Psychoacoustics

An Introduction to Sonic Activism

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Sammandrag:

Mitt slutarbete är en litteraturanalys om psykoakustik, ljudets beståndsdelar samt övriga komponenter som påverkar vår uppfattning av ljud. Inspirationen till ämnet härstammar från en nyfikenhet på generellt oförklarade upplevelser kring ljud och musik. Vad är psykoakustik och kan det finnas andra vetenskapliga förklaringar på ljudets enorma kraft att påverka oss?

Eftersom vi konstant omringas av ljud och oljud är det väsentligt att vi förstår hur vi påverkas av ljud och hur vi i tur kan påverka vår akustiska omgivning. Oljud som vi utsätts för i stora städer kan orsaka försämrad funktion i vårt hörselsystem. Detta gäller inte endast fysiska hörselskador från höga ljud men även psykiska skador som framkommer när vår hörsel överbelastas.

Psykoakustik är ett tvärvetenskapligt forskningsämne vars mål är att förklara relationerna mellan ljudets fysiska attribut och lyssnarens subjektiva tolkning eller upplevelse av ljudet. Vår hörsel, inklusive öronen och hjärnan, uppfattar inte ljud på samma sätt som våra mätinstrument. Dessa egenskaper är relaterade och det är psykoakustisk forskning som strävar till att vetenskapligt förklara dessa relationer, framförallt genom kliniska experiment där deltagarna lyssnar och markerar skillnader som upplevs i testljudet.

Ljudets fysiska egenskaper delas upp i fem beståndsdelar; frekvens, ljudtryck, spektrum, varaktighet (också längd) samt omslag (eng. envelope). Dessa egenskaper påverkar indirekt på vår uppfattning och förmåga att beskriva ljudets volym, tonhöjd, längd och klangfärg.

Psykoakustiska modeller tar nytta av avvikningarna mellan våra subjektiva tolkningar och ljudets fysiska bestånd för att till exempel ändra ljudets fysiska egenskaper utan att vår uppfattning av detta ljud förändras. Denna vetenskap kan användas bland annat för komprimering av ljud då ett nätverks bandvidd inte räcker till för transmission av okomprimerad ljudinformation. Förutom komprimering används psykoakustiska modeller för till exempel planering av rumsakustik, utveckling av hörapparater, mätning av oljudsnivåer samt otaliga andra syften.

I mitt examensarbete föreslår jag att det, utöver ljudets objektiva och subjektiva dimensioner, övrigt finns en intersubjektiv dimension av ljud som inte framkommer i den litteratur jag forskat. Intersubjektivitet förklarar relationen mellan människornas uppfattning och hur vi påverkar varandras uppfattningar i första hand genom social interaktion. Andra faktorer som påverkar vår uppfattning är bland annat kulturella, samhälliga och sociala konventioner, normer samt regler.

I examensarbetet presenterar jag metoderna för forskning av intersubjektivitet i detalj. De mest använda metodologierna för forskning av intersubjektivitet är komparativ självrapportstudie, observation av beteende, talanalys och etnografiskt engagemang. Dessa metoder presenteras i detalj i detta examensarbete framförallt för att avse läsaren med en sammanfattande beskrivning av intersubjektivitet.

Om vi vill förstå ljudets alla egenskaper, både nyttiga och skadliga, bör vi forska vidare genom nya perspektiv och en ny vy om vad ljud kan betyda för oss. Jag är övertygad om att det finns ett enormt forskningsområde inom ljudets intersubjektiva dimension som kan framföra nya tankar och ställningar kring ljud. Vi kan stöta på nya sätt att påverka vår existerande omgivning och använda uppfinningarna och resultaten till nytta när vi planerar akustiken för framtiden.

Mitt examensarbete strävar främst att väcka läsarens tankar kring ljud genom att framföra en intersubjektiv dimension som förslag för ett nytt perspektiv. Det viktigaste är dock att läsaren kan, genom nya perspektiv, skapa individuella initiativ för att påverka och förbättra sin akustiska omgivning till eget tycke.

