Perceptual effects of noise mitigation

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Abstract. Noise mitigation reduces the audibility of a noise source at the location of the receiver, making the source less annoying and less likely to interfere with activities, such as sleep, rest, and speech. Many mitigation methods change temporal and spectral properties of noise, which may influence perceived annoyance, over and above the effect related to the overall reduction in A-weighted sound pressure level. Noise reduction also may increase the noticeability of other sources, which may influence the perception of the overall acoustic environment. Finally, well-designed noise mitigation solutions may improve the visual environment, e.g., a vegetated noise barrier or earth berm can visually shield the traffic and increase the amount of visible greenery. This chapter provides examples of such perceptual effects of noise mitigation, from effects on perception of the noise itself, via effects on the soundscape, to potential effects on the overall audio-visual environment.

9.1 INTRODUCTION

The goal of noise mitigation is to reduce the audibility of a noise source at the location of the receiver, making the source less annoying and less likely to interfere with activities, such as sleep, rest, and speech. Noise mitigation also can indirectly influence the acoustic environment (soundscape) by making previously masked sounds, such as birdsong or sounds of moving water, more noticeable. In addition to auditory effects, noise mitigation may improve the scenery of a place, e.g., a vegetated noise barrier or earth berm can visually shield the traffic and increase the amount of visible greenery. This chapter provides examples of such perceptual effects of noise mitigation, from effects on perception of the noise itself, via effects on the soundscape, to potential effects on the overall audio-visual environment.

The first section of the chapter discusses the psychoacoustics of noise mitigation, with a primary focus on how well accomplished reductions in sound pressure level predict changes in perceived annoyance of noise. The second section broadens the perspective and looks not only at unwanted sounds,
but at the overall soundscape, including its wanted and unwanted components. The main focus in this section is on the role of sound masking and how it relates to noise mitigation. The last section broadens the picture further and looks at the total environment, and, in particular, audio-visual aspects of noise mitigation.

This chapter is limited to perceptual aspects of noise mitigation, and will not discuss long-term effects of noise, such as effects on residential noise annoyance, sleep disturbance, or cardiovascular effects related to changes in exposure caused by noise mitigation.\textsuperscript{1–3} Perceptions are immediate, but their effects may be long term. Noise mitigation that makes the noises less loud and less disturbing will, of course, influence how the noise source is assessed in the long run, for instance, in questionnaire studies, where residents typically are asked to evaluate noise sources as experienced at home during the past several months.\textsuperscript{4}

\section*{9.2 Noise: Psychoacoustics of Noise Mitigation}

Noise mitigation reduces the audibility of a noise source by reducing the sound pressure level of the noise at the point of the receiver. The efficiency of noise- mitigation methods is typically assessed in terms of the achieved reduction in A-weighted sound pressure level, expressed in dB(A), which, in many cases, gives a fair indication of the effect on the audibility of noise.

However, most mitigation methods do not merely reduce the overall level, but also alter other aspects of the noise. For example, a noise barrier will reduce high frequency sounds to a larger extent than low frequency sounds, and will reduce the temporal variability of the noise behind the barrier. Such changes may influence how annoying the noise is perceived to be, over and above the effects explained by the overall reduction in A-weighted sound pressure levels.

Spectral or time-pattern changes may influence perceived annoyance in two ways. First, the perceived loudness of the noise may change in a way not well predicted by the reduction in A-weighted sound pressure levels. For most noise sources, including traffic, perceived loudness is the main determinant of annoyance.\textsuperscript{5} That is, the louder the noise, the more annoying it is perceived to be. A-weighting has been shown to underestimate the loudness of traffic noise with sizeable low-frequency components.\textsuperscript{6–7} For noise mitigation methods that reduce high frequency sounds more than low frequency sounds, the reduction in A-weighted sound pressure levels, therefore, may overestimate the reduction in perceived loudness, and, thereby, annoyance. An alternative to the A-weighted sound pressure level is the psychoacoustic indicator loudness (unit sone) and loudness level (unit phon).\textsuperscript{8,9} This indicator was derived to predict the perceived loudness of sounds, and it is based
Perceptual effects of noise mitigation on a detailed model of how sound is processed in the ear (i.e., the peripheral hearing system). Loudness level was found to be a better indicator of annoyance than the A-weighted sound pressure level in an experimental study of the perceptual effect of a 4.1-m-high barrier close to a highway.

