Buildings **2013**, *3*, 728-738; doi:10.3390/buildings3040728

OPEN ACCESS

buildings

ISSN 2075-5309

www.mdpi.com/journal/buildings/

Article

Understanding Soundscapes

Nicholas Miller

Harris Miller Miller and Hanson Inc., 77 S. Bedford St., Burlington, MA 01720, USA;
E-Mail: nmiller@hmmh.com; Tel.: +1-781-229-0707; Fax: +1-781-229-7939

Received: 12 September 2013; in revised form: 12 October 2013 / Accepted: 21 October 2013 / Published: 25 October 2013

Abstract: This paper offers a new approach to understanding, improving and designing soundscapes. "Soundscape" means all the sounds that can be heard in a specific location. Soundscapes can be understood only through peoples' perceptions, and this paper proposes using those perceptions to link soundscape improvement and design with traditional noise control methods. Decades of experience have yielded in-depth understanding of how undesirable sounds may be controlled or reduced. The control methods, however, are generally applicable to single sources of sound while soundscapes are composed of multiple sounds. Using human judgments, first in the laboratory and later in the field, it will be possible to deconstruct any soundscape into its desirable and undesirable sounds, which may then, one-by-one, be subjected to proven methods of noise control. This approach includes complications, not the least of which is deciding how much the undesirable sounds should be reduced to perceptually improve the soundscape. Previous published studies, primarily laboratory, but also field studies, suggest that initial laboratory work followed by increasingly complex field applications, should result in an understanding of how soundscapes can be improved and desirable ones designed.

Keywords: soundscape; noise; acoustical design; urban design

1. Sustainability and the Role of Soundscapes

Sustainability in planning and design implies spaces that are planned, designed and managed to achieve the "triple bottom line" of being economical, environmentally friendly and improving the quality of life. The quality of life dimension addressed here is the sound environment (soundscape) which we experience in those spaces. Most places that we live, work, play and move through are characterized not only by landscape, cityscapes or architecture, but also by a characteristic soundscape. In terms of improving the soundscape, it is not only the undesirable aspects of the sounds that need to be considered, but preservation or restoration of the desirable sounds that are covered up or masked by the undesirable. If our living spaces are to provide the triple bottom line, then the full panoply of sounds we experience needs to be considered with the goal of preserving or restoring desirable soundscapes.

It should be noted that providing soundscapes that people judge as having desirable sounds is not the only goal. Soundscapes can have both beneficial and detrimental effects on the health of the people experiencing them. "The significance of the health and wellbeing benefits from interacting with nature, including in park settings cannot be overestimated" [1]. A brief literature search will reveal many studies verifying the health benefits that can be derived from time spent viewing or being in nature; Maller [1] provides a readily accessible review of much of this literature.

Previous research has addressed both subjective and objective measures of soundscapes, but usually only on the totality of the soundscape and not simultaneously on the subjective, the objective and the *individual contributors* to the soundscape [2–5]. The approach described here is intended to examine all three aspects, and provide sufficient quantitative information that traditional noise control methods can be applied to individual sources with the goal of improving the soundscapes people experience.

This paper first defines and discusses the concept of "soundscape", elaborates on the difficulties of characterizing a given soundscape, and then proposes a method for analyzing and improving soundscapes. The goal of the soundscape analysis presented here is to construct an approach that is harmonious with the classic approach to noise control. The classic approach focuses on one source of noise at a time, and all the tools and expertise we use to control noise are specialized to one particular type of noise. In sum, the approach offered here is to deconstruct the soundscape into its undesirable and desirable components so that each one can be addressed with the appropriate tools and expertise.

Traditional noise control for individual sources is largely well developed. We know what sound levels are produced by virtually all transportation noise source and industrial noise sources. We know how much reduction results from such things as of noise walls or berms; how much reduction can be achieved with sound absorbers or enclosures for industrial equipment; how much quieting of traffic noise can be achieved by use of quiet pavements; how moving aircraft flight corridors reduces noise in communities; what technologies for lawn-care equipment produce the quietest devices. So the issue to address is: What sources are least desirable in a soundscape. Chances are they are the sounds of a modern developed economy, and those we know how to quiet.