Nyckelord:	Ljud, psykoakustik, musik, oljud, uppfattning, associering, intersubjektiv, aktivism,
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Abstract:

My thesis is an analysis of existing literature about psychoacoustics, the components of sound and how they shape our perception of sound. My initial interest in the topic stems from a desire to understand what psychoacoustics are and if there are additional scientific concepts that can further explain the power that sound has over us. Because we are constantly surrounded by sounds it is crucial to understand how we are affected by these sounds and how we can in turn affect our acoustic environment. Psychoacoustics is a multi-disciplinary field that aims to explain the relations between the measurable aspects of sounds and the subjective perception of the sound by the listener. With the help of psychoacoustic models we are able to modify sounds so that the listener experiences a desired variation or indeed no variation at all. Psychoacoustic models such as these are applied in various ways in areas such as online streaming, compression algorithms, acoustical planning, development of hearing aides and noise measurement. These models rely on two dimensions and their relationship, the physical or objective, and the subjective perception of the physical. I further propose that there is an intersubjective dimension to sound that is dictated by norms, conventions and traditions within our societies. If we plan to understand the qualities and attributes, in particular the social meaning of sound, there is a need for further scientific study to explore this third dimension of sound. I am convinced that these newfound ideas and resulting scientific knowledge could help us to evolve sound in our existing environment and revolutionize how we plan our acoustical future.

Keywords:	Sound, psychoacoustics, music, noise, perception, association, intersubjective, activism,
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CONTENTS

1 SOUND, MUSIC AND NOISE: A REVIEW OF DEFINITIONS

[In this chapter I propose a preliminary conceptual mapping of the aforementioned concepts as it emerges from a non-exhaustive review of available literature]

1.1 Sound

According to the Oxford Dictionary of Current English (1993) sound is defined as the sensation caused in the ear by the vibration of the surrounding air or other medium, or as the vibration causing the sensation. The New Penguin English Dictionary (1986) adds a couple of definitions to this, namely that sound is mechanical radiant energy that is transmitted by longitudinal pressure waves in a material medium, or that it can refer to a characteristic musical style e.g. the *sound* of the 1970s.

Webster's Encyclopedic Unabridged Dictionary of the English Language (1989) defines sound as any audible vibrational disturbance, and adds that sound travels at approximately 1100 feet per second at sea level. Rossing et al. (2002 p. 3) further define the study of sound as *acoustics*. Sound is ubiquitous vibrational energy experienced through our skin and ears where it is transformed into electrochemical impulses sent to the brain (Leeds 2010 p. 14).

1.2 Music

Music is the art of combining vocal or instrumental sounds in a harmonious or expressive way, it can also mean a pleasant natural sound (Oxford Dictionary of Current English 1993). An alternative but similar definition can be found in the New Penguin English Dictionary (1986), which states that music is the science or art of ordering tones or sounds in succession and combination to produce a composition having unity and continuity. Music can also mean the tones or sounds occurring in single line (melody) or multiple lines (harmony) to be sounded by one or more voices or instruments, or both (Webster's Encyclopedic Unabridged Dictionary of the English Language 1989).

Erkkilä (1997 p. 13) views music as a diverse symbolic language, through which expression of the deepest human feelings and experiences, even those that spoken language cannot express, is made possible. Music is also timeart; it is a form of art where the listener can hear the time passing, an event floating on the current of time (Lehtonen 1996 p. 33). Stefani (1992, p. 9 & 31) defines music as the multifaceted producement of meaning as well as an enormous collection of conventions and individual experiences that melodies contain.

1.3 Noise

Noise is most often defined as unwanted sound (Rossing et al. 2002 p. 5) (Kryter 1950 p. 6). It can also mean an especially loud or unpleasant sound, or irregular fluctuations accompanying a transmitted signal (Oxford Dictionary of Current English 1993). The New Penguin English Dictionary (1986) further defines noise as irrelevant or meaningless information occurring with desired information in the output of a computer. It is also classified as a nonharmonious or discordant group of sounds (Webster's Encyclopedic Unabridged Dictionary of the English Language 1989).

2 PSYCHOACOUSTICS AS A DISCIPLINE

2.1 Origins of psychoacoustics

Psychoacoustics is categorized as a branch of psychophysics. Psychophysics studies not only the reception of information by the appropriate sensory organ, but the coding, transmission, and processing of this information by the central nervous system (Rossing et al. 2002 p. 91). The study of psychoacoustics focuses specifically how *sound* is perceived.

G.T. Fechner, a pioneer in the field of psychophysics and author behind the work entitled *Elements of Psychophysics* (1860), explains that the basis of psychophysics is studying the relations between stimuli and the subjective sensations they produce. Fechner

originally came to the conclusion that the relationship between stimulus and sensation is logarithmic[1]. This theory is often referred to as *Fechner's law*.

