- Ich fahre mit dem Rollstuhl, bitte parken Sie mein Fahrzeug für mich.
- Ich bin sehgeschädigt und benötige die Tagungsunterlagen in Großdruck.
- Ich bin gehörlos und benötige einen Dolmetscher für DGS.
- Ich bin schwerhörend/ertaubt und benötige einen Dolmetscher für LBG.
- Ich bin schwerhörend/ertaubt und benötige einen Schriftdolmetscher.
- Ich bin schwerhörend und trage Hörgeräte/CI mit T-Spule, eine Induktive Höranlage wäre eine große Hilfe.
- Ich bin schwerhörend, aber noch ohne Hörgerät, eine Empfangsanlage mit Kopfhörer wäre eine große Hilfe.

Ausblick

Albert Einstein hat vor über 100 Jahren seine Relativitätstheorie veröffentlicht. Er hat sein Leben lang nach einer „Weltformel" gesucht. Die „sensorisch barrierefreie Weltformel" widerspricht den Gesetzen der mathematischen oder physikalischen Logik. Sie lautet (trotz dieser Widersprüche sehr einleuchtend):

3 + 2 = 1

3 Prioritätsstufen und das
2-Sinne-Prinzip machen es
1-fach für Alle!

Und bitte: Beim Anwenden der Normen zum barrierefreien Bauen nicht das Denken einstellen, sondern beachten: Eine Norm ist ein Hinweis für das richtige Verhalten im Regelfall. Aber welche Hörschädigung ist eine normale Hörschädigung? Wer hat eine mittlere Schwerhörigkeit? Wer hat eine mittlere Blindheit? Zu Mittelwerten einer Behinderung gibt es keine Definition, denn nur darin sind wir alle gleich: Jeder ist anders behindert.

Dipl.-Ing. Carsten Ruhe
Referatsleiter Barrierefreies Planen und Bauen beim Deutschen Schwerhörigenbund e. V. (DSB)

Dipl.-Ing. Carsten Ruhe

Literatur

DIN 18040-1:2010-10 Barrierefreies Bauen, Öffentlich zugängliche Gebäude, Planungshinweise, Ersatz für DIN 18024-2:1996-11
DIN 18041:2004-05 Hörsamkeit in kleinen bis mittelgroßen Räumen (zurzeit in Überarbeitung)
DIN 4109:1989-11 Schallschutz im Hochbau
RiLSA:2010 Richtlinie für Lichtsignalanlagen

Thinking outside the box:
A tribute to Ernst Terhardt on his 80th birthday

I first became aware of Terhardt's research on pitch, consonance and harmony when my Australian PhD supervisor, Neville Fletcher, showed me an article with that title that had been published in the Journal of the Acoustical Society of America in 1974. Little did I know at the time that this article, which I at first found difficult to understand due to the author's unfamiliar "cybernetic" approach and ever-so-slightly Germanic English, would become the foundation for my PhD thesis - and after that for a large part of my academic output.

This short text is not intended as some kind of Terhardt biography. I know too little about his early background, playing jazz piano for American soldiers, studying in Stuttgart, the history of the research group around Zwicker and Feldtkeller so on, to write such a text. It is more appropriate for me to recount my personal impressions, and what I learned from Terhardt about the perception of pitch and music, because these are the things that I am surer about. I would like to tell you about Terhardt the person, the scientist, and the scholar whom I was privileged to meet and get to know during some of his most productive years.

Back in the 1980s, we still sent letters by air mail. As a PhD student in Australia, I somewhat boldly wrote to Terhardt directly. Encouraged by his friendly and informative replies, I then enquired about the possibility of working with him in Munich as part of my PhD project at the University of New England, Australia. After that, I spent 15 months in Munich, including all of 1983. That, incidentally, was the year of the human chain from Ulm to Munich, a massive failed protest against American plans to station even more Pershing and Cruise missiles directed toward the Soviet Union. That protest was just one of several life-changing events that I experienced during this time. My time in Munich was my first experience of living in a foreign country and becoming immersed in a foreign language and culture. I also discovered my main research question, and the person who was going to help me answer it.