2. Soundscape Defined

We define the soundscape to be the totality of the sound environment "with emphasis on the way it is perceived and understood by the individual, or by a society" [6]. In other words, if a soundscape is to be properly analyzed, its subjective meaning to individuals who experience it needs to be understood.

Judgments of a soundscape can depend upon the specific location and its visual appearance [7], the type of activity or activities that occur there [8], the observer's personal history and expectations, emotional content and culture [9] and age [4]. How can this multiplicity of factors be evaluated in a useful way so that decisions about soundscape improvement or preservation can be made?

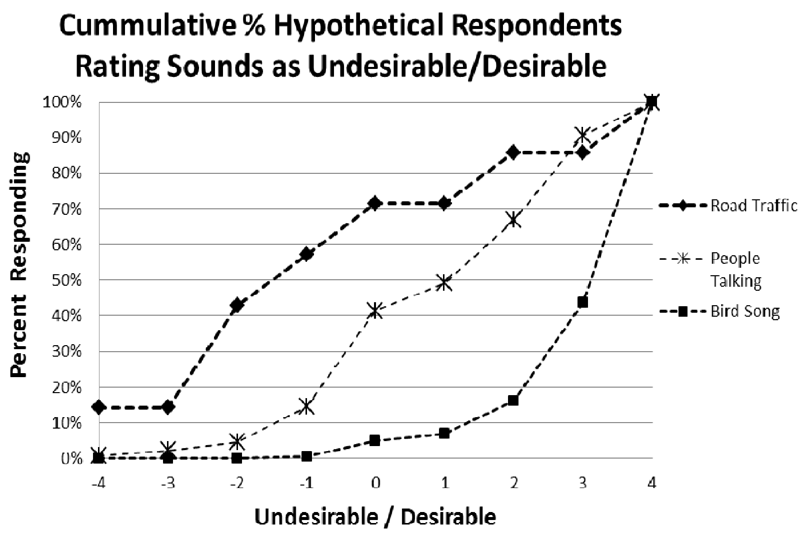
3. Simplified Data to Rate Soundscapes

For practical reasons, we do not need to understand or characterize all of these factors that influence a person's reaction to a soundscape. Recall that the concept of "annoyance" as reported by social surveys has been used rather successfully to summarize the multiple adverse effects of transportation noise on people [10,11]. Similarly, there should be a simplifying subjective judgment of a location's soundscape. For example, some evaluations of National Parks have asked visitors to rate sounds on a scale of −4 (very unacceptable) to +4 [12]. The approach suggested here focuses on determining a soundscape's contribution to quality of life by rating the components of the soundscape on a scale of "desirableness".

Different methods have been tried for describing soundscapes with acoustic metrics [5], or with verbal descriptions of soundscapes and sources [3,9]. These tend to rate the total soundscape and often use either a subjective evaluation or a physical description (e.g., use of sound quality metrics [5]). However, in order to provide information useful for decision making and for application of traditional noise control methods, contributors to the soundscape, both the desirable and undesirable, need to be identified and ultimately associated with objective measures.

One method to collect this information is simply to ask or survey residents or regular users of a space or place to identify the sounds they hear and ask them to rate each one. A possible rating scale would be one of desirability, ranging from −4 (extremely undesirable) to +4 (extremely desirable). Intermediate semantic ratings could be: very, moderately, slightly, and neither undesirable nor desirable. Figure 1 shows hypothetical results from such a survey and readily distinguishes among the sounds people like and those they don't. The values are cumulative, moving from undesirable on the left to desirable on the right. The more rapidly the cumulative value increases, the less desirable is the sound. Bird song is desirable for most people, while road traffic is undesirable for most.