> Fechner's Law expresses the relationship between stimulus and sensation rather simply: As stimuli are increased by *multiplication*, sensations increase by *addition*. For example, as the intensity of a sound is doubled, its loudness increases by one step on a scale. […] Fechner argued that the same relationship applies to any stimulus and its corresponding sensation: to light and vision, etc. Recent investigations have pointed out its inadequacies; nevertheless, Fechner's law served as a basis for psychophysical theory for nearly a century thereafter.
>
> (Rossing et al. 2002 p. 91)

Fechner's theory was at the time considered groundbreaking and even if the simple logarithmic theory has since been proven to not be accurate, it is still worth a mention when considering the origins of psychoacoustics.

In recent years the interest in psychoacoustics has been growing as more people start to think about sound as a tool to improve our quality of life. This has naturally led to many new studies and publications that consider the potential of sound, within fields such as music therapy, through psychoacoustic concepts. There is also renewed interest in sound as vibration (Leeds 2010 p. 8).

Psychoacoustics is an interdisciplinary field of science that utilizes principles from physics, biology, psychology, music, audiology, and engineering in order to deal with the perception of sound (Rossing et al. 2002 p. 77). This means that there are multiple approaches to psychoacoustics, as well as multiple fields of application of psychoacoustic knowledge. Scientists and researchers with different academic backgrounds and interests share the same desire; to understand how sound – including music, speech and noise – is perceived by us and what the consequences of sound are both psychologically and physiologically.

Defining the term psychoacoustics is therefore, to some degree, problematic because of the interdisciplinary nature of the field itself. This means that the definitions will inevitably have variations depending on the multitude of scientific approaches. Pantelis N.

[1] Mathematical term made up by Scottish mathematician John Napier (1550-1617), from the Greek word *logos* meaning "proportion, ratio or word" and *arithmos* meaning "number".

Vassilakis, Ph.D. (2013 chapter 01. Introduction), defines psychoacoustics as a multi-disciplinary field that "forges a link among the physical, physiological, and perceptual frames of reference, examining ways in which physics and physiology interact to give rise to auditory sensations/perceptions".

Joshua Leeds defines psychoacoustics as the study of the perception of sound. He claims that within the realm of psychoacoustics the terms *music, sound, frequency,* and *vibration* are essentially interchangeable, because they are different approximations of the same essence. (2010 p. 7)

2.2 The field of psychoacoustics

When sound is perceived through our communication receivers – the outer, middle and inner ear, as well our bodies when subjected to low frequencies – we can describe it with certain attributes. However, the sound wave we hear is scientifically measured and quantified with a different set of attributes. Psychoacoustics is the intellectual tradition that is practiced in order to better understand and study the relations of subjective auditory perception and the physical attributes of sound. In short, psychoacoustics aims to explain the function(s) that shape our perception of a sound wave.

> Loudness, pitch, timbre, and duration are four attributes used to describe sound […] these attributes depend in a rather complex way on measurable quantities such as sound pressure, frequency, spectrum of partials, duration, and envelope. The relationship of these subjective attributes of sound to physical quantities is the central problem of psychoacoustics.
>
> (Rossing et al. 2002 p. 77)

There are also intersubjective aspects that shape our perception of sound. This means that the subjective experience of sound is influenced by shared meanings stemming from for example social interaction or agreements between two or more people. The intersubjective dimension of psychoacoustics is further explained in chapter 2.3 of this text.

The following section looks at how perception (subjective) is described, which attributes constitute the physical (objective) description of sound, and how these are dependent on each other. After this, a third section will introduce the intersubjective dimension of sound.

2.2.1 Perception

Sound perception can be described by four attributes: loudness, pitch, timbre and duration. Listed below is a short description for each of these four attributes.

Loudness is a subjective auditory sensation with which a sound can be classified on a scale from quiet to loud. It can best be explained as the "strength" of the sound. Humans perceive sound loudness not only by the actual amplitude of the sound but also depending on which frequency the sound vibrates at.

Pitch is the perceived frequency of a sound. This means how "high" or how "low" the sound is described as being. This does not mean the actual frequency of the sound, quantified scientifically in Hz.

Timbre, also known as tone color, is what makes it possible to distinguish one sound from another even when the loudness and pitch are identical. For example two instruments – let's say a piano and a flute – that play the same note (pitch) at the same amplitude (loudness) will still be perceived as different to one another. This difference is described by the timbre of the sound.

Duration is simply put the attribute that describes if a sound is perceived as "long" or "short". For example a high-pitched and irritating sound can be perceived as long even if it would only last 1 second. The sound can be perceived as a "long" sound because of the increased effort to endure the sound exerted by the listener.

