
VEGETATIVE
TRANSPARENT
Barrier material type
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Preconception

Figure 7

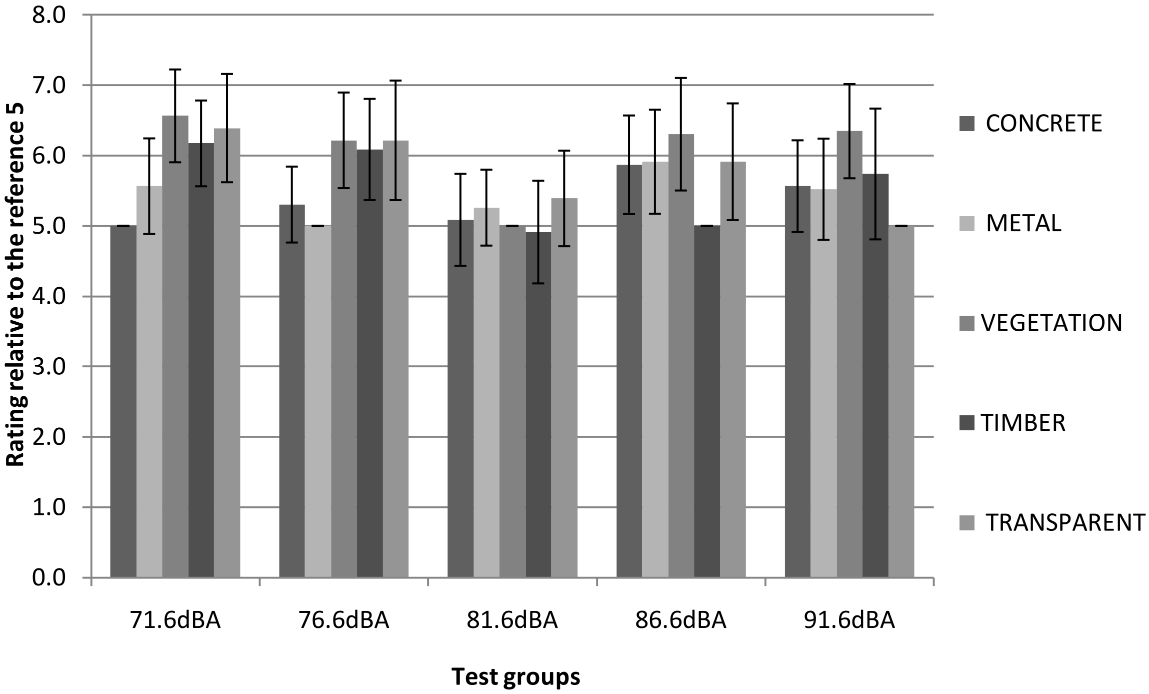
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Rating relative to the reference 5
71.6dBA
76.6dBA
81.6dBA
86.6dBA
91.6dBA
Test groups
CONCRETE
METAL
VEGETATION
TIMBER
TRANSPARENT

