Fascination of Hearing

Vibration patterns of the smallest bone in the human body

According to the WHO, 360 million people worldwide suffer from hearing loss, often caused by damage to middle-ear structures from disease or accidents. The University Hospital Zurich has measured vibration patterns of the impaired structures in order to select appropriate prostheses and related surgical techniques. The goals of the research are optimal coordination of hearing aids, improved interpretations in clinical diagnostics and further development of current diagnostic procedures.

The ear is an important sensory organ for protection as well as communication. It warns us about approaching dangers – even during sleep! So, how do we perceive sounds and alert signals? Acoustic sound waves are nothing more than fluctuations of air pressure. The acoustic sound waves collected by the pinna travel through the ear canal and cause vibration of the ear drum. The vibration of the ear drum is transmitted via the ossicular chain of the middle-ear into the inner ear, where hair cell movement causes nerve impulses generating perception of hearing in the brain. Our research project focuses on the ossicular chain consisting of the hammer, the anvil, and the stirrup which is the smallest bone in the human body.

A middle-ear sound transmission line that is broken or damaged will reduce hearing ability. To assess changes in middle-ear sound transmission caused by a damaged middle-ear and assess related surgical treatments, the University Hospital of Zurich has investigated the differences in vibration patterns of damaged middle-ears compared with those of normal intact ears, using instrumentation from Polytec. The sound transmission mechanisms in normal and damaged middle ears could be revealed from the measurement results. The measurements were also used to find optimal choice of hearing aids, improve interpretations in clinical diagnostics and further develop current diagnostic procedures. The impaired sound transmission line in the damaged middle-ear can be surgically treated bypassing the damaged middle-ear structure using implantable middle-ear prostheses. Such surgical treatments with middle-ear prostheses include replacement of the entire ossicular chain and replacement of a part of the ossicular chain, for example, the stirrup (stirrup prostheses). Analysis of the measurement results has provided information on development and optimization of the middle-ear prostheses and related surgical techniques. Our current project with such measurements focuses on functional roles of the joint between the hammer and the anvil (hammer-anvil joint).

EXPERIMENTAL SETUP

The ossicular chain is made up of temporal bones. The eardrum is stimulated with a loudspeaker, and the ossicular chain vibrates. The loudness of the stimulation level is monitored with a microphone inside the ear canal. Vibrations of the stirrup are measured simultaneously with a scanning laser vibrometer system. ▶