2.2.2 Measurement of physical attributes of sound

The measurable quantities of sound can be described by attributes such as pressure, frequency, spectrum, duration, and envelope. Listed below, in a similar manner as earlier, is a short description for these attributes as well as (where applicable) the unit of measurement for each attribute.

Sound pressure is the fluctuation or deviation that a sound creates in local atmospheric pressure, which the ear is sensitive to. The intensity of a sound wave is proportional to the pressure squared (Rossing et al. 2002 p. 103). The unit for sound pressure is *pascal* (Pa). Sound pressure should not be confused with *Sound Pressure Level*, or *SPL*, which is a logarithmic measure of sound pressure relative to a reference value. *SPL* is measured in *decibels* (dB).

Frequency (when measuring sound) is the number of oscillations a sound wave makes during one second. The unit for frequency is *hertz* (Hz). The audible range for humans is between 20 Hz (low sounds) and 20,000 Hz (high sounds). It is however highly unusual for individuals to hear across this entire range as sensitivity, especially to high frequencies, deteriorates gradually throughout life (Rossing et al. 2002 p. 80).

Spectrum is the so-called *recipe* of several simultaneous vibrations of sound on different frequencies (Rossing et al. 2002 p. 34). For example: a musical instrument rarely produces a single tone, vibrating only at one frequency, but is instead composed of multiple vibrations (*components*). The spectrum of a sound describes the amplitude and specific frequency for all these components, which combine in the sound of a voice or an instrument.

Duration is the length of a sound often quantified in *milliseconds* (ms). The physical duration is, according to Rossing et al. (2002 p. 95), closely related to perceived duration, however the subjective attribute is also affected by other physical attributes such as sound frequency and pressure.

Envelope is described as the time history of the amplitude (Rossing et al. 2002 p. 36). A vibrating system loses amplitude over time due to loss mechanisms such as air friction; conversely there is also an initial build-up of the sound. These two events are called *decay* and *attack* respectively. Envelope describes the loss and gain of amplitude, usually on a horizontal graph or timeline for the sound wave.

2.2.3 Dependencies of subjective attributes

The subjective attributes, which can be used to describe sound, are dependent on the measurable quantities. This means that the way we perceive a sound depends on what the physical parameters are. For example the perceived loudness of a sound depends highly on sound pressure but can also be influenced by the duration of the sound. An annoying sound, such as a jackhammer demolishing the pavement outside your office or classroom, can be perceived as being louder if the duration is longer.

Below is a table that illustrates, in a very rudimentary way, how each of the four subjective attributes depends in varying degree on physically measured parameters of sound.

Table 1. The dependence of subjective qualities of sound on physical parameters according to Rossing et al. (2002, p. 95).

	Subjective Quality			
Physical Parameter	Loudness	Pitch	Timbre	Duration
Pressure	+++	+	+	+
Frequency	+	+++	++	+
Spectrum	+	+	+++	+
Duration	+	+	+	+++
Envelope	+	+	++	+

+ = weakly dependent; ++ = moderately dependent; +++ = strongly dependent.

2.3 The intersubjective dimension of psychoacoustics

The study of psychoacoustics is the tool that dissects the listening experience (Leeds 2010 p. 7). Traditionally, this has meant the relationship between physical attributes and perception of sound both physiologically and psychologically. These are the objective and subjective attributes of sound. When the perception of sound is influenced by norms, conventions, and traditions etc. this establishes criteria to interpret the (social) meaning of sound, thus creating the intersubjective dimension of sound.

If we consider psychoacoustics to pertain to the perception of sound and the production of speech (Leeds 2010 p. 7), then this would imply the need for scientific or systematic attention to the intersubjective dimension of psychoacoustics as a research program. The study of music semiotics for example, considers music as a language with inherent communicational aspects (Stefani 1985 p. 164), and that music speaks to us about reality and the culture of a specific community. This is why sound, specifically musical improvisation, is used in therapeutic instances where it substitutes verbal communication as the means to address a psychological problem.

Perception of sound can be influenced by not only the physical characteristics of sound or the limitations of our hearing apparatus, but also by the perspectives of individuals, groups, traditions and discourses. The social nature of human life and society means that our opinions and thoughts have been shaped, and are continuously reshaped, based on our social environment and the perspectives of others. The concept of intersubjectivity refers to the relations between people's perspectives (Gillespie & Cornish 2009 p. 19). This could for example be the distinction between "music" and "noise" on an individual level when referring to a musical genre such as heavy metal or psychedelic trance.

According to Gillespie & Cornish (2009 p. 22) there are currently four major methodological approaches to the study of intersubjectivity: comparative self-report, observing behavior, analyzing talk, and ethnographic engagement. The following sections describe each in order to familiarize us with the concept of intersubjectivity through the methodological approaches which researchers use.

