History of Psychoacoustics

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Abstract
Psychoacoustics, or rather Psychological Acoustics, plays a significant role to date in many areas of application within acoustics. It therefore has a long and vast history to look back upon. Within its history, one central figure is definitely Hermann von Helmholtz. He paved the way for interdisciplinary acoustic research in his genius book “Die Lehre von den Tonempfindungen”. At his laboratory in Leipzig, his assistant Wilhelm Wundt created the foundation of experimental psychology – with international impact. Later, Carl Stumpf and the Berlin School of Gestalt psychologists who emigrated from Germany during the Nazi period created influential works of similar significance. Eberhard Zwicker collaborated with Stevens and shaped psychoacoustics so significantly that it internationally became a vast area of application research. The aim of this lecture is to illustrate the intellectual roots of current standpoints and ways of thinking. In doing so, the diversity and partial incompatibility of historical standpoints will be revealed.

1. Introduction
When reporting on the history of psychoacoustics, one is faced with the difficult task of deciding what belongs to the field. Which areas of research are encompassed by the term itself? Which historical developments are they based on? According to Beyer (1998, p. 271) [1], Schubert moulded the term „psychoacoustics“, yet I assume S.S. Stevens used it even earlier. Boring, one of Steven's colleagues in Harvard, published the term in the index of his work "A History of Experimental Psychology" in 1929. The German language had no knowledge of this term even though psychologists occupied themselves with hearing psychology very early. Zwicker once proposed using the expression psychoacoustics for perceptible auditory phenomena. Yet he inclined to describe non-auditory phenomena with the term „psychological acoustics“. Such definitions are helpful and convenient, but they are shadowed by scientific opinions, ideas and even ideologies which have been effective until this day. That is why it is worth taking a closer look at scientific history. One will surely hold nothing against my illustrations of the special role Japan played in these historical developments.

2. Ernst Heinrich Weber and Gustav Theodor Fechner
These two researchers from Leipzig played a significant part in the development of psychoacoustics: Weber formulated the general law regarding the Just Noticeable Difference (JND) for perception, Fechner incorporated Weber's law into another idea: Sensation experienced by an individual increases as a logarithmic function of the stimulus intensity. By introducing mathematics and experimenting, Fechner paved a significant path for the development of an independent empirical psychology – at that time still labeled psychophysics. Fechner's notions were taken up by researchers from various disciplines.

3. Hermann von Helmholtz and Lord Rayleigh
Undoubtedly, Helmholtz and Rayleigh are both considered among the most important people in the history of psychoacoustics. In his work „Die Lehre von den Tonempfindungen“, Helmholtz built the fundament of acoustical research from a wide interdisciplinary basis; he was interested in a general theory for diverse observations made in disciplines such as musical aesthetics, physics and biology: "In the present work an attempt will be made to connect the boundaries of two sciences, which, although drawn towards each other by many natural affinities, have hitherto remained practically distinct – I mean the boundaries of physical and physiological acoustics on the one side, and of musical science and esthetics on the other. The class of readers addressed will, consequently, have had very different cultivation, and will be affected by very different interests. It will therefore not be superfluous for the author at the outset distinctly to state his intention in undertaking the work, and the aim he has sought to attain. The horizons of physics, philosophy, and art have of late been too widely separated, and, as a consequence, the language, the methods, and the aims of any one of these studies present a certain amount of difficulty for the student of any other of them; and
possibly this is the principal cause why the problem here undertaken has not been long ago more thoroughly considered and advanced towards its solution” (1863, p. 1) [2]. For Helmholtz, physiology is the basis of all hearing perceptions; perceptions only represent concomitant phenomena of physiological processes. This viewpoint pervades the history of psychoacoustics until present; it can be found when reading Stevens and Zwicker and in many neurosensory and neurocognitive approaches. Instead of phenomena, epiphenomena are mentioned. Rayleigh, who was about 20 years younger, comprised solutions to fundamental acoustic problems in the "Theory of Sound" (1877) using a mathematical groundwork. That created the possibility of presenting the basic principles and research methods of physical acoustics; thus enabling the scientific investigation of many auditory phenomena.

