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## Noise annoyance and restoration in different courtyard settings: Laboratory experiments on audio-visual interactions

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### ABSTRACT

Having access to restorative, natural environments in urban residential areas is important for health and wellbeing. However, previous research on restorative environments is mainly focused on the visual impression. Knowledge is needed on the interaction between the acoustic/perceived soundscape and the visual appearance in residential settings intended for restoration and recreation. The present study examines audio-visual interactions in two laboratory settings – an attractive vs. unattractive courtyard. At each courtyard setting, six sound conditions were presented in a randomised order during 4 minutes each: only sounds from road traffic at  $L_{Aeq}$  43, 50 and 55 dB, and these traffic sound levels together with birdsong. 24 subjects (12 men, 12 women) participated in the experiment. The results indicate that visual courtyard perception, road traffic noise annoyance, perceived soundscape (e.g., soothing, stressing), emotional reactions, and possibilities to rest/relax were affected by courtyard setting, sound levels, and birdsong. For example, noise annoyance decreased with the attractive courtyard setting and presence of birdsong. However, about 35 to 50% and 75 to 90% were annoyed at 50 and 55 dB, respectively. At these sound levels, few of the participants reported that they would like to visit the courtyards, even if it was the attractive one.

### 1 INTRODUCTION

For most people, our home is a place for rest and relaxation and where we seek relief from stress and demands of every day life. It is therefore essential that the housing environment provide opportunities for restorative processes [1-2]. The research programme “Soundscape Support to Health” has previously shown that access to positive outdoor soundscapes at residential settings and in their close vicinity, for example, in backyards/courtyards and other nearby outdoor places (e.g., green areas/parks) are of great importance for health and well-being [3-5, 19-21]. Particularly the implementation of the “quiet side concept” in noise-polluted urban residential areas has proved to be a factor of significance for moderating the adverse health effects of road traffic noise [3]. The definition of a quiet side is as follows: a dwelling with access to a quiet side is a dwelling that have window/s and a courtyard/backyard towards at least one side where the total sound level –  $L_{Aeq,24h}$  – from traffic at ground and other noise sources are lower than 45 dB free field value, with the association + 3 dB measured 2 m from the façade corresponding to 48 dB.

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The modifying effect of having access to a quiet side of one's dwelling can be interpreted in terms of increased perceived control of the noise exposure by providing an opportunity to reduce the amount of time the individual is exposed to stress from noise, including possibilities for non-noise disturbed sleep, relaxation, opening of windows etc., [6, 2].

Although access to a quiet courtyard *per se* was found to be essential for health and well-being, additional studies within the research program indicate that the physical environmental quality of the quiet courtyards furthermore can modify resident's noise responses. Thus, quiet courtyards with high physical quality in terms of presence of natural elements such as greenery, flowers, and sounds from nature (e.g., birdsong) and possibilities for social relations (garden furniture, playground) decreased road-traffic noise annoyance, disturbed relaxation when being outdoors, and disturbed outdoor visits. These results are in line with previous research which shows that high neighborhood quality (greenery and aesthetic appearance) significantly lower dissatisfaction with traffic noise [7-8]. Experimental studies on audio-visual interactions and their influence on how environments are perceived confirms the abovementioned findings [9-14]. For example, adding natural sounds and presence of vegetation positively affected perceptions of a ventilation noise-contaminated residential environment and also significantly increased its restorative quality [13]. According to Carles et al. [14], presence of natural sounds may 'improve the quality of built-up environments to a certain extent' (p. 200). However, of importance is soundscape expectations connected to the visual setting or the specific area, which influences preference and judgments of its environmental quality [9, 14].

For a better understanding of the links between courtyard quality and its soundscape and to gain knowledge on how to produce health promoting residential environments, an audio-visual experiment was conducted in the new laboratory at the Department of Occupational and Environmental Medicine, The Sahlgrenska Academy at Göteborg University. The main objectives of the experiment were to study how visually attractive and unattractive courtyard settings in combination with various soundscapes (road traffic and birdsong) interact and influence perceptions of the courtyards and sound environments, noise annoyance, mood, and opportunities for relaxation and restoration.