In my regular meetings with Terhardt (on the 2nd floor of a very grey modern concrete building on the corner of Arcisstrasse and Gabelsberger Strasse, which has since been demolished and replaced), he generously gave his time – and as an academic myself, I know how difficult that can be. We discussed central aspects of his theories of pitch, consonance and harmony. This happened first in English and later in German: Ernst was not only the source of the most important ideas for my PhD, he also patiently helped me to express my ideas (academic and otherwise) in his own language. Our discussions regularly overflowed into philosophical questions and personal issues, for which he also seemed to find the time, beside all his other commitments.

Terhardt was first and foremost a passionate academic. One could say that he relentlessly and idealistically searched for the "truth", whatever that means exactly. As his first name implies, he was very serious about this task – honest, conscientious, and thorough. This is an attitude that inspired me, and continues to inspire. He carefully investigated every sentence in every publication draft for any possible error, until none could possibly remain. He believed that knowledge is gradually built up, brick by brick, until one has constructed a wall that one can use for other purposes. Critics, especially from the humanities, might say that this was a positivist approach, and I have struggled myself to find a middle path between positivism and relativism; however, Terhardt was also remarkably open to ideas that challenged his theories and approach. I know that, because I regularly challenged him myself, both verbally and in writing.

Terhardt "looked over the edge of the plate", as we say in German. He was "thinking outside the box" before that English expression was invented. He was not satisfied with an answer to a question before it had been carefully considered from multiple viewpoints. He was not content to apply only an engineering approach, or only a psychological or music-theoretical approach. For example, he was one of the few people in pitch research to seriously consider philosophical aspects that are all too often neglected by scientists. It took me some time to digest Terhardt's idea that the Three Worlds concept of Karl Popper could serve as a philosophical foundation for research in pitch and music perception. If I had never worked in Terhardt's group, I might never have understood that point. Today, I shudder to think of the time I would have wasted as a result, going down wrong academic paths. I remember after I had been in Munich for a few weeks or months, the penny dropped. I realized what Terhardt meant when he said pitch is 100% subjective in the sense of an *Erlebnis* rather than a physical measurement. After that, I had to learn to see the whole problem of pitch perception in a fresh way, from a new perspective. Since then, I have been a fan of Terhardt's philosophical approach to pitch perception, although many of my international colleagues either don't agree with it or don't understand it (sometimes it is difficult to tell the difference). I have tried repeatedly to explain

this idea to my students, and I guess several of them really understood. I only wish that more of my scientific colleagues would take this concept seriously and regard it, like Terhardt did, as the best and clearest basis for empirical work in areas as diverse as the psychoacoustics of pitch perception, empirical work on intonation in ensemble music, the categorical perception of musical pitch, and the theoretical and artistic interpretation of musical scores.

Terhardt is also a jazz pianist. The idea of virtual pitch was evidently inspired by jazz harmony, in which the root of a chord is often not one of the tones that is actually played – analogous to a pitch at a missing fundamental. In spite of his academic commitments, Terhardt managed to find time to devote to playing the piano, which evidently gave him enormous enjoyment (I have never seen a broader grin, in fact). When he got tired of Bebop improvisations, he explored the works of J. S. Bach, which fascinated him. He evidently believed that to be able to explain music, one must also have the direct experience of performing it at a high level, which is another way of "looking over the edge of the plate".

Terhardt wanted research to be *useful*, and on this point it is hard to disagree with him. To understand his pragmatic attitude, the best place to start is his pitch model, which he first presented in the German language in his Habilitation thesis in 1972 and later in more detail in two articles published in 1982 in the Journal of the Acoustical Society of America with co-authors Gerhard Stoll (a communications engineer with focus on IT and cybernetics, who passed away suddenly and far too young in April 2010) and Manfred Seewann (a pianist who is currently active in Munich).

In his pitch model, Terhardt did not attempt to solve the mind-body problem. Other researchers, then and now, have naively assumed some kind of one-to-one correspondence between brain states and processes on the one hand, and the experience of pitch on the other. Terhardt had the courage to identify this as a fundamental philosophical question that could not (and still cannot) be answered empirically. The brain is simply too complex; the number of neurons is too great; and our ability to measure brain states and processes too limited. But that is not all! Even if we knew exactly what each neuron in the auditory cortex was doing at any time, we would still not be able to answer this question, because physical measurements of neuronal activity are fundamentally different from subjective pitch judgments. Terhardt was adamant, and I believe that time has shown he was correct, that pitch is a purely subjective variable that in a (natural-) scientific approach must be strictly separated from the physical variables upon which it depends, whether those variables be measurements of sound in air (using a microphone) or brain measurements of any kind.