2.3.1 Comparative self-report

This approach to intersubjectivity examines the extent to which people are able to accurately take the perspectives of each other (Gillespie & Cornish 2009 p. 22). It involves a questionnaire where the participants are tasked with examining a given phenomenon both from their own perspective and the perspective of another person or group. The basic principle is to compare what person A indicates on a questionnaire with what person B thinks person A will indicate on the questionnaire (Gillespie & Cornish 2009 p. 23). The most sophisticated self-report questionnaire methodology proposes the existence of three levels of intersubjectivity and was developed by Laing, Phillipson and Lee (1966) (see Gillespie & Cornish 2009 p. 23). These levels are called *direct perspectives, metaperspectives,* and *meta-metaperspectives.*

Table 2.Three levels of intersubjectivity between Self and Other in relation to X (Gillespie & Cornish 2009 p. 23)

Level	Self (Person/group)	Other (Person/group)
Direct perspectives	Self's perspective on X	Other's perspective on X
	(S➔X)	(O➔X)
Metaperspectives	Self's perspective on Other's perspective on X	Other's perspective on Self's perspective on X
	(S➔O➔X)	(O➔S➔X)
Meta-metaperspectives	Self's perspective on Other's perspective on Self's perspective on X	Other's perspective on Self's perspective on Other's perspective on X
	(S➔O➔S➔X)	(O➔S➔O➔X)

> The first level is called the level of "direct perspectives", and concerns both Self's (S) and Other's (O) perspectives on a given phenomenon (X). This is the level of attitude, opinion, and direct representation. The second level is termed "meta-perspectives" and pertains to Self's and Other's ideas about each others' perspectives on the given phenomenon. The third level is called "meta-metaperspectives", which refers to Self's perspective on Other's perspective on Self's perspective on the object (and vice versa).
>
> (Gillespie & Cornish 2009 p. 23)

The data that this type of questionnaire provides is a clear articulation of various possible intersubjective relations between people or groups (Gillespie & Cornish 2009 p. 23), identifying things such as agreement or disagreement, understanding or misunderstand-

ing. Although this particular methodological approach to intersubjectivity was developed in the context of family therapy, it can also be used to examine *perceived* convergences and divergences of perspective (Gillespie & Cornish 2009 p. 24). This means that we can use this model to for example distinguish between actual agreements and perceived agreement.

2.3.2 Observing behavior

Another methodology, in contrast to the cognitive approach, assumes that intersubjectivity is more behavioral and embodied (Crossley 1996, see Gillespie & Cornish 2009 p. 26). This point of view focuses on things like non-conscious body mimicry. For example it has been found that an audience would imitate a leaning actor by leaning slightly in the same direction. Using new technology such as high-resolution video recording, high fps (frames per second) footage, and multiple camera angles, has enabled researchers to observe the target and model in increasing detail (Gillespie & Cornish 2009 p. 27). This development has proven the "phenomenon of motor mimicry to be widespread, being evident in smiling, leaning, dodging, wincing, and baby feeding among many other behaviors" (Gillespie & Cornish 2009 p. 27).

Researchers have also found that so called "mirror neurons" would resonate the excitement felt by another subject (in this particular study, monkeys) while for example observing the other opening a nut, tearing paper, certain gestures and movement and eating-related behaviors (Gillespie & Cornish p. 27-28). There has been a lot of enthusiasm concerning mirror neurons because of the extensive range of actions covered in humans as opposed to other primates, more specifically about the significance for language, theory of mind, empathy, self-consciousness, etc. (Hurley & Charter 2005, see Gillespie & Cornish 2009 p. 28). The study of mirror neurons has convincingly demonstrated that embodied intersubjectivity exists and that this type of intersubjectivity would not be visible using self-report methodology (Gillespie & Cornish 2009 p. 28).

2.3.3 Analyzing talk

Analyzing social interactions, more specifically how intersubjective relations are produced and reproduced in dialogue, is another methodological approach to studying intersubjectivity. Garfinkel (1984, see Gillespie & Cornish 2009 p. 29) proposed that intersubjectivity tends to become visible when the "tightly woven intersubjective fabric of assumptions" is breached. In order to explore this idea further he suggested that his students would for example interact with their families as they would interact with strangers and their home as if it was a hotel (Gillespie & Cornish 2009 p. 29). The students would record these interactions and report back to Garfinkel. The results of this and other similar tests that Garfinkel devised showed that this type of breaking of the assumptions that are taken for granted profoundly disrupted the social interaction (Gillespie & Cornish 2009 p. 29).

