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Relevance and applicability of the Soundscape concept to physiological or behavioral effects caused by noise at very low frequencies which may not be audible

Wade Bray
HEAD acoustics, Inc.
6964 Kensington Road
Brighton, MI 48116
wbray@headacoustics.com

A central tenet of the Soundscape concept is that humans immersed in sonic environments are objective measuring instruments (New Experts), whose reports and descriptions must be taken seriously and quantified by technical measurements. A topic category in acoustics meetings of recent years is "Perception and Effects of Noise." There is growing evidence from the field, and from medical research, that the ear's two-part transducer activity involving inner hair cells (IHC, hearing, velocity-sensitive) and outer hair cells (OHC, displacement-sensitive) may, through demonstrated OHC activation and neural signals at up to 40 dB below the audibility threshold, produce behavioral and physiological effects as reported by a growing number of people. The Soundscape concept centering on human responses, New Experts, is as important and applicable to responses to effects from sound as it is to responses to directly audible sound. In a wider sense, this is a new sound quality and psychoacoustic issue.

Introduction

Soundscaping integrates two relationships of sound and people: that people are the ultimate analysts or data sources about their responses to sound because it is they who are immersed in it or make it, and that sounds (receptions by people) are always part of human contexts; panoramas involving other senses, the environments in which people live or work, and the people's cognitive as well as sensory circumstances.

Sound elements causing negative responses or effects can be meaningfully defined and mitigated by triangulating or associating technical measurements with human reports. In this way, conversely, soundscapes with their elements can also be designed and optimized. The human receiver with its high simultaneous sensory sensitivities in level, time, frequency and pattern [1], an active receiver/participant with mind, attention process (even unbidden) and lifestyle, is at the center. The soundscape concept, only relatively recently recognized for its absolute validity, focuses why the science of acoustics is practiced. Sounds must be "taken out from under the microphone" where they have historically been studied in isolation, and put into the "big and anthropocentric sound field" – the soundscape.

Soundscaping and sound quality engineering, another discipline which also considers human receivers, are merging. The main consideration of both has been responses and attitudes toward audible sounds. Sound quality engineering has provided technical tools important to soundscaping (for example, psychoacoustic measures).

It is appropriate and timely to include in the soundscaping sphere human physiological or behavioral effects reported from subliminally heard or even inaudible sound. If a person reports a bad or inappropriate sound or effect from sound, that is an objective measurement and must be taken seriously with triangulation to technical data.

Data from New Experts, and effects from largely unheard soundscapes

At present a growing number of people are reporting sleep deprivation, unease and even illness which they most often ascribe to low-frequency sound either near the hearing threshold or, more frequently, sub-audible [2]. Such reports are most frequent in rural or quiet suburban areas following the installation of large wind turbines, a new sound source without historic acoustic reference.

Recent writings and studies by a variety of authors contribute perspectives into the soundscape and New Expert concept. Genuit and Fiebig [3] write, "Moreover, as 'soundscape' considers human perception including cognitive aspects, it goes beyond physics and psychoacoustics." Case [4] describes, "A receiver's assessment of the quality of any single element of a soundscape is not limited to the objective values of sound attributes at the receiver location, but includes an intuitive or instinctive compensation for the source-to-receiver path." Schulte-Fortkamp and Voigt [5] write, "The focus of each research varies from perception of places to questions of the overall feeling of safety at the different locations." Ambrose and Rand, describing measurements they made inside a residence near two large wind turbines [6] state, "The best acoustic analyzer for determining human response is the human listening. This research shows it is not appropriate to use unattended sound measurement instruments."

Good soundscape situations typically involve harmonious multisensory information (not only hearing, but also vision and other senses) reinforcing an appropriate, non-disruptive whole. Individual senses in normal situations receive reasonably balanced signals, for example with two eyes open not seeing a scene with one eye and darkness or blurring with the other, or with low-frequency hearing (where sound wavelengths are much larger than the size of the head) not experiencing significantly different sound levels or phase relationships at each ear. Abnormal situations with individual senses or disagreements among multiple senses can introduce imbalances, only revealed through the "human analyzer" whose active receiver responds unfavorably. Hearing or physiologically detecting low frequencies in the absence of other sound is another imbalanced circumstance.

It is the author's view that if multisensory and/or contextual information imbalances or disjoins the mind's harmonizing of senses either consciously or unconsciously, the mental construct of comfort and safety can be weakened or destroyed ultimately leading to conscious distress. For example people entering their homes "know" and expect their personal safe space with the outside world excluded. Very low frequency or infrasonic sound inside a residence, whether directly audible or unheard yet activating the physiology, is intuitively or instinctively “a violation of the sanctity and safety of my home.” Except for the ears’ reception (always functioning), the mind knows, “I am home, safe, isolated from outside in my own space.” But via the ears the physiology, even below audition [7] can signal, “But I am still outside, vulnerable; I cannot escape.”