Secondly, noise mitigation may change the perceived character of the noise and, thereby, have an effect on annoyance in addition to effects related to the loudness of the noise. Two equally loud sounds may differ in perceived annoyance due to differences in their perceived character or quality. The importance of the character of the noise for its annoyance seems to be inversely related to the loudness of the sound; two moderately loud sounds are more likely to differ in annoyance than two very loud sounds.

Certain noise characteristics are especially annoying, for example, tonal components (e.g., ventilation system noise), intermittent time patterns (e.g., pile driving), slow and regular fluctuating time patterns (e.g., wind turbine noise), rapid fluctuations leading to a rough sound (e.g., drilling noise), and strong, high-frequency components leading to a sharp sound (e.g., squeals from rails). Strong, low-frequency components may be perceived as specifically annoying and tiring, especially when they interact with resonances in the building shell (e.g., noise from an idling diesel engine). Moderate hearing loss (e.g., age related) may strengthen the importance of some of these characteristics.

9.2.1 Case study of low, vegetated barriers

The perceptual effects of a low, vegetated noise barrier in central Lyon, France, were evaluated in a field questionnaire study, complemented with a listening experiment in the laboratory. The barrier was erected to protect a popular esplanade from road traffic noise. The purpose of the evaluation was to determine the acoustic and perceptual effects of the barrier.

In the field study, pedestrians were asked to assess the sound environment. Questionnaire responses were collected on two occasions: one before and one after the barrier was erected. Each time, data were collected at two locations: at a place behind the barrier and a place 20 m to the side of the barrier (Figure 9.1(a)(b)). Acoustic measurements made at the same locations where the questionnaire was completed showed that the sound pressure level behind the barrier was, on average, 4 dB(A) lower than without the barrier. The noise variability also was reduced by the barrier, whereas the relative level of low-frequency sound increased, because barriers reduce high-frequency sounds more than low-frequency sounds (Figure 9.2(a)–(c)). These measurements illustrate that noise barriers not only influence the overall level, but also spectral and time-pattern parameters.

The questionnaire responses showed that the barrier improved the perceived acoustic environment. The percentage of noise-annoying respondents decreased from 59% at places uninfluenced by the barrier to 47% behind
the barrier, and ratings of the overall quality of the sound environment indicated that the barrier made the soundscape slightly calmer and less unpleasant. However, traffic was still the dominant sound source, which explains the fairly high number of annoyed respondents also after mitigation.11

A listening experiment with traffic noise events simultaneously recorded behind and beside the barrier verified that the barrier reduced the

Figure 9.1 Questionnaire data collection and simultaneous sound level measurements behind (a) or beside (b) a vegetated barrier in central Lyon, France.
Figure 9.2 Box plots of the instantaneous values of acoustic variables measured during time intervals when questionnaire data were collected. “No barrier” measurements were either taken before the barrier was erected or after, at the side of the barrier; “barrier” measurements were taken behind the barrier. (a) A-weighted sound pressure level, LAeq, 10 min. (b) Difference between C- and A-weighted sound pressure level (LCEq, 10 min–LAeq, 10 min). (c) Difference between A-weighted sound pressure levels exceeded 10% and 90% of the time (LA10–LA90). The five vertical lines of each box plot show, from top to bottom, the 10th, 25th, 50th (median), 75th, and 90th percentile of the data; the circles show data points more extreme than the 10th or 90th percentile.
annoyance of the traffic noise, and that this effect was fairly well predicted by the associated reduction of A-weighted sound pressure level (Figure 9.3(c)). However, there was a tendency for the annoyance reduction to be a little less than would be expected from the A-weighted sound pressure level reduction (green symbols located slightly above grey symbols at similar A-weighted sound pressure levels). The loudness level was a slightly better predictor of noise annoyance (Figure 9.3(d)) than the A-weighted sound pressure level, but had the same trend, which suggests that part of the effect was related to perceived loudness and part to the perceived character of the noise. Statistical analysis suggested that this could be explained partly by the barrier’s lower reduction of low-frequency components of the sound, as compared to high-frequency components, witnessed by a larger difference between C- and A-weighted sound pressure levels compared to without barrier influence. The barrier also reduced the noise variability, measured as the difference between levels exceeding 10% and 90% of the time. However, statistical analyses suggested that this did not strongly influence the perceived annoyance of the noise.

