If a tree falls in a forest, can you hear it?

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Anthropogenic noise, from slowly rotating/reciprocating machinery, contributes immensely to environmental low-frequency noise below 100Hz. This poses an acoustic low-energy problem as our technology offers no effective passive method for remediation. While attention is given to negative impact on human health and ecosystems, we still know and publicly do too little about it. Technical standards in Europe are A-weighted measurements that disregard actual energetic contributions of low frequencies. Different aspects of low-frequency sound have been illuminated by complementing acoustic measurements with findings from technical acoustics, bioacoustics and human medical science. Sound pressure levels (SPL) were measured from 2.5Hz to 20kHz. The measurement setup consisted of SINUS Soundbook quadro (2.3Hz - 22kHz; linear@0dB; ±0.1dB tolerance; 1Hz high-pass enabled), 1/2-inch Preamplifier/Free-Field Microphone (3.15Hz - 20kHz: ±2.0dB; 5Hz - 10kHz: ±1.0dB). Signals were processed with SINUS Driver version 5.1.0.8 and Samurai version 2.0.134. SPL in quiet forest [during 60s: LZ,eq = 49.4dB; LA,eq = 28.7dB(A)] were compared to a quiet university room [during 60s: LZ,eq = 74.4dB; LA,eq = 28.2dB(A)]. Healing properties of felid purrs produced with strong frequencies at an SPL between 30-60dB suggest a general correlation of low-frequency background noise levels and health. Perhaps nature knows better than we do.
INTRODUCTION

Paracelsus was convinced that "he who heals is right". A natural environment – untouched by anthropogenic impact of any kind – presents a well-balanced system that provides optimal living conditions for species adapted to it. The author assumes that natural soundscapes likewise provide an acoustic environment, which is beneficial for the species inhabiting it. Therefore, this work turns towards nature as a guide in order to find evidence, in what ways the acoustic spectrum of a natural soundscape differs from a cultural one created by man. The interesting question is, if certain characteristics exist that define a "healthy" soundscape?

Effects, which are known to come along with the presence of higher levels of low-frequency noise, are no normality in nature and only occur temporarily. During natural disasters, many animals instinctively react to deviations from the normal low-frequency spectrum with fight & flight-behavior; this was observed in connection with earthquakes (Tributsch, 1984) and more recently during the tsunami events in the Indian ocean in 2004 (Traufetter, 2005; Mott, 2005). The adaptation of species to their natural environment therefore suggests that the predominant natural sound spectrum provides optimal conditions for living, as hearing is essential for survival. Predominant background noise in nature is assumed to assist survival and not to reduce its probability by decreasing health. This must also be true for humans, as actually we are part of a natural soundscape, and as such – during our own evolution – adapted to the spectrum nature provided us. It seems likely that we need a certain composition and quality of sounds in our environment to be healthy.

In modern societies however, we generate considerable amounts of noise, exposing ourselves and other species to sound with significant energy in the low-frequency region < 100-200 Hz (Pedersen, 2008; Malsch et al., 2007). Main sources of anthropogenic noise in this range are slowly rotating and reciprocating machinery such as combustion engines and slow-speed fans (Leventhall et al., 2003).

Studies have shown that low-frequency noise at audible levels, and levels close to the hearing threshold, can cause different adverse psychological, and aural as well as extra-aural physiological effects. These are for example annoyance, different unspecific stress reactions, temporary and permanent threshold shifts, sleep deprivation, change of breath and pulse frequency as well as reduced mental performance (Gono, 1978; Leventhall et al., 2003; Stepanov et al., 2003; Borgmann, 2005; Schust, 2004). As the low-frequency spectrum coincides with many bio-mechanical resonance frequencies, the external stimulation through environmental noise is also recognized as cause for adverse resonance effects (Malsch et al., 2007).

So far, attention is mostly given to the impact of audible low-frequency noise. But why is subliminal low-frequency noise disregarded in many studies, despite the fact that there is a lot of it around? Leventhall (2007) reported, evidence is that the ear is the most sensitive receptor for low-frequency sound including infrasound, and if the ear was not able to perceive it, it could not be perceived in other ways and it does not affect us. However, particularly in the frequency region of so-called infrasound (< 16-20 Hz) the human hearing threshold rises quickly with decreasing frequency, and with it the imparted sound energy that interacts with an organisms' physiology: At 50 Hz we perceive sounds at around 44 dB, at 20 Hz sound already need to be at levels of 79 dB, and to detect a 4 Hz infrasound the human threshold is at about 107 dB (Leventhall, 2007).