In the human receiver’s processing of information from sound, its context and connotation are important and linked. Very low frequency sound can connote something large and foreboding impending, not explained or revealed by other simultaneous senses. The first sensation or alerting of the approach of a distant thunderstorm is a case in point, cited by the residents of a dwelling near a large wind turbine where the author acquired acoustic data as similar to some of the conscious effects they experience due to the turbine [8; private communication with residents of property where data were taken].

The ear is known to be a complex receiver not only containing a unique transducer with the frequency-to-place transform within a fluid medium, but also having two different sets of hair cells (inner and outer) and two different sets of afferent nerves delivering signals to the brain [7 op. cit.]. The inner hair cells (IHC), connected to the auditory cortex by Type I afferent nerves, provide the sense of hearing. The ends of their cilia are not attached to the overlying tectorial membrane so, viscous-coupled (AC-coupled) and driven only by relative liquid motion, they are velocity-sensitive and respond less and less to lower and lower frequencies. The outer hair cells (OHC) on the other hand, connected by Type II afferent nerves, have their cilia ends attached to the tectorial membrane and hence are displacement-sensitive, also shown to be DC-coupled [7, 9]. It has been shown that the neural signal known as the cochlear microphonic is present in the Type II afferent nerves and delivered to a location on the auditory cortex due to low-frequency sounds up to 40 dB below the threshold of hearing of the IHCs. This pathway also is involved in alerting [7 op. cit.], a function not associated with the hearing cells and active at levels below auditory threshold.

The OHCs near the apex (helicotrema), the distal end of the cochlea sensitive to the low frequencies, are stimulated more intensely by low-frequency sounds than previously understood. A low-frequency-predominant sound of 40 dB(A) indeed activates the ear. Salt and Lichtenhan [7 op. cit.] have found the largest electrical response from the low-frequency (apical) region of the cochlea to occur when very low frequency sound dominates the stimulus and mid-frequency components (200-2000 Hz) are absent. Such situations exist in the extremely steep rates of level rise toward low frequencies in wind turbine signals [8 op. cit.], rates further steepened by the low-pass filter effect of residences or buildings strongly attenuating mid and high frequency sounds within but passing largely unchanged, or even amplifying through resonance, the lowest frequencies. As Ambrose and Rand state [6 op. cit.] “The dB(A) measurement does not correlate directly to complaints; health symptoms were stronger indoors where dB(A) levels were significantly lower.”

Salt’s research concludes that low frequency sounds not perceived as hearing events are clearly transduced by the ear, activating the physiology, and may affect people in ways that have yet to be fully understood.

Krahé’s work [10] corroborates these medical findings, describing for audible situations higher annoyance reported by test subjects due to sharp-cutoff (toward higher frequencies) low-frequency noise.