Given this apparently insoluble problem, Terhardt adopted the attitude of a hard-nosed empirical scientist. A pitch model, like any other scientific model, must be based only on solid empirical evidence. He collected that evidence in a range of psychoacoustical experiments: some in his research group at the Institut für Elektroakustik der TU München (as it was then known) by students such as Wilhelm Aures and Wolfgang Heinbach, some by his colleagues in the same institute, (Eberhardt Zwicker, Hugo Fastl), and research by international colleagues whom Terhardt respected such as Reiner Plomp or Andrzej Rakowski.

Unfortunately, not all of that research is published, and sometimes the description of methods and analysis in relevant publications does not meet modern psychological standards. That was partly a question of time: Terhardt was a creative researcher who didn't take kindly to being slowed down by unnecessary bureaucracy. He made a lot of intuitive decisions about designing experiments and interpreting data that were not scrutinized in peer-review procedures. What matters in the end is the final product. Conversely, Terhardt differed from many of his local and regional colleagues in his willingness to write in the English language, submit to leading international journals, and deal with laborious peer-review procedures.

If researchers in an empirical area of research are not convinced about a colleague's claims, and they have no better data or theory, they should repeat the experiments and try again to explain them. Take for example Terhardt's disputed theory of the origin of interval stretch. It is generally accepted that octaves in music are generally slightly larger than a 2:1 ratio, and other intervals are stretched accordingly. Musicians play them that way, on average, and they also prefer them that way in listening experiments. Terhardt explained this phenomenon in terms of pitch shifts. The pitch of a pure tone shifts slightly when its sound level is changed and when it is masked by other simultaneous sounds. This is presumably due to some kind of non-linearity in the spectrum analysis of the auditory system – not surprising considering the enormous range of frequencies and sound levels to which we are sensitive. It follows that the intervals between the audible partials of a harmonic complex tone, as we experience them as spectral pitches, are slightly stretched. If the ultimate origin of the octave interval in music is the interval between the 1st and 2nd harmonics (or the 2nd and 4th, or the 3rd and 6th), then we can immediately explain why octaves are stretched in music, regardless of whether they are sung or played by different kinds of instruments (not only pianos, in which the spectrum of individual tones is physically stretched relative to a harmonic series). This original explanation by Terhardt is consistent with the idea that music perception is generally primarily learned and not tied to mechanical properties of the ear or neural networks in auditory cortex, an idea with which modernist 20th century musicologists in the humanities enthusiastically agree. Given the absence of another accepted explanation for this phenomenon, those researchers who disagree are challenged to repeat the experiments and try to build a better general model to account for the data.

What is "useful" about Terhardt's approach to pitch? His model aimed to predict what people would perceive in any situation, when hearing any sound. This was a difficult task, and there will always be deviations between measurements and predictions. Terhardt believed in coming as close as is practically possible to a general solution. He was the first to create a pitch model that takes any sound signal at all as input and produces reasonable predictions; later researchers in other countries tried to emulate this feat, but their models were more complex (contradicting the principle of parsimony) and their predictions were not generally more accurate. Another useful aspect of Terhardt's approach was the use of programmable, executable computer algorithms as a means to test his theory, then to develop it, and finally to apply it. At a time when computing applications were gradually becoming popular and accepted, he was something of a pioneer. He could see the potential and usefulness of digital computer applications, and set out to develop such an "application" (not yet called "app") at a time when many of his colleagues, both at home and abroad, were still promoting old-fashioned analog technology.

The music-theoretical implications of Terhardt's pitch theory are one example of a practical application. His approach had, and still has, the potential to provoke a kind of music-theoretical revolution, comparable with that provoked for example by the Pythagoreans, Jean-Philippe Rameau, Hugo Riemann, Heinrich Schenker, or Arnold Schoenberg. The foundation for Terhardt's music-theoretic revolution is the realization that the tones that we perceive in music ("pitches") do not necessarily correspond to the tones that exist physically in musical sound or the notes that we write in a musical score. To understand harmony and tonality in western music, and probably important aspects of different non-western musics, it is necessary first to understand the functional relationships between pitches, tones and notes (as an example of Popper's three worlds). That involves understanding several things: how and why the ear performs a kind of spectrum analysis (Terhardt's explanation was based on a unique combination of environmental acoustics and evolutionary considerations); which partials in a signal are masked (a physiological limitation); and on that basis how complex tones are perceived with a pitch corresponding to the (approximate!) fundamental of an (approximate!) harmonic series of audible partials. After that, the next challenge for music theory is to base a theory of tonal musical structure on pitch (what the listener experiences) rather than notation (the traditional foundation of most music theory) or physical measurements (which materialist music theorists and acousticians assume to be the ultimate foundation). It is important to understand that some pitches sound more important than other (salience) and how this can affect the perception of music and its structure. It seems that the world of music theory is yet to understand, let alone acknowledge, the far-reaching consequences of this idea, which can be used to shed light on the historical emergence of western harmony and tonality by considering the constant interaction between perceptual universals and the specificities of western culture in different periods.