9.2.2 Perceptual effects of soft and hard ground along tramways

The acoustic and perceptual effects of soft or hard ground between tramways and receivers were evaluated in a study involving measurements, binaural recordings, and a listening experiment. Recordings at a height of 1.5 m were made 4 and 7 m from a tramway in Grenoble, France, at a location with soft ground (grass) and at another location with hard ground (asphalt). A large number of tramway passages were recorded, and these were matched to allow comparisons of recordings made in places bordered by different types of ground, but of trams of the same type travelling at the same speed (Figure 9.4(a)(b)).

At the closer distance (4 m), sound pressure levels from tram passages were about the same at both the grass and asphalt locations. However, at a distance of 7 m, the grass reduced the level of noise by approximately 3 dB(A) compared with the asphalt (cf. this volume Chapter 6).

A listening experiment using segments of tram noise centred around the maximum level verified that recordings made near the tramway were about equally annoying, regardless of whether the tramway was bordered by grass or asphalt; for recordings made farther from the tramway, however, the grass margin clearly resulted in less annoyance. The effect at this distance could be predicted fairly well from the associated A-weighted sound pressure level reduction. There was, however, a clear tendency for the annoyance difference between the grass and asphalt recordings to be greater than one would predict from the A-weighted sound pressure level difference alone (Figure 9.5(a)). Verbal reports from listeners suggest that a main perceptual effect was a reduction of high-frequency sounds in the tram noise,
Figure 9.3 Recordings made using artificial head technology (a) to obtain high-quality recordings for listening experiments (b).
and this observation was supported by acoustic analyses (see spectra in Figure 9.4(c)).

This is an example of noise mitigation that reduced not only the perceived loudness, but also altered the character of the noise in a way that led to a larger reduction in perceived annoyance than expected.
Figure 9.4 Photos from recordings in Grenoble of tram noise, at a location with asphalt (a) or grass (b) close to the rail and microphone.
from the reduction in A-weighted sound pressure level or loudness level. The effect was fairly large (1–2 dB(A)) and statistically significant, and corresponds to the horizontal distance between the regression lines in Figure 9.5(a) and (b).

The results of this experiment suggested that replacing hard ground with soft ground (grass) between tramways and listeners may reduce sound pressure levels by about 3 dB(A) at a 7-m distance, and that the associated effect on perceived annoyance may be even greater thanks to perceptual changes related to the change in spectral composition of the noise. Further studies are needed to confirm these results, and to find out whether they generalise to other settings and noise sources. Nevertheless, the results are promising and this is, to the best of our knowledge, the first experimental study that has demonstrated a case where noise mitigation might lead to a perceptually larger effect than expected from the reduction in overall level (the opposite to the previous example; see Figure 9.3(c)(d)). Note that this is not the same effect as has been demonstrated in several field studies, where noise reduction has been followed by an initial, temporary strong reduction in long-term noise annoyance at home. Such effects are thought to be related to attitudinal or response behaviour factors, rather than to purely perceptual factors as in this experiment (where the listeners were blind to what condition they were assessing).
9.3 SOUNDSCAPE: WANTED AND UNWANTED SOUNDS IN INTERACTIONS

Conventional noise control aims at protecting people from harmful effects of noise. During the past few decades, the primary focus of noise control has been the indoor environment of residential dwellings, with the goal to protect the indoor environment from external (e.g., road traffic) or internal noises...
(e.g., ventilation), and thereby minimise annoyance, sleep disturbance, and other adverse effects of noise. When successful, a quiet indoor environment is created, and residents are free to design their acoustic environment as they like, by turning on the radio, playing music, or just keeping it as it is.

Outdoors, absolute quietness is neither possible nor desirable. We expect the outdoor soundscape to contain sounds from many sources. Specific sources can often be heard individually; for example, in a city park, you may hear sounds from traffic, birds, and wind in the trees at the same time. This complexity notwithstanding, we can easily assess the overall quality of the acoustic environment (the soundscape), and say whether we prefer one soundscape over another, or say whether we like or dislike a given soundscape as perceived in relation to our goals and activities (rest, relaxation, enjoyment, etc.).

The overall quality of the soundscape (on a like–dislike dimension) depends on its composition of specific sounds and on how these sounds are perceived in interaction. The sounds of a specific soundscape may roughly be classified as unwanted, wanted, or neutral sounds. Unwanted sounds (noise) detract and wanted sounds add to the overall quality of the soundscape, whereas neutral sounds neither do good nor harm.