Figure 8

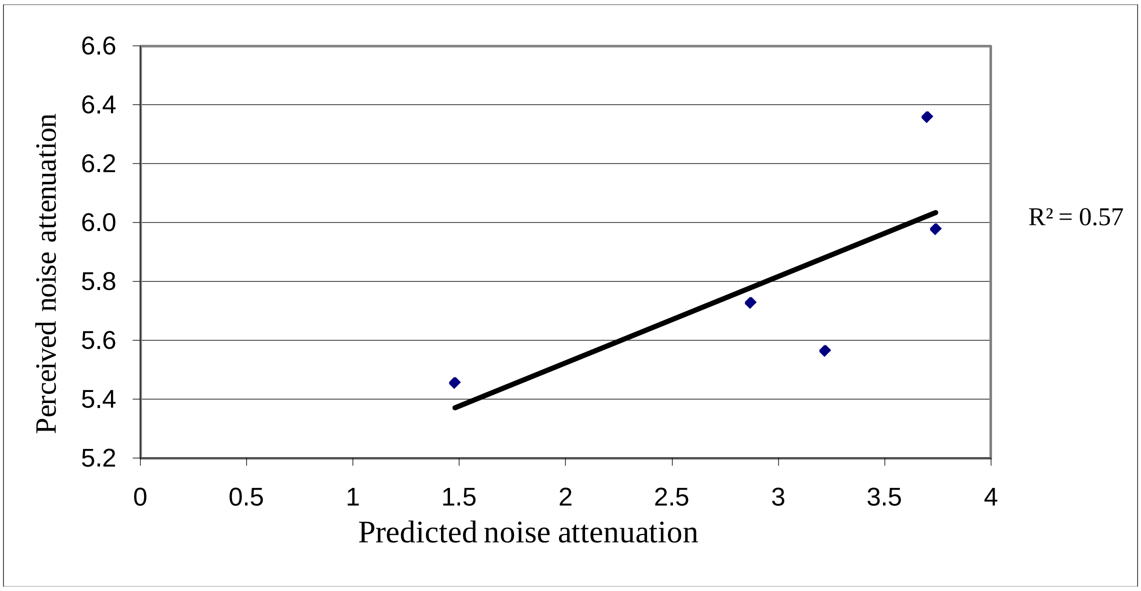
6.6
6.4
6.2
6.0
5.8
5.6
5.4
5.2
Perceived noise attenuation
0
0.5
1
1.5
2
2.5
3
3.5
4
Predicted noise attenuation
R² = 0.57

Figure 9

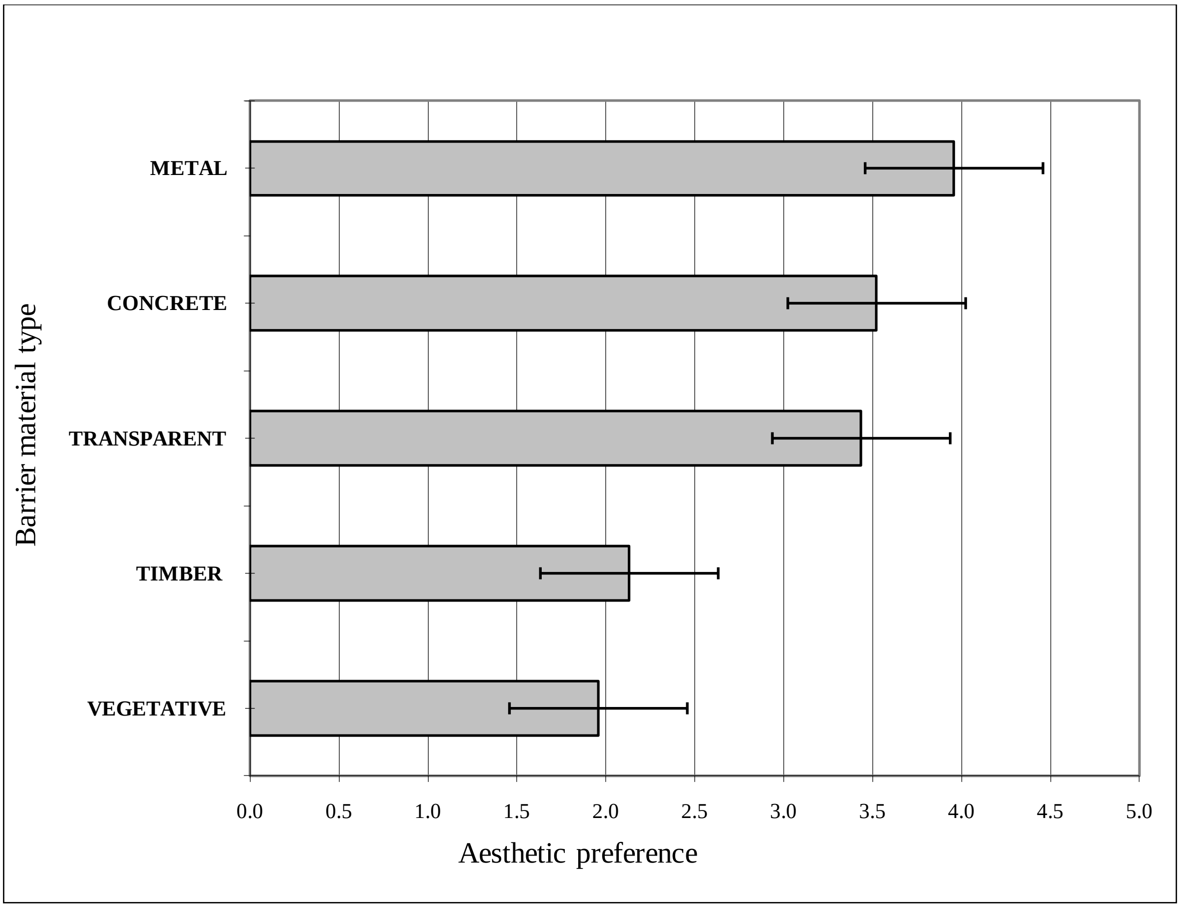
METAL
CONCRETE
TRANSPARENT
TIMBER
VEGETATIVE
Barrier material type
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Aesthetic preference