Figure 1. 1 Hypothetical respondent ratings of three sounds in a selected location or neighborhood: Extremely Undesirable to Extremely Desirable.



4. Factors Complicating Data Collection

The type of data shown in Figure 1 could be acquired through a mail survey or brief intercept survey [12,13], but there would be important questions unanswered: Are all respondents hearing the same types of sounds (are some responding to trucks on a local road, while others respond to automobile traffic on the freeway)? Most importantly, what are the levels of the sounds that respondents are rating? What time of day/week/year do the ratings represent? Proper identification of respondent location and wording of the survey could answer some of these types of questions, but determining objective noise metrics for each source for each person is an expensive and complicated proposition.

Theoretically, behind the data of Figure 1, are data of the form shown in Figure 2 where each rating is associated with the sound level of the source rated. In the figure, sound level is left undefined to suggest that an appropriate metric of the level or loudness would be used. Traditionally, some 24-h or long-term (many hours) metric would be used if subjects were asked to rate the overall desirability of the sounds. Alternatively, they could be asked to sit and listen for 30 min at a specific time of day, noting and rating the sounds they heard and then determining the sound levels for that period.

Figure 2. Respondent ratings of traffic sound desirability as a function of the traffic "sound level" at the respondents' location.

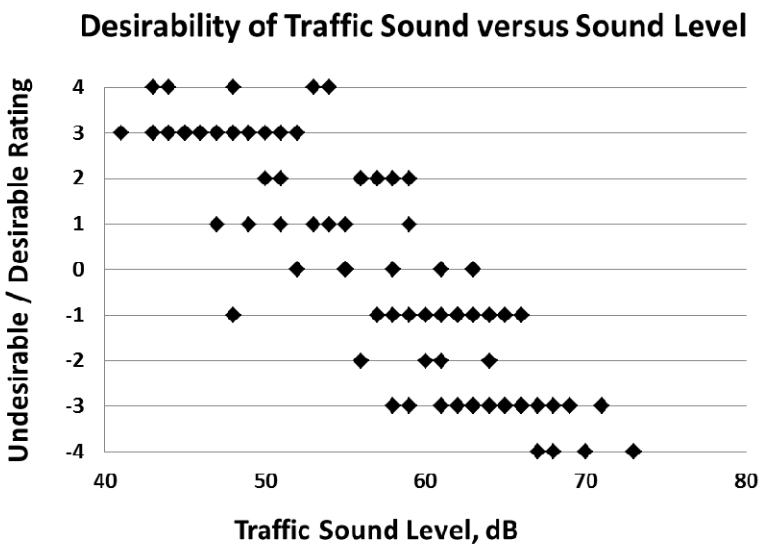


Figure 2 type data would permit judgments of how reducing sound levels below some threshold could improve the desirability or reduce the undesirability of one source in the soundscape. For National Parks, a technique was developed using continuous logging of sources by a trained observer during simultaneous continuous sound level monitoring and interviews of visitors [14]. This method quantified the sound level each respondent could have heard and associated the level with the visitor's reported annoyance. This approach has proved successful when quantifying dominant noise sources, but isolation of the levels produced by quieter sources can be imprecise. How then to quantify all sources present in a soundscape?

It should be noted that in the study of public health issues, there is an increasing interest in integration of qualitative and quantitative methods [15]. What is proposed here is just that. We can learn a great deal about how people feel about the sounds that surround them. But if we are going to make progress in improving these soundscapes, we need to know not only how they feel, but how to judge improvement or worsening of those soundscapes. The argument here is that the most direct method is to associate some objective measure of the sounds with the human judgment of those sounds. For an initial approach, a simple concept of nine levels—extremely undesirable to extremely desirable is proposed.