Like Albert Bregman in Montreal at about the same time, Terhardt was one of the first to apply ideas from Gestalt psychology to modern research in audition. Terhardt and Bregman do not seem to have communicated with each other; they seem nevertheless to have respected each other's work. Their pioneering work was based on the well-known ideas of Koffka, Köhler and Wertheimer. But neither Terhardt nor Bregman cited the Gestalt psychologists very often. Terhardt also refrained from citing Carl Stumpf's well-known theory of tonal fusion (Verschmelzung) as a basis for musical pitch and consonance (Stumpf was head of the Institut für Experimentelle Psychologie at Berlin's Humboldt University from 1893 to 1922). Perhaps both Terhardt and Bregman were put off by the more subjective aspects of Gestalt theory, which had their place in 19th century psychology, but as the 20th century proceeded seemed increasingly inappropriate. Their work was nevertheless broadly consistent with the Gestalt idea that the perception is self-organizing, and that holistic perception is more spontaneous than analytic perception. Both Terhardt's theory of spectral-pitch contours and virtual pitch and Bregman's analogous theory of auditory stream integration can be regarded as a revisions and modernizations of Stumpf's theory based on what had been learned in the meantime about pitch perception in empirical studies.

Like other psychophysicists of the 1970s and 1980s, Terhardt did not directly investigate individual differences in pitch perception, instead focusing on the average listener. But it was clear to him that big individual differences existed, and unlike other researchers he not only talked about them but also incorporated them into his thinking and modeling. It was obvious to him that the subjective experience of sound depends on more than just the physical properties of the sound impinging upon the ear: it depends on the person listening, the state or attitude of that person, and the context in which the listening is taking place. He was fascinated by the idea that one person can perceive the same sound differently, just as Escher's famous etchings can be perceived in different ways. Terhardt's distinction between holistic (or synthetic) and analytic modes of listening, which can refer either to individual differences or to different listening attitudes in a single person, later inspired Annemarie Seither-Preisler (Cambridge, Münster, Graz) and Peter Schneider (Heidelberg) to investigate interindividual differences between "fundamental listeners" and "overtone listeners".

A cornerstone of Terhardt's theory, and another point that set him apart from other psychophysical research of this time, was the idea that the ability to recognize harmonic pitch patterns is *learned*. The auditory system is constantly learning from the patterns of sound to which it is exposed, regardless of whether the patterns are part of speech, music or other environmental sounds. The original harmonic pitch pattern that the auditory system learns is the pattern of spectral pitch produced by the audible partials of a harmonic complex tone. That is the harmonic series that later music theorists accepted as a foundation of western music theory. Terhardt showed that the relevant musical foundation is not the physical phenomenon that Rameau called *corps sonore* but the corresponding perceptual experience, which differs from the physical object due to specific parameters of the auditory system's spectrum analysis (masking, dominance regions). Terhardt realized that familiarity with the harmonic series as perceived in speech and other sounds must begin to early in life, well before language acquisition. This led him to hypothesize that the ability to recognize harmonic pitch patterns begins to develop either prenatally or during infancy. The primary stimulus before birth is the mother's voice (her voiced speech sounds, including vowels, voiced consonants and non-linguistic vocalisations); after birth, it is the mother's voice and the infant's own voice. Research since that time has been consistent with Terhardt's assumption, lending credence to it and shedding new light on questions of nature versus nurture in the perception of pitch and music. This was also the trigger for my published speculations on the origin of music in prenatal experience and motherese; without Terhardt I would never have had that idea.

Terhardt's work was better understood outside Germany than inside. The international music psychology community, represented by several American and Canadian colleagues, was interested in his original and promising attempts to explain the foundations of western musical structure. But Terhardt was equally well connected to international community of pitch perception research, of which the strongest school was in Cambridge, England.