Conversely, researchers can create a divergence of perspective, and then observe how the participants repair it (Gillespie & Cornish 2009 p. 29). For example, a group is given a set of pictures, one per person, that are related without the participants knowing how they are related and without knowing what is depicted on each other's pictures. Through verbal communication alone they are tasked to put the pictures in the correct order, face down on the floor. This shows how communication allows us to form a deep mutual understanding from small individual parts through intersubjective collaboration.

In the view of conversation analysis, brief paralinguistic communications such as head nodding are designed to provide ongoing feedback about comprehension (Schegloff 1982, see Gillespie & Cornish 2009 p. 30). According to Gillespie & Cornish (2009 p. 30) this informs the speaker about their effective construction of intersubjective understanding. Instead of contributing anything new, a listener will often respond to a speaker with an utterance, which simply displays understanding of what has been said. This establishes intersubjective agreement between the two by allowing the first speaker to correct a misunderstanding or consolidate an understanding (Gillespie & Cornish 2009 p. 30). This is in short how conversation analysts have convincingly shown that intersubjectivity is routine and even mundane in ordinary conversation (Gillespie & Cornish 2009 p. 30).

2.3.4 Ethnographic engagement

Gillespie & Cornish (2009 p. 31) say that separating methods in to the three categories mentioned above is considered somewhat artificial from the point of actual research. Intersubjectivity appears in everyday life context and as such does not conform to this separation (Gillespie & Cornish 2009 p. 31). Ethnographic engagement is a combination of the methods used above where the researcher participates in the life of the people, observing the social realm and reflecting upon the experiences (Gillespie & Cornish 2009 p. 31). This approach to researching intersubjectivity enables analysis of the different perspectives in the field and how they interact (Gillespie & Cornish 2009 p. 31).

The researcher is in this case part of the intersubjective web where the sources of data are naturally occurring. Gillespie & Cornish (2009 p. 31) consider intersubjectivity as being embedded and implicit in everyday language and practices, which makes ethnography an ideal methodology for studying it.

3 APPLICATIONS OF PSYCHOACOUSTICS

Communication through sound plays a very important role in our society. We not only receive acoustical information through our ears but also transmit sound with our speech organs. This is in part the reason why the applications of psychoacoustics are spread across many different fields such as software development, musical acoustics, music therapy, noise control, etc. It is psychoacoustic data that provides the fundamental basis from which solutions to problems are elaborated (Fastl & Zwicker 2007 p. 315). The development of technologies such as hearing aids, or the acoustical design of a space or building, relies entirely on this data.

The following sections contain brief examples of some of the different applications of psychoacoustics in various fields of science.

3.1 Signal processing

By using psychoacoustic models it is possible to find the physical attributes of a specific sound or musical arrangement, which can be modified or even removed while the listener's perception of the sound remains the same. This means that software developers are able (by creating complex mathematical functions based on psychoacoustic data) to compress the amount of information that is transmitted. One practical benefit is for example more efficient online streaming of music due to diminished bandwidth requirements. This use of psychoacoustics relies on the known physiological limitations of sound perception as a basis to accordingly modify sounds.

3.2 Speech recognition

Any speech recognition device, such as a mobile phone or computer, uses the input of a voice in order to execute commands. These devices usually only understand single words instead of complete sentences. This is in part because the human hearing system is still by far the best speech recognition system and thus worth simulating (Fastl & Zwicker 2007 p. 361). This simulation of the hearing system, and subsequent development of speech recognition software, is based on psychoacoustic knowledge and research results.

3.3 Evaluation of noise

Noise evaluation is the process that is used in order to limit unwanted sound. Noise was previously assessed by only measuring sound pressure level (SPL), but this proved ineffective, as some sounds are not perceived as loud as others. This is because of how the human sensation of loudness works.

Modern noise evaluation relies almost entirely on psychoacoustics. It is done through measuring noise *emissions* through specifically designed microphones, which strive to simulate the human hearing system. Noise *immissions*, according to Fastl & Zwicker (2007 p. 323), are assessed for example by presenting a subject with stimuli for 15

minutes, which includes a background noise as well as several louder events. The subject has to indicate how loud they perceive the sound to be at any given point by varying the length of a bar on the monitor of a PC (Fastl & Zwicker 2007 p. 323).