## **2 METHOD**

### **2.1 Subjects**

Twenty-four subjects (12 men and 12 women) participated in the experiment (they were paid 600 SEK for their services). Most subjects were students and between 20 – 29 years of age (average age  $\approx$  24 years), 96 % lived in apartments and 29 % considered their home environment to be rather/very noisy. All participants were tested for normal hearing in the frequencies 1-8 and 125, 250 and 500 kHz with a pure-tone audiometer. Normal hearing was defined as hearing threshold level less than 20 dB in any of the tested frequencies. Based on single-item rating scales assessing sensitivity to environmental factors, 46 % of the subjects considered themselves to be rather/very much sensitive to noise and 33 % to dust/air pollution.

### **2.2 Visual Stimuli: Attractive and Unattractive Courtyards**

Great care was undertaken to create an "in-situ"-feeling by furnishing the attractive courtyard with nice garden furniture, flowers, and green surface, and the unattractive courtyard with worn out garden furniture, no flowers, and an asphalt-like surface. Photos of an attractive and unattractive courtyard were printed on 7 x 2.5m of textile, respectively, and hanged up on the laboratory-room walls (see Figure 1).



Figure 1: Attractive (upper) and unattractive (lower) courtyard settings.

### 2.3 Auditory Stimuli

The auditory stimuli were sounds from road traffic and birdsong (blackbirds). They were combined in six sound conditions with duration of 6 minutes each: Only sounds from road traffic at  $L_{Aeq,6min} = 43, 50, \text{ and } 55 \text{ dB}$  in conditions 1-3, and these road traffic sound levels together with birdsong in conditions 4-6. All sound clips were synthesised from recorded vehicle passages over a background sound recorded at a shielded courtyard. For the 55 dB clip, vehicle passages were taken at a distance of approximately 20 m and the speed was around 50 km/h. For the 50 dB and 43 dB clips, vehicle passages were recorded on another site with an average speed of about 30 km/h, and only a few very quiet passages were added to the background for the 43 dB clip. The birdsong sample was taken from a professional recording. The bird song was equally loud for all clips, and did not affect the A-weighted level except for the quiet clip (43 dB) where the level was increased by approximately 1 dB. The sounds were presented via 4 loudspeakers mounted in the upper corners of the laboratory room for frequencies higher than 120 Hz and via a loudspeaker wall for frequencies lower than 120 Hz.

### 2.4 Procedure

Half of the subjects started with exposure of the attractive courtyard followed by the unattractive courtyard (within a week), and vice versa for the other half of the participants. At each courtyard setting, the six sound conditions were presented in a randomised order during about 6 minutes each. Two subjects at a time performed in the experiment. When arriving into the laboratory room they were told to imagine that they were sitting outdoors in the current courtyard during a summer day. They were instructed to look around at the environment, to listen to the six different sound conditions, not to talk to each other during

the experiment and to try to give their immediate reaction to each question of the questionnaire. After each sound condition had lasted 4 minutes the experiment leader instructed the subjects (from the control room through a microphone) to answer the questions while continuing to listen to the sounds (during about 2-3 minutes). The whole sound exposure time was approximately between 36 and 40 minutes, but with information and instructions the entire experiment took about 45 minutes. Fruit juice was available during the experiment.

## 2.5 Questionnaire

After each sound condition, the subjects were requested to report on perceived soundscape, traffic noise annoyance, and visual appearance of the courtyard. To assess possibilities for restorative processes, questions on preference/behavior, opportunities for relaxation/restoration, and current mood were included:

(i) *Perceived soundscape* was assessed with respect to ten attributes (pleasant, unpleasant, eventful/varying, uneventful, stressful, soothing, exciting, dull, calm, and confusing) on 11-point numeric scales with verbal endpoints (0 = “no fit at all”, 10 = “fit very well”) [4]; (ii) *Noise annoyance due to traffic noise* was assessed with one question on a 5-point category scale ranging from “not at all” to “extremely much”; (iii) *Visual courtyard appearance* was assessed with six descriptors (attractive, beautiful, barren, boring, pleasant, possibilities for social relations) on 11-point numeric scales with verbal endpoints (0 = “not at all”, 10 = “very much”). Negative items were coded reversibly. Scale values for the six items were added to form a sum score with higher score indicating a more positively perceived visual appearance of the courtyard; (iv) *Preference/behavior*. This refers to how various environments are preferred. Preference has been found to relate to the “fascination” component of restorativeness indexes [15]. The subjects were instructed to imagine that the current courtyard environment (including the visual and the sound stimuli) was available at their home. On an 11-point numeric scale with verbal endpoints (0 = “not at all”, 10 = “very much”) they were then requested to report on how willingly they wanted to visit this courtyard; (v) *Opportunities for relaxation/restoration*. The subjects were instructed to imagine that the current courtyard environment (including the visual and the sound stimuli) was available at their home and that they during a period had experiencing stress due to certain circumstances. On an 11-point numeric scale with verbal endpoints (0 = “not at all”, 10 = “very much”) they were then requested to report on how much the courtyard environment could offer relaxation and restoration. This type of relaxation question is related to components of restorativeness indexes [15-16]; and (vi) *Current mood*. How a person is emotionally affected by the environment (core affects – cognitively accessible parts of a current mood) is commonly assessed and described by a two-dimensional circumplex model reflecting degrees of pleasantness-unpleasantness and arousal [17]. In the present study, current mood was assessed with eight adjectives (peppy/dull, interested/bored, pleased/displeased, and serene/tense) from the Swedish Core Affect Scale [18]. Unipolar 11-point numeric scales with verbal endpoints (0 = “not at all”, 10 = “very much”) were used.

## 3 RESULTS

### 3.1 Perceived Soundscape

In the present paper, results from two soundscape attributes (soothing, stressful) are presented. Figure 2 (left panel) shows that soundscapes perceived as highly soothing are only occurring at the lowest sound levels from road traffic (43 dB), but this decreases strongly with increasing traffic noise. Presence of birdsong has a significant influence ( $p < 0.05$ ) on soothing in 43 and 50 dB noise conditions presented in the attractive courtyard setting (green dotted line) but only in the 43 dB noise condition in the unattractive courtyard (grey line).

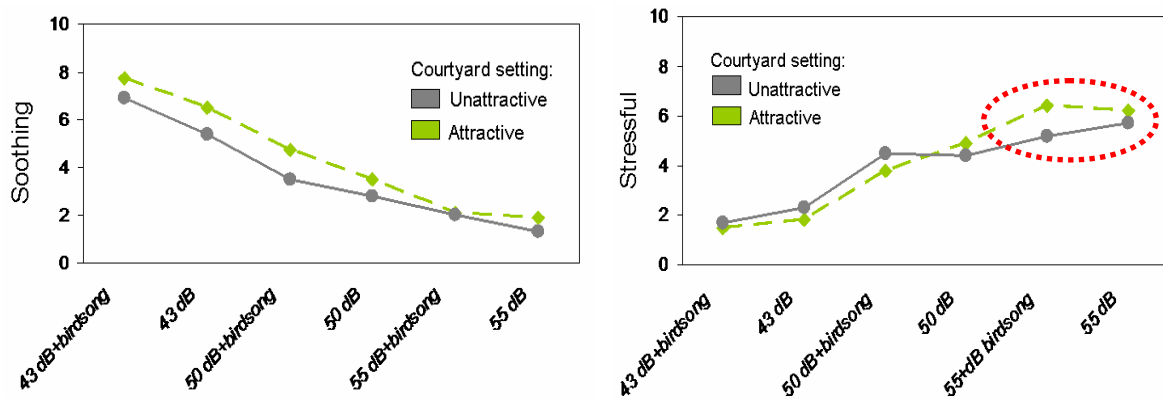


Figure 2: Attributes of perceived soundscapes (mean values): Soothing (left) and stressful (right) in relation to courtyard setting, road traffic sound levels and presence of birdsong.

Perception of a soothing soundscape was also affected by the visual appearance of the courtyards. When seeing the attractive courtyard, a significantly ( $p < 0.05$ ) more soothing soundscape was perceived, but only in 43 and 50 dB noise conditions without and with birdsong present, respectively. Stressful soundscape perceptions (right panel) increases with higher traffic noise, but presence of birdsong significantly lower these responses in the 43 dB noise condition presented in the unattractive courtyard (grey line) and in the 50 dB condition in the attractive courtyard (green dotted line). When comparing the two courtyards at 55 dB, we found that the soundscape is perceived as significantly more stressful in the attractive as in the unattractive courtyard.