4. Wilhelm Wundt

Wundt worked from 1858-71 with Helmholtz in the Physiological Institute in Heidelberg, at first as the latter's assistant and later as an extraordinary professor. In 1879, Wundt himself founded a psychological laboratory in Leipzig; his laboratory became known worldwide as a Mecca for experimental psychology. Around the turn of the century, there was no method available for objectively measuring sound intensity. The early days of research were characterized by the implementation of various musical instruments or devices similar to them. In particular, sirens, whistles and pipes proved to be useful for creating different sound intensities, since their length and width of could be exactly controlled. In addition, it was possible to exactly determine the blowing pressure. K. R. Koenig developed significant methods and the corresponding technical instruments in the arena of sound production. Wilhelm Wundt was therefore able to access this groundwork. Even electric tuning forks were used beyond 1920. People were seated at different distances away from them and, hence, sound intensity was varied for listeners. In addition, three apparatuses thoroughly described in Wundt's Physiological Psychology (1902, Vol. 1, S. 509-514) [3] are quite noteworthy: The sound pendulum (Schallpendel), the falling phonometer (Fallphonometer) and the sound meter (Tonmesser) (Wundt 1902, Vol. 2, S. 84) [3]. Experimenters in those days were posed with the problem of constructing a sound generator with which objective sound intensity could be adjusted. At the same time, sound quality should not be altered when changing sound intensity. The sound pendulum attempted to fulfill both demands. Many experiments were conducted with the falling phonometer. It was most likely constructed similar to drop machines common in those days which were used to prove Galileo's laws of falling bodies.

If the electricity in the electromagnet is interrupted hence causing ball B to drop, B will hit the ebony panel P thus initiating a sound wave of certain intensity. By adjusting the punching tool accordingly, sound intensity can be varied. The falling phonometer was the most modern acoustical development of the times. What is nowadays possible due to computer-aided experimental apparatus, was enabled by the discovery of electricity and electromagnetism. Although the sound pendulum and the falling phonometer were only the beginning to research on sound intensity, the idea of the falling phonometer had been reflected in a particular device until modern day, namely the standardized tapping machine (impact sound generator) found in building acoustics.

The sound meters made by father Georg and son Anton Appun functioned according to the bellow principle, similar to an organ (Wundt 1902, Vol. 2, S. 84) [3].

Both acousticians collaborated with the physiologist and zoophysicist Preyer (1841-1897); these names have been mentioned since their research first determined the audible sound range as being between 16 and 20,000 vibrations per second, later termed Hertz.

Wundt's students, in particular Merkel and Frank Angell, worked with the falling phonometer from 1880 to 1890. Angell founded a psychological institute modeled after the one in Leipzig at Cornell University in 1891. Cornell quickly became a center for acoustic research, just as Stanford did after Angell relocated there.

Which problems did the Wundt School dedicate itself to? Wundt summarized the state of research in his textbook on Physiological Psychology [3]. Working on the following areas was the point of focus:

- A physiological explanation had to be found for why we hear tones of various level. As with other senses, the question of absolute sound thresholds as well as differential thresholds for intervals was of great interest. Karl Eduard Luft (1888) in particular dealt with questions on how many sound sensations the ear can differentiate.

- Another problem was the perception of complex tones: What happens when tones of different vibration ratios occur at the same time? Research on beats (when two tones have similar vibration ratios), consonance and dissonance, octave similarity and tone fusion is connected to this problem. The theory of resonance presented by Hermann von Helmholtz in 1863 [2] was of great importance for explaining the fundamental facts on perceiving tones.

- A further problem was the perception of noise: Researching noise turned out to be very difficult,
because although tones could be generated with instruments in various controlled ways, analyzing and measuring natural noise had not progressed very far.

- Differentiating sound intensities: Ernst Theodor Tischer (1882) [4] dedicated himself to the differential perception of sound intensities. How many sound intensity sensations can we differentiate? At roughly the same time, an American by the name of Carl Seashore completed a test procedure for the psychophysical testing for musical aptitude.

I would like to illustrate Wundt's special connection to Japan. Wundt had over a dozen distinguished Japanese students who taught at representative Japanese universities (Wundt 2000). I will mention only Yujiro Motora, who taught psychophysics at the Imperial University of Tokyo from 1889; along with Matataro Matsumoto he established the first experimental psychology laboratory according to Wundt's model; Matsumoto was called to Kyoto in 1906 where he founded the second Japanese laboratory of this kind. During the world economic crisis of the 1920's the Wundt family offered to sell Wundt's personal library to the German Reich, but the government did not have the financial means to purchase it. Due to the mediation of one of Wundt's Japanese admirers, the purchase was made by the Tohoku University in Sendai. That is why Wilhelm Wundt's entire estate has been in the University Library of Sendai for 75 years. Takashi (1983) took stock of Wundt's Library. Kinya Maruyama from the Psychological Institute in Sendai devoted himself in particular to the care of Wundt's experimental equipment.

5. Barkhausen

Heinrich Barkhausen, one of the first inventors of the sound level meter, also had many Japanese followers to whom he lent his support in his lectures during journeys to Japan. I am surely not qualified to speak about Barkhausen's lifework: The former Academy of Sciences of the GDR and the Technical University of Dresden even issued a festschrift in 1981 which was published by Klaus Lunze [5]. This publication contains many important informations. The porcelain manufacturer, Meissen, even created a commemorative coin for Barkhausen. Eberhard Zwicker named the bark after him. Barkhausen's father was a jurist in Bremen. The family coat-of-arms can still be seen in the Townhall in Bremen. Barkhausen was in Japan for two months in 1938 and gave many lecturers there. In a little more than two weeks he taught 30 engineers from the firm Kawanishi in Kobe, who called him the father of Japanese communications technology. He reported on "band filters with and without feedback", making use, in part, of results provided by his daughter, Marlene. Yoyi Ito, who translated the book entitled "Electron Tubes".