3.4 Evaluation of sound quality

In order to evaluate sound quality Fastl & Zwicker suggest that, in addition to the acoustic features of sound, aesthetic and/or cognitive effects may play an essential part. This means that the annoyance or the pleasantness of sounds cannot always be assessed in laboratory situations. (2007 p. 327)

What can be described though are the psychoacoustic elements of annoying sounds. This is done through a combination of hearing sensations called psychoacoustic annoyance (Fastl & Zwicker 2007 p. 327). The formulas that Fastl & Zwicker (2007 p. 327-328) list are highly complex mathematical functions that, simply put, show how psychoacoustic annoyance depends on the loudness, tone color, and the temporal structure of sounds. By comparing the psychoacoustic annoyance, measured in psychoacoustic experiments, with the data calculated by their formula, Fastl & Zwicker (2007 p. 328-329) found that the formula was able to predict the level of annoyance in specific sounds.

4 SONIC ACTIVISM

The fundamental idea of sonic activism is that sound can and should be controlled for our benefit. Harmful sounds can be identified through psychoacoustic knowledge, which in turn enables us to take appropriate measures to shield us from negative effects. This could be done by for example using hearing protection or avoiding noisy environments whenever possible. Sound can also be an ally, for example energizing a tired person or soothing a stressful mind through music.

4.1 New Sound Awareness

Joshua Leeds, author of *The Power of Sound* (2010), asks us to consider the following:

> Anything that moves has a vibration. Though invisible, every aspect of our material world at the atomic level moves constantly. Wherever there is motion, there is frequency. Though inaudible at times, all frequencies make a sound. All sounds resonate and can affect one another. In the spectrum of sound - from the movement of atomic particles to the sensory phenomenon we call music - there is a chain of vibration:
>
> - All atomic matter vibrates
> - Frequency is the speed at which matter vibrates
> - The frequency of vibration creates sound (sometimes inaudible)
> - Sounds can be molded in to music
>
> This chain explains the omnipresence of sound.
>
> (Leeds 2010 p. 7)

This solidifies the need to acquire at the very least a rudimentary knowledge of our sonic environment and the effects it produces. By understanding how sound affects us, we can apply positive psychoacoustic principles to our situations and environments, Leeds calls this *sonic responsibility* (2010 p. 10).

In order to get started with sonic responsibility, Leeds (2010 p. 10 & 65) encourages us to first establish a new awareness of sound that allows us to function fully in our society, noisy or not. This means that we should think of sound as fuel and the ear as a portal for charging the nervous system (Leeds 2010 p. 70). Leeds states that this model for a new kind of sound awareness stems from "personal experience and passing references within broader articles" (2010 p. 67).

> After a few years of extreme, compacted emotional stress – loss of community, loss of employment, premature birth of a child, tax audits, broken marriage – I began to notice aspects of my personality beginning to change. Mentally, I was slowing down in my thought processing. I was not quite so sharp. I began mixing up letters when I typed at the computer – something that had never happened before. Also, I seemed to be having difficulty not taking everyday occurrences personally; as time went by, I was becoming emotionally overreactive. I felt like I was suffering from post-traumatic stress syndrome, even though I didn't know what the actual symptoms of that disorder are. I felt like I had been through a war, and my nervous system was showing the effect.
>
> (Leeds 2010 p. 67)

The references that grabbed Leeds' attention say the following:

> Poor listening can begin at any age and for any number of reasons. It might result from a health problem, an accident, a major lifestyle disruption, or from stress.
>
> (Thompson & Andrews 1999 p. 92)

> Abnormal neurodevelopment may be caused by psychological, physiological, or environmental problems in childhood; deviations of a normal auditory development may also occur later in life due to stress or trauma.
>
> (Doman, Robert Jr. 1982, *Dominance and Emotionality*, see Leeds 2010 p. 67)

Leeds' motivation, to deepen his knowledge about how emotional stress and trauma affect the auditory system, stems from not only his personal experience quoted above, but also because he found that there was reluctance to engage in discourse concerning this topic (2010 p. 67). The new way of thinking about sound is to consider the impact of our psychological state on our auditory system (Leeds 2010 p. 70).

The agenda of sonic activism is to usher in a new way of thinking about the vibratory energy that is sound. Leeds (2010 p. 70) wants us to tend to our auditory health just as we tend to the health of our hearts, our eyes, and our teeth. Proper auditory function is not simply about passive hearing but about the ability to engage in "active listening" (Leeds 2010 p. 71). According to Leeds (2010 p. 71) this active listening facilitates the loop of language, education, communication and social interaction.

4.2 Adverse effects of sound

[This section will explain the adverse effects of sound stimuli based on Leeds' work.]