5. A Modest Start at Analyzing Soundscapes

Though collecting desirability ratings and sound levels *in situ* would be the gold standard for soundscape analysis, associating human reactions to soundscapes with metrics of sound could be initiated with laboratory studies. Several researchers have had success bringing an outdoor experience into a laboratory setting for purposes of judging outdoor sounds [9,16–18]. The technique of using various combinations of audio and visual reproductions in the lab has been shown to permit subjective evaluations that are highly correlated with the evaluations made in the field. Pheasant [16] duplicated outdoor ratings of the "tranquility" of eight different scenes in a laboratory using binaural recordings and simultaneous videos of the scenes. Aasvang [17] using binaural recordings combined with a projected slide of the field location, found that laboratory annoyance ratings of single aircraft events correlated highly with *in situ* ratings of the identical aircraft events. Hartig [18] found that, using slides, subject evaluations of the restorative qualities of various outdoor locations were not significantly different from on-site evaluations of the actual locations by different subjects. Dubois [9] found that laboratory tests of subjective reactions to soundscapes provided results similar to everyday listening situations if high quality multichannel sound reproduction (6.1 channel Ambisonics) were used. Specifically, Dubois found that for similar laboratory and *in situ* subjective judgments of ambient background noise, high quality sound reproduction is required.

The suggestion here is that laboratory tests with high-definition videos and high quality sound can be used to learn how people rate the components of different soundscapes, and to test the correlation of various sound metrics with the ratings. For the laboratory setting, the soundscapes would be constructed from separate recordings of individual sources and of different ambient backgrounds. This patching together of the soundscapes will permit accurate determination of the various sound metrics of each contributing source—a disaggregation not always possible with *in situ* measurements.

Admittedly, the laboratory approach, especially if conducted with subjects unfamiliar with a specific soundscape, may be far removed from the actual experience of living with that soundscape. However, work in the laboratory could help to develop a general understanding of how people subjectively evaluate different soundscapes and the component sound sources and to test the value of different noise metrics.

6. Laboratory Studies and Possible Benefits

6.1. Laboratory Study Concept

The approach would be that used by others—a visual presentation with associated sound [19–21]. Subjects would experience the presentations in a darkened, quiet room and register their judgments, probably after a listening session of a few minutes to each presentation. Responses might include: sounds heard; desirability/undesirability of each identified sound; and tranquility ratings (for possible comparison with Pheasant [16,21]). Because the initial tests are exploratory, the questions should probably be few and brief. Study design would be to achieve several specific purposes.

6.2. Initial Laboratory Study Purposes

6.2.1. Develop General Guidance on Hierarchies of Desirability

By selecting several ambient soundscapes and several specific sources, hierarchies of desirability could be developed, similar to those shown in Figure 1. Videos would be made of locations that are consistent with the ambients, and recordings of individual sources mixed with each ambient, either singly or in groups. Outcomes would suggest, for example, the relative desirability/undesirability of different transportation modes: nearby freeway traffic, distant freeway traffic; helicopter overflights, propeller overflights; interactions of these types of transportation modes. City sounds could be constructed using ambient distant non-specific sounds, generally of traffic, bird song, distant freeway, nearby arterial, *etc.* Indoor soundscapes could similarly be constructed, some with lively reverberation, others with sound absorption.

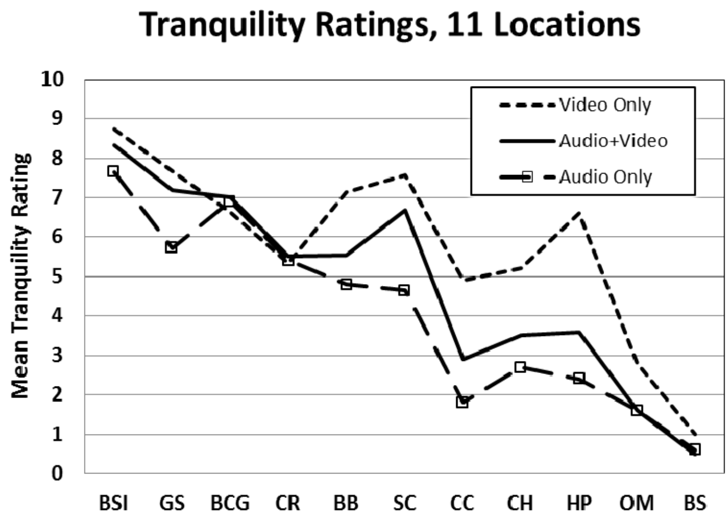
6.2.2. Examine Interaction of Visual with Audible