Standard in Europe are A-weighted measurements, which practically disregard low-frequencies in and just above the infrasonic region (Genuit, 2007). Although A-weighting is only really valid for relatively quiet sounds and pure tones, since it is based on the 40-phon Fletcher-Munson curve which is now found in standardized equal loudness curves of ISO 226:2003, it is also applied for all kinds of loud noise emissions in Europe.

This study hypothesizes that the degree of presence of low-frequency background noise in an environment accounts for a big part of the health- and performance-related quality of this respective soundscape. The author is not aware that research has been done on the direct comparison between natural and cultural soundscapes. This work with therefore focus on the comparison of both.
EXPERIMENTAL METHOD

Locations

In and around the city of Villach in Carinthia (Austria) background sound pressure levels were assessed for the 1/3-octave bands in the frequency range from 2.5 Hz - 20 kHz (re. 20 µPa).

Measurements were conducted on August 28, 2012 between 09:00h and 14:30h and on August 30, 2012 between 10:00h and 11:40h at the following locations:

- 'Innerteuchen' (forest): N 46° 43.950'; E 013° 56.785' (± 6 m). See Fig. 1(a)
- 'TPV T01 HS04' (university lecture room): Technologiepark Villach, building T01, Hörsaal 4 (E.04). See Fig. 1(b).

Noticeable noise source during measurement in 'Innerteuchen' was a small stream at about 100 m distance. Noticeable noise sources in 'TPV T01 HS04' were closing doors in the foyer outside the lecture room.

![Figure 1](image1.png)

**FIGURE 1.** Measurement setup and location in (a) forest environment, (b) university lecture room.

Equipment

Measurement hardware consisted of SINUS Soundbook quadro (SINUS Messtechnik GmbH; range: 2.3 Hz - 22 kHz; linear @ 0 dB with ± 0.1 dB tolerance; 1 Hz HighPass enabled), 1/2-inch free-field microphone (type 40AF, G.R.A.S. Sound & Vibration; frequency response: 3.15 Hz - 20 kHz: ± 2.0 dB; 5 Hz - 10 kHz: ± 1.0 dB) and 1/2-inch preamplifier (type 26AK, G.R.A.S. Sound & Vibration). A sound level calibrator was used (type 4230, Brüel & Kjaer; 93.8 dB @ 1 kHz). The signal processing was carried out with the software SINUS Driver version 5.1.0.8 and Samurai version 2.0.134. The software allows for graphical display of the sound pressure level signal in the time- and frequency-domain, and saving of measured data in the proprietary file format. Samples were taken every 100 milliseconds. For evaluation and graphical post-processing, the data was transferred to the software package Noise and Vibration Works (NWW).
Recording Protocol

At each location, preamplifier and microphone were mounted on a vertically extendible tripod and adjusted to the desired height (outdoors: 4 m, indoors: 2.5 m). During measurements, the Soundbook was mounted on a tripod for better operation. The measurement setup was calibrated prior to and inspected again after each measurement. All measurements were performed with a windscreen imposed on the microphone to block out sound pressure fluctuations due to direct wind on the diaphragm. SPL were measured in FAST-mode. Measurement durations were 60 seconds for both locations.

Analysis

From the assessed data available the following SPL were analyzed:

- Un-weighted SPL (LZF)
- Un-weighted equivalent SPL (LZ,eq)
- C-weighted SPL (LCF)
- C-weighted equivalent SPL (LC,eq)
- A-weighted SPL (LAF)
- A-weighted equivalent SPL (LA,eq)

RESULTS

Upon listening on-site, both locations could be described as "quiet". SPL plots in Figs. 2 and 3 show the development of LZF (black curve), LCF (blue curve), LAF (green curve) and LA,eq (orange curve) over the time. For the duration of measurement LA,eq shows 28.7 dB(A) for the forest and 28.2 dB(A) for the lecture room. More pronounced differences between both locations become evident when looking at the C-weighted level plots. In the forest, LCF fluctuates between 30 and 40 dB(C) while in the university lecture room the level fluctuates between 40 and 60 dB(C); two peaks in LAF of Fig. 3 after time-mark 12:13:38 and 12:13:53 coincide with the banging of doors in the foyer outside the room. The differences between both locations show up even stronger in the un-weighted values of LZF; SPL in the forest fluctuate between 40 and 60 dB while the university room exhibits fluctuations in SPL between just below 60 and approximately 85 dB, with peaks following the event of the banging doors. Although both locations show only little fluctuation in the A-weighted levels, un-weighted levels vary erratically.

FIGURE 2. SPL plots for 'Innerteuchen' (forest).
FIGURE 3. SPL plots for 'TPV T01 HS04' (university lecture room).