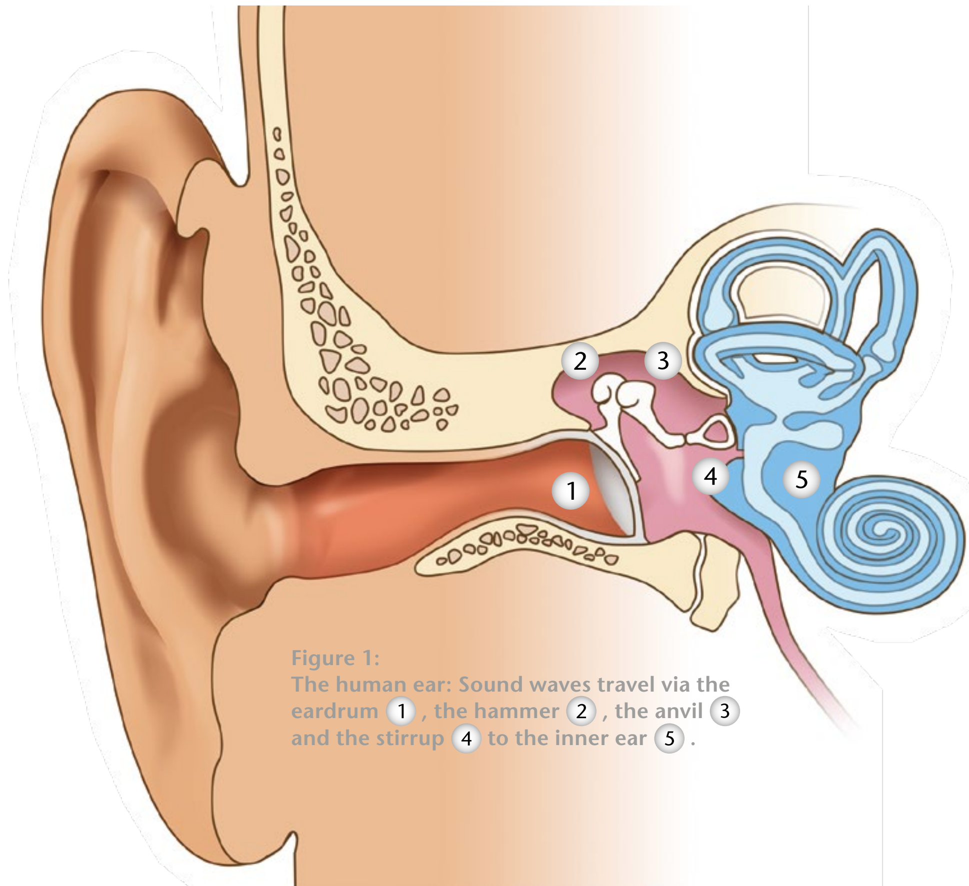

Figure 1:
The human ear: Sound waves travel via the eardrum (1), the hammer (2), the anvil (3) and the stirrup (4) to the inner ear (5).

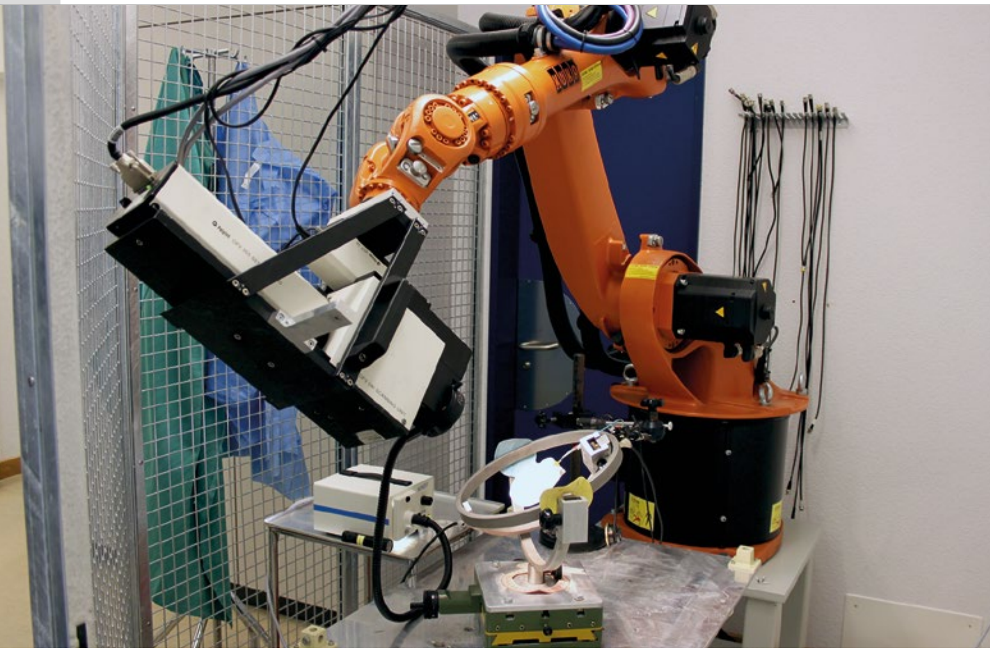

Figure 2: Experimental setup: the robot arm enables control of the desired position of the scanning-laser-vibrometer so that vibration of the stirrup can be measured as well as vibrations of the temporal bone.

The desired position of the scanning laser vibrometer is controlled by a robot arm (KUKA KR-16, position repeatability <± 0.05 mm), and a video camera (VCT 24) captures the area to be scanned.

Figure 3: Example of a middle-ear prosthesis: stirrup-prosthesis (NiTiBOND®): the immobilized stirrup is replaced by a mobile prosthesis. Thanks to the prosthesis, sound transmission is restored and hearing capacity improved. .

The reflection of the laser beam is optimized with retro-reflective glass beads (50 µm diameter). Vibration measurements of the stirrup are made at several frequencies, and repeated for the immobilized hammer-anvil-joint. From differences in the stirrup vibration between functioning and immobilized hammer-anvil joints, we can deduce the role of the hammer-anvil joint in sound transmission through the middle-ear.

RESULTS AND APPLICATIONS

What influence does the hammer-anvil joint have on sound transmission in the middle-ear? Preliminary data suggest that the hammer-anvil joint influences the frequency content of vibrations in the stirrup. These determinations will serve as the basis for modelling the dynamic behavior of a virtual middle-ear. It may also help to explain the influence of the hammer-anvil joint on age-related hearing loss and a potential damping function of the hammer-anvil joint for protection against sudden exposure to high intensity sounds or air pressure. Moreover, middle-ear prostheses that bypass conductive hearing loss and therefore improve hearing will be developed and continually optimized.
A new kind of stirrup prosthesis (NiTiBOND®) has already been developed and brought to market by KURZ® together with the Institute of Engineering and Computational Mechanics at the University of Stuttgart. ■

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