Obviously, the same sound may be preferred in one environment but not in another. For example, traffic noise may add to the vibrancy of a downtown shopping area, but would be a nuisance in a green city park intended for rest. Moreover, people may differ in which sounds they prefer and dislike in a given environment, although, in general, people tend to agree more than they disagree about which sounds they prefer. For example, in urban open spaces, most people classify birdsong and water-generated sounds as wanted, and technological sounds, such as traffic noise and ventilation noise, as unwanted.

9.3.1 Auditory masking and noticeability

Successful noise mitigation will improve the soundscape by increasing its ratio of wanted to unwanted sound. This is achieved not only by reducing unwanted sounds (noise), but, potentially, also by allowing wanted sounds to attract attention once the “masking” noise has been removed or attenuated. A deeper understanding of the effect of noise mitigation on soundscape quality, therefore, requires knowledge on how wanted and unwanted sounds are perceived in interaction.

Researchers at Ghent University have developed a theoretical and computational framework for studying such interactions. At the heart of their approach is their notice-event model, which takes its starting point in the following assumptions:

1. Only sounds that are both audible and noticed (through a notice event) may be annoying and potentially threatening to well-being.
2. A notice event is any event that draws attention to the sound. This could occur when a sound suddenly emerges above the background generated by everyday activities, e.g., when the background level itself drops, when attention for one’s environment increases, etc.

Whether or not a sound is audible and noticed in a given environment is determined by peripheral and central processes of the auditory system. At the periphery, a masking sound makes a target sound inaudible (complete masking) or less loud (partial masking) by decreasing signal-to-noise ratios (SNRs) in the frequency regions surrounding the target at the basilar membrane of the inner ear.\(^{19}\) This kind of masking is referred to as energetic masking, to distinguish it from effects on a sound’s noticeability related to auditory processes at higher levels, sometimes called informational masking.\(^{20,21}\)

Energetic masking is asymmetric in the sense that low-frequency sounds mask high-frequency sounds more than the other way around. Many unwanted sounds, like traffic noise, have more energy in the low-frequency part of the spectrum than typical wanted sounds, such as sounds from water features.\(^{22-24}\) Consequently, noise reduction may increase audibility of wanted sounds previously masked, provided that also low frequencies are reduced.

Whether an audible sound is noticed is determined largely by attention mechanisms. An inattentive visitor to a space will notice some of the sounds without noticing others. Acoustic design aiming to provide a restorative environment for people using the space may include facilitating the occurrence of notice events for wanted sounds. Making wanted sounds more noticeable requires a detailed analysis of the spectro-temporal structure of both the wanted and unwanted sounds.

Note that the noticeability of sounds is not only influenced by the amount of energetic masking and auditory attention. Prior knowledge and expectations of what kind of sounds to hear in a given environment, as well as information from other senses, may enhance the noticeability of sound sources. For example, if the peak noise level is low enough, noticing might be influenced by the sound source being visible or not. Visible sound sources, particularly when moving, can attract attention visually and, thereby, direct auditory attention to a source that would otherwise have gone unnoticed.

In listening studies, participants are instructed to assess sounds in various ways. The instructions, thereby, direct the listener’s auditory attention to specific aspects of the soundscape, and, therefore, it is difficult to study noticeability using such methods. Accordingly, listening studies are used mainly to assess perceived loudness, annoyance, or other characteristics of specific sounds or soundscapes (examples were given in the previous section). An alternative approach is to model the relevant phenomena and
to use these models to compute a sound’s noticeability. The notice event model discussed above (Figure 9.6) has been implemented in computer models predicting whether the average visitor will notice a sound in a given soundscape, and developments of the model are increasingly accurate and powerful.\textsuperscript{18,25}

Figure 9.7 gives an example of noticeability computation predicting time intervals in which attention is attracted by sounds from birdsong in the presence of traffic noise, in a given environment with and without a noise barrier. In this 30-second time interval, birdsong is predicted to be noticed three times more often when a noise barrier (reducing the noise level by 6 dB(A)) is introduced.

This illustrates the potentially dual effect of noise mitigation, reducing unwanted sounds and increasing the noticeability of wanted sounds. This naturally leads to the idea discussed next, of adding wanted sounds to improve the soundscape by masking unwanted sounds.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure9.6.png}
\caption{Model mimicking human auditory perception.}
\end{figure}
9.3.2 Adding wanted sounds

Is it possible to improve the soundscape by adding wanted sounds? In theory, yes. Adding wanted sounds may mask unwanted sounds or divert attention away from unwanted to wanted sounds. In practice, however, this is easier said than done, for reasons discussed below.