FIGURE 4. Histograms for (a) forest and (b) university lecture room.
Fig. 4 shows histograms of the regarded locations. The left column of diagrams in Fig. 4(a) gives (from top to bottom) the equivalent un-weighted, C-weighted and A-weighted levels. Fig. 4(b) shows the respective measurement results for the university lecture room. $L_{C,eq}$ of the forest results in a value of 34.9 dB(C), and for the university of 49.8 dB(C). $L_{Z,eq}$ for the forest is 49.4 dB and for the university it shows 74.4 dB. Comparing the histograms of both locations, the higher levels of low-frequency sound pressure in the university room is obvious. Although A-weighted levels differ only by 0.5 dB, the difference of un-weighted levels between the university and the forest sums up to 25 dB. The un-weighted measurements for the forest reveal that equivalent levels do not exceed 34.3 dB in any 1/3-octave band, with the 2.5 Hz band exhibiting the highest level. Slight but not very pronounced peaks can be seen at 16 Hz (28.8 dB) and 100 Hz (25.1 dB). The university room on the contrary shows clear peaks around 2.5 Hz (58.6 dB), 25 Hz (51.2 dB) and 200 Hz (31.7 dB). Referring to DIN 45680, the difference between $L_{C,eq}$ and $L_{A,eq}$ for the forest is 6.2 dB. In the university room this difference sums up to 21.6 dB. This fulfills the condition of DIN 45680 to investigate further into potentially harmful environmental impact due to low-frequency noise.

Spectrograms in Figs. 5 (forest) and 6 (university) show the distribution and course of un-weighted SPL in the measured frequency bands from 2.5 Hz to 20 kHz over the time. The colored SPL axis on the right maps the gradient from 0 dB (black) over 40 dB (green) to 80 dB (red).

**FIGURE 5.** Spectrogram for 'Innerteuchen' (forest).

Fig. 5 displays a rather heterogeneous distribution of SPL with increased values towards the lower end of the measured spectrum between 2.5 and 4 Hz. The spectral pattern appears irregular with no clearly visible static sound sources; these would show up as horizontal stripes in the measurement. Above 250 Hz, levels drop below 20 dB.

**FIGURE 6.** Spectrogram for 'TPV T01 HS04' (university lecture room).
Fig. 6 shows a well defined distribution of sound pressure levels in the different frequency bands over time in the lecture room, exhibiting roughly three segments; 2-31.5 Hz, 31.5-500 Hz and 500 Hz-20 kHz. The highest sound pressure levels are found in the first segment, especially in the lowest frequency bands between 2.5 and 8 Hz. The first segment additionally presents an area of reduced SPL between 8 and 16 Hz, showing values around 30 dB. Horizontal lines in the spectrogram suggest the presence of permanent noise sources that were not clearly distinguishable by simple listening. Above 500 Hz, SPL levels drop below 20 dB.

**DISCUSSION**

Measurement results of the quiet forest revealed that middle-range frequencies are present at levels below 20 dB SPL and high-range frequencies above 4 kHz even below 10 dB SPL; in other natural environments, this well audible range however might already be influenced by a louder stream or vocalizing animals. The findings generally confirm the presence of low-frequency background noise in a natural environment. Levels do not exceed 30-35 dB SPL and thus can describe as low-level low-frequency sound. SPL below 100 Hz appear heterogeneous over time, showing no specially defined sound sources and no striking peaks on certain frequencies. Spectrograms appear relatively blurred and irregular, with a stronger emphasized towards very-low low-frequency sounds between 2-4 Hz. Compared to the university room, low-frequency SPL were considerably lower.

In case of our two locations, the middle- and high-range frequencies were at low levels so that pronounced differences between the natural and cultural soundscape are found in the low-frequency range alone.

In nature, low-frequency sound serves as a means of communication in a wider sense: Different animal species that inhabit densely vegetated environments with reduced eye-sight or which live as individuals or in groups that are far from each other, intentionally apply low-frequency and infrasonic calls to communicate with conspecifics. Examples are cassowaries (Mack and Jones, 2003), tigers (Von Muggenthaler, 2000), elephants (McComb, 2003) and baleen whales (Au et al., 2001). If produced by natural disasters, loud levels of low-frequency function as passive warning signal for species sensitive to it. This sensitivity can cause fight & flight-reactions and save animals' lives. Since humans from modern societies once also inhabited natural environments, they must have possessed this clear reaction to loud low-frequency sounds that stimulated readiness for survival-securing actions. Sapozhnikova and Taymanov (2008) report that low-frequency and infrasonic oscillations define an elementary emotional response; "the same response – emotional stress preparing a subsequent action – has multiple meaning and comes before fear, aggression, or happiness depending on additional previous or expected information". The modern human however widely lost this sensitivity and in modern cultural environments our inherited behavior often cannot recognize the imminent threat that should follow high levels of low-frequency noise. The emotional stress response, that once prepared us to take flight secured survival, cannot be lived out, and thus builds up. This might be a reason for many cases of noise-induced stress in today's societies. Results of this unhealthy soundscape we live in can be seen in the DALYs-calculation (disability-adjusted life years) of a recent study by the World Health Organization (2011). Some animals, like tigers, exploit this stress response, that can even paralyze a biological system, by intentionally generating low-frequency roars at levels between 120-130 dB SPL in order to catch prey (Muggenthaler, 2012).