Previous research has demonstrated an interaction between the scene and the sound [4,7,16–25]. The evaluation of tranquility quantified the importance of the interaction between the visual and the soundscape. In Pheasant [21], a combined field and laboratory test of subjects' judgments of tranquility revealed how a soundscape can alter the perception of a scene. Pheasant [21] used two studies to explore subjective tranquility ratings. A first study had 102 subjects rate 100 photographs from most tranquil appearing to least tranquil, where tranquil meant to them "a quiet peaceful place, a good place to get away from the demands of everyday life." (A detailed description is found in Pheasant [16]).

Using the photo location rated the most tranquil and every tenth photo, simultaneous videos and binaural recordings were made at the eleven sites. Forty-four subjects then viewed and rated for "tranquility", using the same definition as used for rating the photographs. Figure 3 plots the results of tranquility ratings of eleven scenes made by the 44 subjects in the laboratory. Subjects were presented sequentially with audio only, video only and combined audio-video. The videos and associated binaural recordings were made on-location. Clearly, the tranquility of the entire scene depends on the combined effects of the audible and the visual.

Multiple scenes could be tested with single soundscapes. For example, the state of maintenance or cleanliness has been found to influence reactions to soundscapes. While exploring the concept that aesthetically pleasing streets would lower people's annoyance with road traffic noise, Fyhri [26] discovered that most people associated a "beautiful street" with aspects of upkeep or maintenance. Had the grass been cut, was there paper or other litter on lawns, were road surfaces in good condition or full of holes? Further, annoyance with road traffic noise and the "beauty" of the street were negatively correlated. The difference in annoyance between those living on the prettiest street and the ugliest street amounted to a perceived difference in sound level of approximately 6 dB.

Figure 3. Comparison of subjects' ratings of tranquility (10 most tranquil) of Eleven Locations/Scenes from Pheasant, 2008.



6.2.3. Explore Interactions of Noise Sources

Krog [27] found that significantly lowering the sound of one annoying source can lower annoyance with other sources. Laboratory studies could explore, for example, how lowering a significant source of roadway noise (with quiet pavement and/or noise barrier) affects the desirability/undesirability of aircraft flyover noise.

6.2.4. Demonstrate Relationship of Laboratory Results and *In Situ* Results

Several *in situ* locations with a single or perhaps two dominant sources would be identified. The sources would be dominant in the sense that they could be easily quantified acoustically, and possibly recorded separately. For such locations, a mail survey could be designed to collect residents' evaluations of the sounds, and the settings could be duplicated in the laboratory. Design of the laboratory and field study would need to include consideration of the time frame the residents would be asked to evaluate. For example, heavily travelled freeways have a predictable diurnal pattern of noise. Residents could be asked to judge the sound they hear in the early evening, and this time frame could be measured, and the same soundscape could be reasonably duplicated in the laboratory. Residents could be brought to the laboratory (or the laboratory to them) to determine how well *in situ* and laboratory results correlate [28].

7. A Simulated Case Study

To any who have spent time in Boston's Norman B. Leventhal Park, popularly known as Post Office Square, it is immediately obvious that, despite the significant levels of city street noise, the park is an urban setting where people come to relax and refresh, Figure 4 (It is described in reference [29]). The success in terms of soundscape is apparent, and yet whether any real "soundscape design" was part of the planning is unknown. For the sake of illustration, consider how soundscape design might have been implemented using a laboratory setting.

Figure 4. Norman B. Leventhal Park, Boston.