Energetic masking of unwanted by wanted sounds is difficult to achieve for at least three reasons. Firstly, the frequency asymmetry of masking will play in favour of the unwanted sounds, which typically contain more low-frequency energy than many wanted sounds. This was illustrated in a study that measured perceived loudness of traffic and fountain sounds recorded in a city park, and found that the traffic noise, which had sizeable low-frequency components, reduced the loudness of the fountain sound, dominated by high-frequency components, considerably more than the other way around.23 Galbrun and Ali24 looked at different types of water features, and found that only waterfall sounds contained sizeable low-frequency components that might effectively mask road traffic noise. Unfortunately, waterfall sounds are among the least pleasant water-generated sounds, and, therefore, might not help to improve the overall soundscape. In fact, recent experimental studies have shown detrimental effects of adding waterfall sounds on assessments of overall soundscape quality.26,27

Secondly, differences in temporal variability between masker and target sound will diminish any masking effects. Even if a noise is masked at periods when its level is low in comparison to the masking sound, the noise may be audible and thereby potentially noticeable and annoying at periods when its level is high. This was demonstrated by De Coensel et al.28 who found...
sounds from fountains reduce perceived loudness of freeway noise (low variability) more than noise from a major road (moderate variability), but had no effect on the loudness of noise from a minor road (high variability).

Thirdly, when sound sources are located in different directions from the listener, binaural localization cues will make it easier to hear the sounds separately than when they are located in the same direction. This is known as spatial unmasking and is related to how sounds at different locations contribute to binaural level and time differences.\textsuperscript{29} If a fountain is located to the left of a listener, the level of the fountain sound at the listener’s right ear will be reduced by the acoustic shadow of the head. Noise from a road located in front of, or to the right of, the listener will be less shadowed at the right ear, and, by attending to this ear, the listener may hear the road traffic noise better than if it had come from the same direction as the fountain sound. In addition, the auditory system compares the phase of signals between ears and this information is used to “binaurally unmask” sounds from different locations. It, therefore, is advisable to place a masking sound source (e.g., a fountain) in the same direction from the intended listener as the target source (e.g., road), for example, by placing the fountain in-between the listener and the road.

Even if wanted sounds do not easily mask unwanted sounds energetically, there may still be an effect on noticeability. For example, birdsong will hardly energetically mask road traffic noise,\textsuperscript{28,30} because of birdsong’s high frequency content, intermittent temporal pattern, and the elevated location of the source. However, birdsong may still attract attention away from the traffic noise and thereby reduce it noticeability. The notice event model can be used to explore this possibility, as illustrated below.

Oldoni et al.\textsuperscript{25} used an updated version of the notice event model to explore the perceptual effects of attracting songbirds at an urban location. Once the model is trained for a particular location, it classifies the sounds that are present in the soundscape and simulates how a typical listener would switch attention over time between different sounds. The model thus allows to assess the perceptual effect of introducing additional sounds.\textsuperscript{25}

For the particular application described here, a fixed sound measurement station was installed in the city of Ghent, Belgium. The soundscape at the chosen location consisted mainly of a mixture of road traffic noise due to private and public transport on a nearby urban road, and the noise from pedestrians due to the proximity of several shops and one educational institution. In a first stage, a 1/3-octave band spectrum at 1-s time intervals was measured during three weeks at this location. These measurement data were then used to train the computational model, such that it would be able to classify the typical sounds that can be heard at the particular location over the course of the day.

In a second stage, a 1-h sound recording was performed at the location; the $L_{Aeq}$ during this period was 68 dB(A). Subsequently, a series of 30
artificial 1-h soundscapes were created by mixing the original recording with an increasing number of birdsounds at random instances in time. For this, a series of bird vocalizations without background noise, with a duration of up to a few seconds, was used, for which the peak level was adjusted to match the peak level of the few birdsounds present in the original recording. The 1-h $L_{Aeq}$ of the added birdsound ranged from 46 dB(A), representing a few sporadic vocalisations, to 76 dB(A), representing a quasi-continuous bird chorus, resulting in an SNRs for birdsound versus background ranging from –22 dB to +8 dB.