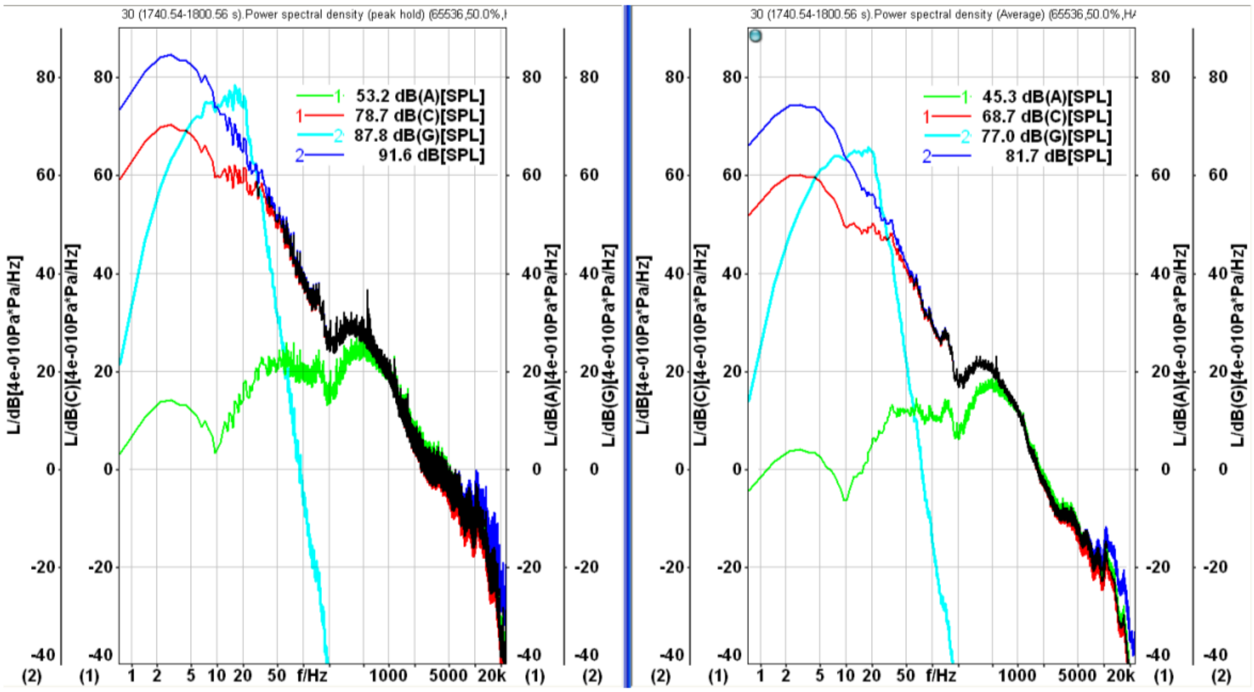

Figure 1. *Spectral measurements from one minute of wind turbine noise outside a rural residence, power spectral density: peak hold (left), average (right). Unweighted (dark blue), G-weighted (“infrasound weighting”, light blue), C-weighted (red), A-weighted (green). Crest factors range from 7.9 to 10.8 dB; the unweighted average slope between 5 Hz and 100 Hz is about 10 dB/octave over more than four octaves [8 op. cit.].*

Time structure, crest factor, and measurement criteria

Human sensory reception, particularly vision and hearing, is sensitive to and derives information from our environment and one another on a micro-time scale. Many acoustical measurements are averaged over much longer intervals, in effect on a macro-time scale. The micro-time structure often dominates in information content and tends to command perception. It is inappropriate to present only macro-time (long term averaged) results as representative of sensation, especially without triangulation to New Expert reports. Many low-frequency sounds have rapid (and varying) time structure, with high crest factors causing peak levels to exceed, sometimes considerably, longer-term average values. High momentary or transient levels can increase perceived loudness [2] and “pattern” impression [1 op. cit.], and can bring peaks above the audibility threshold in situations where average values from conventional results indicate below-threshold. At frequencies below 100 Hz, the human ear has a surprisingly short time response of less than 10 milliseconds [8 op. cit.].

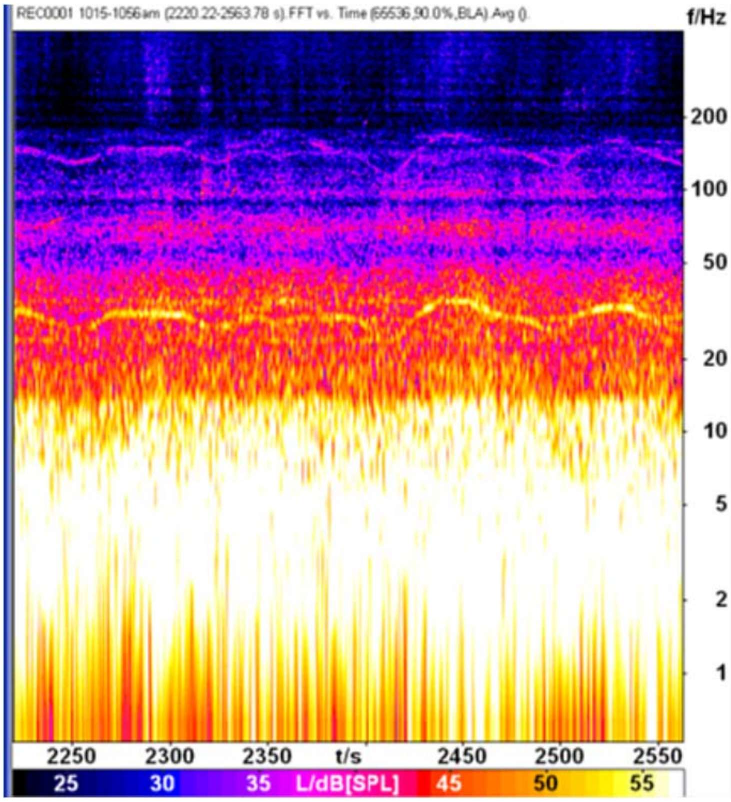

Figure 2. *An unprecedented sound source and character (same location as previous figure, different time of day), a spectrum versus time: at certain times, narrowband structures (modulated at blade-pass rate; level variation approximately 20 dB) were observed, not harmonically related though following near-parallel "trajectories" in frequency. Their frequency, and the lower ones' strength, increase with infrasound strength. FFT vs. time; Δf 0.73 Hz, Δt 1.37 sec: 343 seconds circa 10:30 AM, spectrum vs. time. Note the sharp and uniform level discontinuity at approximately 14 Hz, evident at various times for long durations and during which the tone-like structures appeared. The strongest signals are "overexposed" in this graph (true levels are significantly higher) to clarify the 14 Hz spectral shelving and the tone-like structures.*