### 3.2 Traffic Noise Annoyance

Figure 3 show that the percentage of annoyed (rather/very/extremely) subjects significantly increases with higher sound levels from road traffic. However, annoyance is influenced of courtyard setting (green and grey bars) and presence of birdsong (bars with pattern). In general, annoyance decreases somewhat in the attractive courtyard and when the traffic sound is combined with birdsong in both courtyard settings. At 43 dB only few were annoyed, at 50 dB about 30 – 50 % were annoyed, and at 55 dB almost all were annoyed. The latter is the Swedish guideline value for road traffic noise at courtyards/outdoor spaces in residential settings ( $L_{Aeq,24h}$  55 dB and  $L_{Amax}$  70 dB).

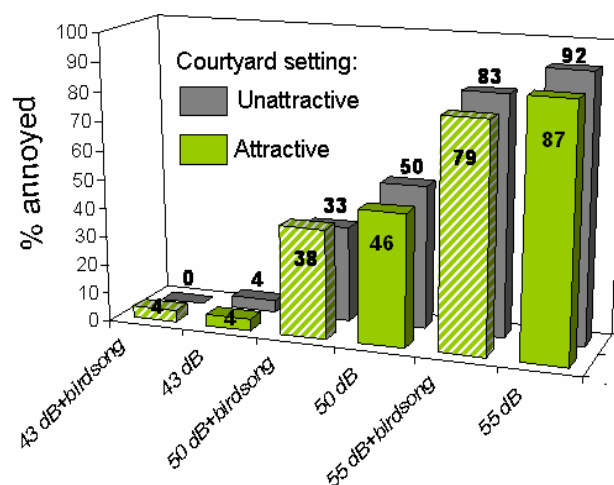


Figure 3: Percentage traffic noise annoyed subjects (rather/very/extremely) in relation to courtyard setting, road traffic sound levels and presence of birdsong.

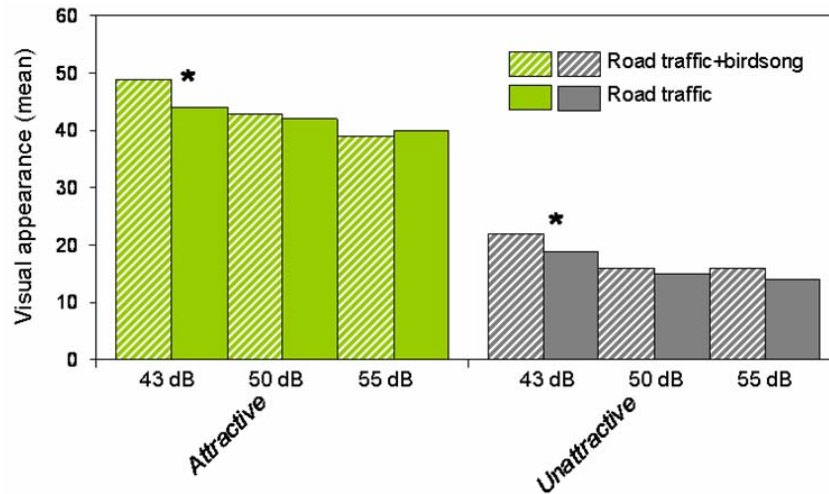


Figure 4: Perceived visual appearance (mean value) of the courtyard in relation to courtyard setting, road traffic sound levels and presence of birdsong.

### 3.3 Visual Perception of Courtyard Appearance

Figure 4 shows how courtyard appearance is visually perceived (higher scores indicate a more positive perception) in relation to courtyard setting, sound levels, and presence of birdsong. As expected, the unattractive courtyard received very low visual appearance scores in comparison with the attractive courtyard. With increasing sound levels from road traffic, the courtyards are less positively valued – largest effect ( $p < 0.01$ ) is seen in the attractive courtyard (left). Presence of birdsong significantly ( $p < 0.05$ ) increases the visual appearance, but only at the lowest sound levels (43 dB).