The computational model, trained for the particular microphone location, was used to classify the sounds that are present in the 30 artificial soundscapes. In the audibility analyses (not taking auditory attention into account), it was found that the model clearly distinguished between the sound of individual birds and the sound of a bird chorus. Figure 9.8(a) shows the percentage of the time that individual bird chirp is dominant, which increases monotonically with SNR until a peak is reached at an SNR equal to –2 dB. At that point, the percentage of the time that bird chorus dominates the soundscape starts to increase with increasing SNR.

The noticeability analyses used the same procedure, but now also taking into account auditory attention mechanisms (see Figure 9.8(b)). The output of the model can then be interpreted as the fraction of time each particular sound is noticed (receives attention). It can be seen that for lower SNR, the percentage of time that attention is paid to birds is slightly higher than in Figure 9.8(a), while for higher SNR, this percentage is lower. This is indeed the expected behaviour, as for lower SNR, each time birdsound is detectable it will get attention because its saliency is higher than the background, and the particular sound source may even receive attention even for a short time after the sound has actually stopped, because of expectation and focussed listening. For higher SNR, birdsound will be continuously detectable, and the inhibition-of-return mechanism implemented in the model will cause attention to shift away. Considering that sounds need to be noticed, in order to contribute to the appraisal of a soundscape, these results are in accordance with empirical results showing the potential of birdsound to increase soundscape pleasantness and eventfulness.

In summary, masking unwanted sounds (noise) with wanted sounds is in most situations difficult to achieve. Studies using water-generated sounds as maskers show small, if any, effects on traffic noise loudness, and, in some conditions, detrimental effects on overall soundscape quality. However, noticeability of noise may be reduced, as suggested by results from models of auditory attention of road traffic noise combined with twittering of birds.

All in all, it seems fair to conclude that unwanted sounds (noise) do more harm to the soundscape than wanted sounds do good. Therefore, noise mitigation will always be the main method for soundscape improvement.
However, soundscape design based on adding sounds may be used as a complement to noise mitigation, especially in environments with moderate-to-low levels of noise. Greening will add natural sound, both vegetation-generated sounds and, to some degree, wildlife sound, and some additional improvement in soundscape quality could be expected from using natural materials for noise mitigation.

Figure 9.8 Fraction of time birdsong is audible (a) and receives attention (b), as a function of signal-to-noise ratio (SNR) between birdsound and background noise. The dotted line denotes individual birds.
9.4 ENVIRONMENT: AUDIO-VISUAL INTERACTIONS

Many noise-mitigation methods influence the visual environment as well, and the use of vegetated mitigation elements can improve the visual quality of environments. The extent to which such visual changes also influence auditory perceptions is unclear, and results in different directions have been published. Any such effects of visual impressions on auditory perception are probably small (closing one’s eyes doesn’t substantially change the auditory perception of a place). More important than auditory perceptions, however, are effects on how the overall environment is perceived, and noise-mitigation methods that, in addition to reducing noise, also improve aesthetic values are obviously better than methods that do not.

Aesthetic values are of particular importance in outdoor areas intended for rest and relaxation, such as city parks or recreation grounds. Previous research suggests that the sound environment and scenery independently contribute to the overall perceived tranquillity of such areas, and that low sound levels combined with a view dominated by vegetation would be associated with a high degree of tranquillity. This suggests that noise mitigation that in addition to noise reduction also increases the amount of greenery would be suitable for areas intended for rest and relaxation, by simultaneously increasing visual and auditory tranquillity.

Effects also may be seen on urban streets, as Hong and Jeon showed in an experiment where participants assessed auditory, visual, and audio-visual stimuli on an 11-point preference scale (from 0 = not at all, to 11 = extremely preferred). The visual stimuli were created by manipulating a street view to obtain a set of “streetscapes” with combinations of various vegetation and water features (Figure 9.9). The street was selected based on a previous sound walk study in downtown Seoul, where participants had assessed the location negatively with regard to both its auditory and visual qualities.

The auditory stimuli consisted of one unwanted sound, traffic noise, and three wanted sounds: sound from falling water, stream water, and twittering of birds, presented alone or in combination. The traffic noise was set to either 55 or 70 dB(A) L_{Aeq} and the water and bird sounds to either 58 or 73 dB(A) L_{Aeq}. Preference ratings of the sounds heard alone showed that the traffic noise was clearly the least-preferred sound. Among the three sounds selected to represent wanted sounds, the sound of twittering of birds was most preferred, followed by the sound of streaming water, with the sound of falling water as least preferred (but still much more highly rated than the road traffic noise) (Figure 9.10).