The first step would have been to make binaural or ambisonic recordings of the existing soundscape in several locations, with locations carefully documented. If possible, recordings of impulse sounds (commonly a balloon burst) would also be made for analysis of reverberation or echoes. Then, renderings of proposed park designs, or better, three dimensional virtual reality presentations would be made and associated for presentation in the laboratory with the recordings. Park features—sounds produced by different types of fountains—would also be blended into the virtual reality so that stake-holders could experience and judge the acceptability/desirability. The effects of any walls or barriers would be included. The soundscape would be developed for different positions in the proposed park.

Alternatively, suppose once the park is constructed, street sounds are too loud. The virtual reality laboratory approach could be used to examine whether additional barriers in the form of walls, berms or structures could be effective in providing adequate reductions.

Creation of a virtual reality for laboratory presentation is no doubt a complex process, but likely no more so than developing the layout of the park, path locations, vegetation and structures, specifying materials, construction schedules, *etc.* The technology exists to create virtual soundscapes that can be associated with virtual cityscapes, landscapes and architectural spaces to permit judgments of desirability, preferably by those people who will experience them. In judging the virtual realities of various alternatives, it might be useful to go beyond basic undesirable/desirable measure and consider the issues that make one alternative more or less desirable than others, e.g., appropriateness, meaning, *etc.* Such detailed assessments should, however, be approached with caution by considering how much alteration of the soundscape is really possible and generally how much value to design do additional judgment categories add.

The simplifying use of "annoyance" mentioned in Section 3 provides a caution. That approach was proposed in 1978 [10] and has been broadly used by transportation agencies to justify setting noise and land use compatibility guidance [30–33]. The approach endured considerable criticism (see Section 4.2 of [34]) but over the 30 plus years since its publication, using the "annoyance" concept as a basis has provided an orderly consideration of noise and its reduction when possible. Use of annoyance is admittedly somewhat imprecise, but it has enabled enormous progress in limiting noise based on fundamental reactions of people and communities.

The approach offered here is intended to raise questions, but provide an operational method for advancing the design or improvement of soundscapes. If this approach were to be used, experience would certainly modify and improve it. But the goal is to avoid waiting for a complete understanding of human judgments of soundscapes, and to begin the process of taking action.

8. Conclusions

How people evaluate soundscapes has been proven to be a complex phenomenon to analyze, and improvement of soundscapes a difficult task to rationalize. We assume that the goal to improve soundscapes will be increasingly desirable to the extent that serious efforts are made to develop sustainable, pleasing environments. Accordingly, this paper suggests an initial laboratory approach that simplifies the soundscape analysis sufficiently to make real progress on a pragmatic approach to that goal. The approach prioritizes the sounds heard with undesirable/desirable judgments and permits identification of which sources should be addressed with traditional noise control methods.

Referenced research has validated the laboratory approach offered here. Notably, previous work has identified the inseparable nature of the visual and the audible and hence, the importance of constructing the laboratory settings to include, as realistically as technology will allow, the combination of the visual and the audible. The goal of creating, restoring and preserving desirable soundscapes represents new challenges in using audio and video recording and virtual reality technologies to satisfy human preferences. The decades of experience developing methods in service of "noise control" can aid in ultimately making the technical serve the aesthetic.

Though previous research has addressed both subjective and objective measures of soundscapes, generally it has focused on the complete soundscape and not simultaneously on the subjective combined with the objective applied to the *individual contributors* to the soundscape. The approach described here is intended to examine all three aspects, and provide sufficient quantitative information that traditional noise control methods and tools for acoustical analysis can be applied to individual sources with the goal of constructing, improving and preserving quality soundscapes.

Acknowledgments

The concepts presented here obviously owe their origins to the many authors and researchers listed in the references, many of whom I know personally. Additionally, there are the almost 40 years of consulting with compatriots at Bolt Beranek & Newman, Inc., Harris Miller Miller & Hanson Inc., and our many clients and co-workers in the field of noise control that have contributed to my thought processes.

Conflicts of Interest

The author declares no conflict of interest.

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