Figure 10

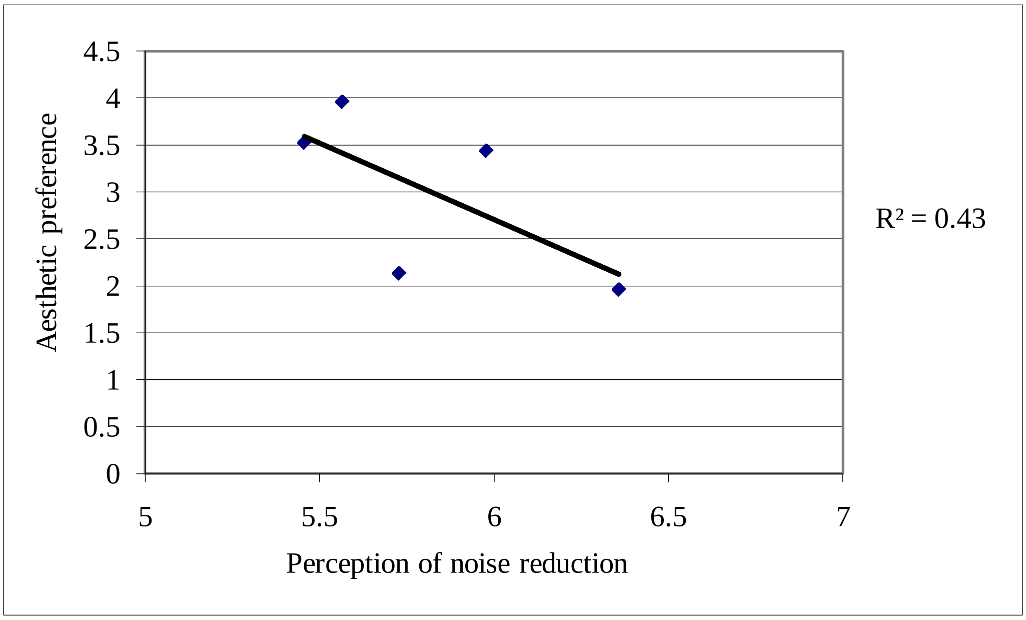
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Aesthetic preference
5
5.5
6
6.5
7
Perception of noise reduction
R² = 0.43

Figure 11

Tables

Table 1. Response sheet for Test 1

	Timber	Metal	Concrete	Transparent	Vegetative
(1) Best – (5) worst					

Table 2. An example of the questionnaire: Sequence of barriers determined using a Latin square function

	Barrier types: In the order they will appear				
Set 1	Concrete	Metal	Vegetation	Timber	Transparent Acrylic
Score 0 quietest to 9 loudest	**5**				
Set 2	Timber	Concrete	Transparent Acrylic	Metal	Vegetation
Score *0 quietest to* *9 loudest*	**5**				
Set 3	Vegetation	Transparent Acrylic	Timber	Metal	Concrete
Score *0 quietest to* *9 loudest*	**5**				
Set 4	Timber	Concrete	Metal	Transparent Acrylic	Vegetation
Score *0 quietest to* *9 loudest*	**5**				
Set 5	Transparent Acrylic	Timber	Concrete	Vegetation	Metal
Score *0 quietest to* *9 loudest*	**5**				