The street seen without vegetation or water features was less preferred than with such features (white bars in Figure 9.11). In the audio-visual conditions, preference ratings were similar to the visual-only ratings when the
Figure 9.9 Images of streetscapes in downtown Seoul, South Korea, with a combination of vegetation (V) and water features (W).

Figure 9.10 Mean preference scores for the acoustic stimuli (audio-only condition). T = traffic noise; F = sound from falling water; S = sound from streaming water; B = birdsong.
Traffic noise was of a moderate level (55 dB), but, in general, less for high levels of traffic noise (70 dB) (see Figure 9.11).

Hong and Jeon conclude that increases in greenery from trees or bushes can improve streetscapes, but water features as visual components may not significantly improve the perceived view. Among natural sounds for soundscape elements, bird sounds were more useful for enhancing soundscape quality with road traffic noise than were water sounds. However, it was revealed that water sounds, such as falling water, could decrease the overall quality of the environment when the road traffic noise level was higher than 70 dB(A). Thus, care must be taken to consider these characteristics when designing soundscapes using water sounds.

In a similar experiment, Hong and Jeon evaluated various noise barrier designs, including barriers made of timber, metal, vegetated substrate, concrete, and translucent acrylic. Participants in the experiment were asked to assess audio-visual presentations of barriers with normalised traffic noise levels (55 or 65 dB(A)) (Figure 9.12). Vegetation was found to enhance overall preference, as seen in Figure 9.13. For both the translucent acrylic, Tr, and the concrete barrier, Co, preferences increased from no vegetation to sparse vegetation, (L), to dense vegetation, (H). The highest preference ratings were found for the concrete covered to a high degree with climbing ivy. In this study, it also was found that participants assessed the noise reduction potential of barriers higher when the barriers were covered with vegetation. These results are based on laboratory experiments and need to be evaluated in real-life settings. Nevertheless, the results point to the possibility of using vegetation on barriers to enhance not only the overall preference of a place, but also perceived noise barrier performance.
This chapter has provided examples of perceptual effects of noise mitigation, from effects on perception of the noise itself, via effects on the soundscape, to potential effects on the overall audio-visual environment. The examples suggest that conventional noise mitigation, which solely focusses on A-weighted sound pressure level reductions, would benefit from perceptual analysis. For example, perceptual effects of methods that mainly affect the high-frequency part of the spectrum may not be well predicted by the A-weighted sound pressure level, and alternative indicators, for instance, the loudness level, may be used as a complement. In addition to loudness level, spectral shape was shown to significantly affect instantaneous annoyance caused by traffic noise. The potential effect of noise mitigation on the soundscape should always be considered, and methods

Figure 9.12 Photomontages for the different types of noise barriers: (a) timber, (b) metal, (c) concrete, (d) translucent acrylic, (e) vegetated substrate, (f) concrete with sparse vegetation cover, (g) concrete with dense vegetation cover, (h) translucent acrylic with sparse vegetation cover, and (i) translucent acrylic with dense vegetation cover.

9.5 CONCLUDING REMARKS

This chapter has provided examples of perceptual effects of noise mitigation, from effects on perception of the noise itself, via effects on the soundscape, to potential effects on the overall audio-visual environment. The examples suggest that conventional noise mitigation, which solely focusses on A-weighted sound pressure level reductions, would benefit from perceptual analysis. For example, perceptual effects of methods that mainly affect the high-frequency part of the spectrum may not be well predicted by the A-weighted sound pressure level, and alternative indicators, for instance, the loudness level, may be used as a complement. In addition to loudness level, spectral shape was shown to significantly affect instantaneous annoyance caused by traffic noise. The potential effect of noise mitigation on the soundscape should always be considered, and methods
that not only reduce the noise but also increase the prevalence of wanted sounds, for instance, vegetated solutions attracting birds and generating sounds from wind in the leaves, may have positive effects on the soundscapes, over and above the effects associated with the reduction of noise. Models for predicting the audibility and noticeability of the sounds in the environment are under development, and may prove useful in the future for evaluating effects of noise mitigation on soundscapes. Finally, well-designed, noise-mitigation methods improve visual aesthetic values, and vegetation is a particularly valuable design element for this purpose. Green noise mitigation that reduces noise, increases prevalence and noticeability of wanted sounds, as well as improves the visual environment, could be well motivated also in situations where a simplistic analysis solely based on A-weighted sound pressure levels would suggest otherwise.

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