### 3.4 Preference/Behavior and Opportunities for Relaxation and Restoration

Courtyard setting and road traffic sound levels are of great importance of how willingly the subjects would like to visit the courtyards and how much they can offer opportunities for relaxation and restoration after everyday stress. Figure 5 shows that willingness to visit the attractive courtyard (green line) is very high at the lowest sound levels and highest when birdsong is present. For both courtyard settings, increasing road traffic noise significantly ( $p < 0.01$ ) declines the desire to be in the courtyard; however, for the unattractive courtyard (grey line) sound levels have not the same strong influence on this behavior. Presence of birdsong significantly ( $p < 0.05$ ) raises the willingness to be in the attractive courtyard with traffic noise at 43 and 50 dB and in the unattractive courtyard at 43 and 55 dB.

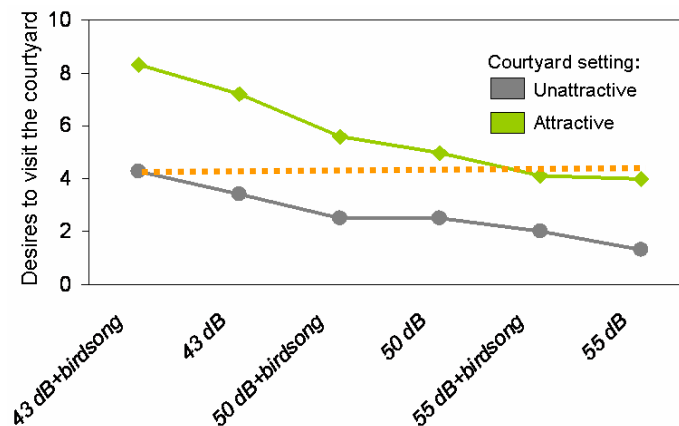


Figure 5: Desires to visit the courtyard (mean value) in relation to courtyard setting, road traffic sound levels and presence of birdsong.

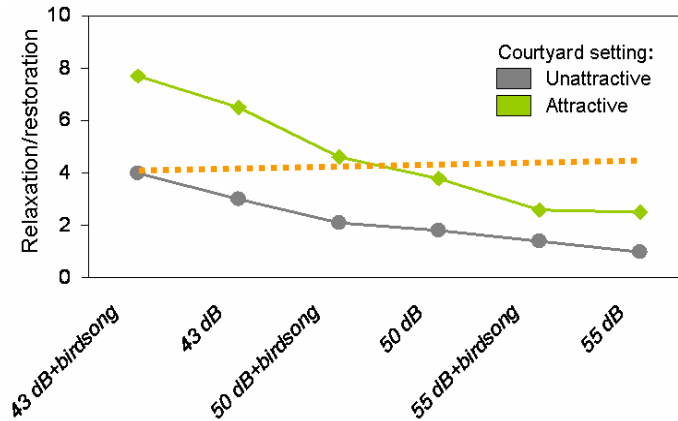


Figure 6: Opportunities for relaxation/restoration (mean value) in relation to courtyard setting, road traffic sound levels, and presence of birdsong.

The results in Figure 5 indicate clearly that despite the presence of a soundscape with good quality (43 dB+birdsong) the subjects are not particularly interested to visit the unattractive courtyard. In a similar way is the attractive courtyard not attractable to visit if it has a bad soundscape in which traffic noise is the dominating sound. The orange dotted line shows that both situations are evaluated more or less similarly.

Opportunities for relaxation and restoration (Figure 6) show similar associations with courtyard setting and type of soundscape. However, in comparison with willingness to visit the courtyard the results indicate that the unattractive courtyard (grey line) with a good soundscape (43 dB+birdsong) can offer somewhat more opportunities for relaxation and restoration than the attractive courtyard (green line) with a bad soundscape (see orange dotted line).

### 3.5 Current Mood

In the present paper, we only present current mood results for the attractive courtyard setting at conditions with sound levels of 43 and 55 dB of traffic noise in the company of birdsong. Figure 7 shows that feelings of being pleased, serene, and interested are significantly higher ( $p < 0.01$ ) and feelings of displeased and tense are significantly lower ( $p < 0.01$ ) in the condition with a positive soundscape (43 dB+birdsong) than in the condition with a more negative soundscape (55 dB+birdsong).