Our ears are constantly being bombarded by sounds. Being aware of the soundscape that surrounds us, and knowing how noise and sound affect us, is vital in order to formulate measures against the adverse effects of noise. Hearing is the first of our senses to fully develop, roughly five months before we are born in fact. The heartbeat of the mother is heard within the uterus as high as 95 dB, which is extremely loud compared to the 40 dB that a regular conversation registers (Leeds 2010 p. 64). This means that our brain

develops mechanisms very early on, which allow us to tolerate and even ignore sound if needed.

> A remarkable quality of the auditory system is its selectivity. From the blended sounds of a symphony orchestra, a listener can pick out the sound of a solo instrument. In a noisy room crowded with people, it is possible to pick out a single speaker. Even during sleep the conditioned ear of a mother can respond to the cry of an infant. We can train ourselves to sleep through the noise of city traffic but to awaken at the sound of an alarm clock or unusual noise.
>
> (Rossing et al. 2002 p. 80)

Every sound that vibrates our hearing mechanism is processed and analyzed by the brain. Even sounds we do not consciously hear are processed because of our ever-present survival instinct that is in place to assess our safety (Leeds 2010 p. 64). This processing of information does not switch off when we go to bed at night, and it is maintained throughout our lives. This can take its toll and we may become overloaded with sound (Leeds 2010 p. 66). What this means is that our hearing apparatus actively starts filtering or shutting out sounds that are overwhelming us. This effect goes unnoticed by most of us but after a period of time we may notice that we don't hear as well as we used to or that our focus seems scattered (Leeds 2010 p. 66).

4.2.1 Auditory dysfunction

Our hearing mechanism may become damaged for a multitude of reasons but the most common ones aside from acoustic trauma are *noise-induced hearing loss* (NIHL) and *stress-induced auditory dysfunction* (SIAD) (Leeds 2010 p. 9). The former happens when loud or continuous noise physically damages the inner ear, where as the latter is the result of a subconscious elimination of vocal frequencies. To reiterate; these two aspects of hearing loss are in their nature a) physiological (NIHL), and b) psychological (SIAD).

- Physiological damage (NIHL) to the inner ear can be either temporary or permanent. This type of permanent damage only occurs after prolonged exposure to loud sound. Temporary damage on the other hand is a testament to the remarkable ability of the ear to recover from short durations of auditory overload (Rossing et al. 2002 p. 717). The only way to prevent physiological damage is to

avoid noisy environments and wear the appropriate hearing protection as often as possible.

- *Stress-induced auditory dysfunction* (SIAD) is a comparatively new concept that attempts to explain how stress can impede the active absorption of sound (Leeds 2010 p. 9). This form of damage affects the muscles in the middle ear, causing them to grow weaker which results in less efficient transmission of auditory information to the brain. As opposed to NIHL, this loss of performance in the muscles of the middle ear can be addressed through sound stimulation. This means that the ear can be retrained and re-sensitized to subconsciously blocked frequencies.

Understanding the incredible power of sound should encourage an increasing number of people to take charge of their sonic environment. There are many approaches because the nature of sound is subtle, powerful and above all personal (Leeds 2010 p. 94). Sound triggers things within us that we aren't even aware of yet. This has prompted us to advent new scientific fields of study such as *music neuroscience* that helps us understand the *hows* of music cognition (Leeds 2010 p. 94). This is Leeds' intention; to inspire, intrigue and encourage the reader to do the next great research study on intentional music and sound (2010 p. 94).

5 CONCLUSIONS

Sound can and should be used to improve the quality of life. We can apply our existing knowledge of sound to develop new technologies and techniques in fields such as software development, musical acoustics, noise control or musical therapy. We can also directly use sound as a tool to relieve stress or gain focus through listening to appropriate tones or music that aim to stimulate our nervous system.

Sonic activism encourages us to re-invent our acoustical environment and establish a new awareness on sound. Whether it is for personal wellbeing or academic curiosity towards sound it is all equally important in the eyes of the sonic activist.

We already know a great deal about sound on a physical level through the multitude of quantifiable aspects of sound. We also know a lot about how the physical attributes shape our perceptions of sound. Looking at the landscape of psychoacoustics, especially from the point of view of for example social sciences, it is clear that the relations of the objective attributes and subjective experiences cannot fully explain our perception of sound.

The intersubjective dimension is but one new approach to the study of sound among many. But it is one approach that I personally think is worth exploring, as it would have the potential to be able to explain the social meaning of sound much in the same way as communicational aspects of music are already studied in music semiotics.

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