6. Stumpf and his pupils

While major interest was dedicated to sound psychology during the 19th century, the 20th century took up problems concerning sound intensity. Investigating these difficulties was tightly related to new technical developments in the field of electroacoustics, such as the development of the oscillator and the discovery of the vacuum tube amplifier, the latter bringing about decisive improvements for the construction of hearing aids.

Carl Stumpf played a major role in the development of psychological acoustics. He published two volumes in 1883 and 1890 on "Tonpsychologie" (Psychology of Tones) [6]. In those works, Stumpf captures two topics we still find ourselves involved with today: How reliable are judgements on tone quality and tone intensity in psychophysical experiments? What roles do attention and fatigue play during them? Stumpf also investigated how we process fused tone quality in memory. Inquiries on complex tone analysis, timbre and fused tone phenomena are discussed in the second volume. I find his representation of the psychology of natural language quite significant; he laid the foundation for research on language perception and phonetics.

Most of his life was spent instructing at the University of Berlin. The notions of his mentor, Franz Brentano, inspired many of Stumpf's students. They created the principles of Gestalt Psychology and developed psychological groundwork with their postulates regarding holistic thinking, phenomenon analysis versus stimulus analysis and the psychophysical principle of isomorphism.

Wolfgang Köhler continued developing Tonpsychologie (the psychology of tones), abandoning the main interest regarding the musicaity of hearing and moving on towards language perception. Stumpf and Köhler argued against Helmholtz's approach, which assumes the properties of complex tones are the sum of the properties of simple tones. Both argue that simple tones possess more qualities than we are capable of discovering in the sound stimuli.

Their gestalt psychological interpretations of hearing put their approaches in an opposing light to mainstream approaches derived from physics, the latter's chief representative being Helmholtz himself ("Reichskanzler of German Physics"). Within psychology, Kurt Lewin [7], [8] advanced to one of the most prominent social psychologists in the USA. Gestalt psychological approaches in psychological hearing research can be found today in works by Alf Bregman, Diana Deutsch und Ernst Terhardt.
The Gestalt laws proved to be general laws on the psychology of perception, memory, motion, action and cognition. Gestalt-theoretical perspectives were adopted by psychologists in the 1920’s, especially by the so-called “Frankfurt School” and its representative Bethe, who was involved in research on neural plasticity. Acceptance for the Gestalt theory did not cease: Gestalt laws not only dominated the realms of phenomena and consciousness, but also the entire cosmos, including the non-living as well as the living world. Köhler published a fundamental contribution to Gestalt theory in 1920 titled “Die physischen Gestalten in Ruhe und im stationären Zustand” (“Physical Gestalts in a Resting and Stationary State”), and its publication was highly supported by Einstein. According to Köhler [9], both worlds are isomorphic; the thought of isomorphism fired the physicist imagination, even Einstein’s, especially since it enabled a world view derived from the single fundament of a few Gestalt principles.

Time and again this attempt revealed how heuristically prolific Gestalt theory is. Wolfgang Köhler found access to psychology in Japan at a very early stage. In 1923, Kanae Sakuma founded a psychological laboratory at the Kyushu Imperial University. Sakuma studied Gestalt psychology as a student of Wolfgang Koehler and his pupil Kurt Lewin (Sakuma 1999). One of Stumpf’s most productive minds was Erich von Hornbostel. At a very early point, he collaborated with Otto Abraham in investigations on the listening to music within diverse cultures.

7. Eberhard Zwicker

Without a doubt, Eberhard Zwicker deserves special acknowledgement due of his far-reaching influence on psychoacoustics for numerous years. He was instructed by Feldtkeller in Stuttgart; the latter known as one of the leading experts for telecommunications during those times. In 1952, Zwicker completed his dissertation work on “Limits of audibility of amplitude- and frequency-modulation of tones and their relation to audiotechnic and hearing physiology”. Several years later, Zwicker relocated to Harvard in order to work with Stevens. During his first stay in the United States of America, S. S. Stevens [11] and Georg von Békésy were two researchers he was extremely influenced by. It seems that a friendship was formed between Békésy and Zwicker. Stevens, on the other hand, appears to have been more distant. Yet despite all personal connections their cooperation was fruitful: 25 years after their famous article on critical band width, the publication appeared in the hitlist of the Science Citation Index.

Zwicker’s psychoacoustical research work [12] have appeared in diverse areas of application. While he was still living he asserted that his discoveries received more attention in East Asia than in Germany. Indeed, psychoacoustic researchers in Japan recognized the value of Zwicker’s psychoacoustical methods very early and hence made them available for engineering sciences. After his death various societies honored him with the highest distinctions.

8. References