Discussion

There are presently challenges on the technical measurement side of a soundscaping approach to issues such as we are discussing from low and very low frequency sound. There is relatively little extant research in low-frequency perception and other activation; more is needed. Current psychoacoustic measures respond differently in magnitude and time at these frequencies depending on the standard used [11]).

Not all people report responses or distresses from situations as described in this paper while others do with sensitization times ranging from hours to months. The sensitization time scale of ultimately-affected people makes short-term tests of audibility or of other response potentially invalid for people not hitherto exposed, although for people with developed sensitization, such tests may be suitable.

Also, due to the rapid time structure of low and very low frequency sounds from sources such as wind turbines and the very short impulse response of the ear at these frequencies [8 op. cit., 11 op. cit.], reproducing the sounds correctly for test subjects requires special equipment.

Binaural acquisition, measurement and presentation to test subjects in this case, as in Soundscaping generally, is the best procedure for acoustic acquisition and reproduction for the main reason that the entire spatial context, loudness as a function of apparent source size, and any response of the two-eared human hearing receiver is able to operate normally. There is a side benefit with very low frequency measurements outdoors. With the two microphones, it is easy to perform an interaural correlation test to determine if local wind has produced pseudo-noise interfering with actual environmental noise. If low and very low frequencies are highly interaurally coherent, wind noise pollution at the microphones may be ruled out.

Conclusions

A soundscape situation is clearly emerging where New Experts are reporting perceptions and, even more, effects from sound in their life contexts. Even if not perceived as sound, these stimuli often ultimately emerge indirectly through the physiology into the active consciousness. There are technical challenges from the newness and uniqueness of the sources and their emissions on the one hand and the relative lack of precedent and insufficiency of technical acoustic research data on the other hand. The best, most appropriate and potentially fruitful approach is certainly the soundscaping process, centered on exposed people and triangulating with both carefully-selected conventional technical methods and updates of acoustic-sensory analysis models based on known time and frequency sensitivities of the ear/brain receiver. The soundscaping concept is essential in order to recognize, respect, coordinate, validate and resolve how low and very low frequency effects as well as perceived sounds from new technical sources in the environment can lead to better circumstances.

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References

1. Genuit, Klaus; *A New Approach to Objective Determination of Noise Quality Based on Relative Parameters* (Proc. InterNoise 1996, Liverpool, U.K.)

2. Hsuan-hsiu Annie Chen and Peter Narins; *Wind Turbines and Ghost Stories: The Effects of Infrasound on the Human Auditory System* (Acoustics Today, Acoustical Society of America; **8**, 51 (2012))

3. Genuit, Klaus and André Fiebig; *Relationship between environmental noise, sound quality, soundscape* (Acoustical Society of America 164th Meeting, Kansas City MO October 2012, 2aNS2)

4. Case, Alex; *I hear what you mean – source intensity versus receiver level* (Acoustical Society of America 164th Meeting, Kansas City MO October 2012, 2aNS5)

5. Schulte-Fortkamp, Brigitte and Kay Voigt; *Soundwalks in urban areas – Triangulation of perceptive and acoustical data* (Acoustical Society of America 164th Meeting, Kansas City MO October 2012, 2aNS7)

6. Ambrose, Stephen and Robert W. Rand, *Falmouth, Massachusetts wind turbine infrasound and low frequency noise measurements* (InterNoise 2012, New York City, August 2012, IN12_325)

7. Salt, Alec N. and Jeffrey T. Lichtenhan; *Perception-based protection from low-frequency sounds may not be enough* (InterNoise 2012, New York City, August 2012, IN12_602)

8. Bray, Wade R. and Richard R. James; *Dynamic measurements of wind turbine acoustic signals, employing sound quality engineering methods considering the time and frequency sensitivities of human perception* (NoiseCon 2011, Portland, Oregon, NC11_61)

9. Békésy, Georg von; *Experiments in Hearing* (McGraw-Hill, New York (1960))

10. Krahé, Detlef; *What makes low-frequency noise annoying?* (InterNoise 2012, New York City, August 2012, IN12_1432)

11. Sottek, Roland, Fabian Kamp, André Fiebig; *Perception of loudness and roughness of low-frequency sounds* (InterNoise 2012, New York City, August 2012, IN12_737)