A clear distinction must be made though between the states of aggregation of the sound propagating medium. The meaning of sound, as used before, refers to airborne sound. For most cases, evidence is that audibility of low-frequency sound is a necessary precondition in order to create any effect, as it is reported that the ear is the most sensitive receptor for airborne sound (Leventhall, 2007). Low-frequency airborne sound below the hearing threshold therefore might not have any effect on us. Since audible low-frequency sounds need higher levels to be audible for human hearing, effects generally tend to be adverse, as air-spaces in the body start vibrating. Some people nevertheless developed extended sensitivity for very-low low-frequency pressure changes and are able to feel meteorological events in their body, even if they cannot hear them; an ability which is similarly reported for elephants that are said to be the first animals walking towards rain-fronts even if these are still days away. Anecdotal evidence for humans is that meteorosensitivity tends to decrease the wellbeing of the respective person; an example of this is foehn-sickness (Forcher-Mayr, 1956).

It is different though when we talk about vibrations, in which solid structures directly stimulate the body. Compared to airborne "vibrations", solid vibrations transfer more energy to the target as the energy density of the structure is higher. It seems, effect ranges can be distinguished more clearly here. Accelerometer-based research on the cat purr revealed that different felid species produce low-frequency inner-body vibrations at levels between 30-60 dB, which assist physiological and psychological self-healing. The found sound levels are similar to externally applied bio-stimulation used in vibration therapy (Von Muggenthaler, 2006; Lundeberg, 1983). From this it can be taken that low-frequency vibrations with levels below approximately 40 dB at the right frequency have the potential
to heal, while higher levels at the same frequencies can cause damage. Depending on the frequency of the vibration, different parts of the body are addressed in resonance.

A last connection to medical science and natural processes can be drawn referring to Fig. 5, showing an irregular distribution of sound pressure levels in the forest. All the time, our body is subject to external low-frequency sound and vibrational stimuli from different sources. At the same time, our body produces vibrations itself, for example through breathing, walking, singing or our own heat-beat. In the book Mai Ching / The Knowledge of Pulse Diagnosis, which was published by the famous Chinese physician Wang Shu-he in the 3rd century, the relation between pulse and disease is described. It is written here that if the heart beats regularly, it is a sign that the patient will die within four days. Modern researchers rediscovered this general concept and called it heart-rate variability. Goldberger et al. (1990) write “[…] have discovered that the heart and other physiological systems may behave most erratically when they are young and healthy. Counterintuitively, increasingly regular behavior sometimes accompanies aging and disease.”

A healthy soundscape might therefore show similar irregularities, which come from the interaction of changes that happen in nature at the same time, such as temperature changes, sunlight, wind, running water or swaying trees, which all create slight pressure changes leading to low-frequency background noise. These chaotically interacting factors are often missing in cultural soundscapes. Low-frequency pressure changes that are loud and acoustically monotone, as seen in Fig. 6, could be characteristic for an unhealthy soundscape. This would mean that not only the amplitude and frequency of a low-frequency background noise, but also the temporal sequence and the harmony of certain frequencies define the effect it has on an organism; similarly as a music piece creates different effect in the listener when played forward or backward.

CONCLUSION

Although generalizations to other natural places can hardly be made due to the small amount of regarded locations, measurements showed that the cultural location exhibits higher levels of low-frequency background noise than the natural location. High levels of airborne low-frequency sound are cause for different adverse effects. When talking about effects of noise though, airborne sound must be distinguished from structural vibrations. Due to higher energy densities, the physiological effect of vibration is stronger than that of airborne sound. Evidence is that effects of airborne low-frequency noise correlate with audibility; yet few people show increased sensitivity and are able to feel rather than hear meteorological events. In case of vibrations, low-frequency sound approximately below 40 dB appears to have healing properties, while low-frequency vibrations levels higher than 50-60 dB induce adverse effects. Like in toxicology findings suggest that low-frequency obeys the principle "the dose makes the poison". It is assumed that healthy natural variability, as for example a body's rhythms of breathing or heart beat, could be appropriate role-models; transferring their pattern-formation principle could help to define beneficial variability of sound pressure in a healthy soundscape, and thus help rating the emission qualities of technical sound sources.

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