There was a fundamental philosophical misunderstanding between the Cambridge and Munich schools. In my opinion this misunderstanding continues to this day, and is still hindering a constructive exchange of ideas. Both schools made essential contributions, of course. Terhardt insisted that both spectral and virtual pitches were entirely subjective experiences; it was the task of empirical psychoacoustics to investigate the quantitative relationships between these experiences and the physical properties of the sound signals that evoked them. For him, psychoacoustics was about much more than cochlear mechanics and synaptic activity. High-profile English researchers in the area of pitch perception such as Brian Moore, Ray Meddis and Roy Patterson assumed a closer correspondence between the experience of pitch and underlying brain physiology, so they were more concerned to investigate that physiology. This difference of approach and assumption lead to a common misinterpretation: Terhardt's model was presented as a "place model", in which spectral pitch depended primarily on the position of maximum excitation on the basilar membrane – an idea that by the 1980s was evidently outdated. In reality, Terhardt was well aware that spectral pitch generally depended on a mixture of temporal and spatial information in auditory periphery and brain pathways, the mixture depending on the frequency range. Instead, he tried to explain to his colleagues that a spectral pitch was not a physical measure at all but an experience belonging to Popper's World Two. Since Terhardt's English colleagues were more interested in the underlying brain physiology, they emphasized the role of the temporal processing for virtual pitch. Terhardt rejected this approach as too simplistic, given the immense complexity of neural networks. He repeated that even if we knew exactly what every neuron in the brain was doing as a function of time while we were experiencing a pitch, we still would not necessarily know what had caused the experience. Clearly, it is misleading to regard Terhardt's as a place model and other models as temporal. Rather, Terhardt's is a model that acknowledges the fundamental difference between physical measures and experience, and attempts to model the quantitative relationship between the two based on empirical data.

Given his focus on subjective experience, Terhardt's approach is also appropriate for understanding the perception of music as art. His focus on learning is consistent with the idea that perceived consonance is primarily learned (from patterns of pitch), not innate (incidentally, Terhardt also made central contributions to what we today know about the perception of roughness in music and everyday sounds). That learning and experience are important is obvious to humanities scholars (e.g. in ethnomusicology and historical musicology), but they may be surprised to find out that the same assumption was made by a hard-nosed scientist on the basis of a long-term empirical research program. Musicologists and other humanities scholars would be well advised to adopt Terhardt as a scientific ally in the ongoing battle against nativism and universalism.

Terhardt did not favor the term "cognition", because after all everything in psychology involves information processing (depending on how you define "information"). But if we accept the term cognition, we can claim retrospectively that Terhardt was one of the 20th century's leading cognitive music psychologists. From an American perspective, he can be placed alongside (or perhaps above) the following leading scholars: Carol Krumhansl and her older colleague Roger Shepard, with whom he was ostensibly in conflict (but whose work can also be seen as complementary to his); Diana Deutsch, with whom he enjoyed a fruitful academic exchange; Jamshed Bharucha, another one of his influential American supporters; and David Huron, who brought together strands from Terhardt, Krumhansl and Bregman in interesting new ways, a project to which I had the privilege to contribute. The German music psychology community, led by Helga de la Motte-Haber, had a more modernist, sociological, and culturally relativist approach, which I equally respect; they were skeptical of Terhardt's attempts to explain aspects of western harmony and tonality on the basis of perceptual universals. As is so often the case, the truth lies somewhere in between: Terhardt's theory of the psychological origin of western musical chords and chord-roots is still the leading theory (that is, I know of no convincing competitor). Of course, the way we perceive chord roots is also strongly dependent on our musical conditioning – but that is exactly what Terhardt meant by making perceptual learning an integral part of his approach and modeling.

Terhardt's contributions made waves in academic worlds as diverse as engineering, psychology, medicine and musicology. In this short text, I have hardly begun to cover the breadth of his academic contribution, which included such diverse topics as the purely mathematical foundations of Fourier analysis, fundamental evolutionary and acoustic considerations of the interaction between humans and their human and non-human environments, the acoustics of musical instruments, and the physiology of the auditory periphery. Dear Ernst, on the occasion of your 80th birthday, please accept my congratulations, my thanks for your impressive academic achievements (without which my own contribution would have been much different and surely much the poorer), and my best wishes for the future.

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Richard Parncutt
University of Graz

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