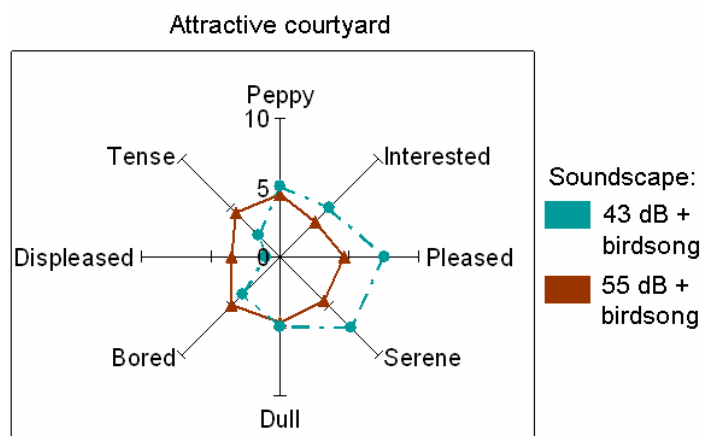


Figure 7: Current mood (mean value) in the attractive courtyard setting in relation to two soundscape conditions.

#### **4 SUMMARY**

The findings in this study indicate that the interplay between a courtyard's visual appearance and soundscape influence how it is visually and auditory perceived and this also forms the image of the courtyard's usefulness. Soundscape quality and noise annoyance was strongly affected by exposure from road traffic noise. In the condition with low sound level (43 dB), the perceived soundscape was described as highly soothing and not stressful and very few were noise annoyed by the sounds from road traffic. When road traffic exposure increases, the perception of a positive soundscape drops and a higher amount becomes noise annoyed. However, the presence of birdsong lowers annoyance somewhat, which is in agreement with previous findings [10-11, 13-14]. Hearing birdsong also significantly affected soundscape responses by increasing the soothing perception, but only at the two lowest noise conditions (43 and 50 dB).

The subject's noise annoyance and soundscape judgments were also influenced of what they saw – in general, annoyance decreased and the perception of a positive soundscape increased in the attractive courtyard setting. However, for the latter when noise levels raise to 55 dB, this effect diminished and the soundscape were instead perceived as more stressing in the attractive than in the unattractive courtyard. This may indicate that the perceived soundscape is not in accordance with soundscape expectations associated with the visual impression of the courtyard setting. Thus, when seeing an attractive courtyard the expectations are probable to hear natural and social sounds and not constant road traffic noise masking these positive sound sources. Our findings are supported by results obtained in a study by Carles and colleagues [14]. They found that when a stream image was combined with the sound of a busy park pleasure ratings drop to the lowest among the presented audio-visual combinations. They concluded that certain landscapes may 'lose quality as the sound environment deteriorates' (p. 195).

The visual judgments of the attractive and the unattractive courtyards were, furthermore, affected by what subject's heard. Increasing road traffic noise reduces visual appearance scores in both settings, whereas presence of birdsong in combination with low road traffic exposure (43 dB) significantly raises the visual impression of the courtyards.

It is important that courtyards and other places nearby residential settings can function as restorative environments [1] that offers opportunities to get away from noise and other daily stressors and in which important restorative activities, such as relaxation and engagements in social contacts are possible. Our results indicate that willingness to visit the presented courtyards, if the subjects had these environments available at their homes, depended highly on courtyard quality (visual appearance), road traffic noise, and hearing birdsong. An attractive traffic noise exposed courtyard (55 dB) as well as an unattractive courtyard with good soundscape quality (43 dB+birdsong) were not tempting to visit for outdoor activities. In a similar way were opportunities for relaxation and restoration judged as rather low by the subjects in these settings. The results on current mood, furthermore, strengthen the belief that potentially stress reducing and restorative feelings of being pleased, serene and relaxed is supported in an attractive residential setting having a positive soundscape with low sound levels from road traffic and other noise sources.

#### **5 ACKNOWLEDGEMENTS**

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