

Spatial Hearing
The Psychophysics of Human Sound Localization
Revised edition

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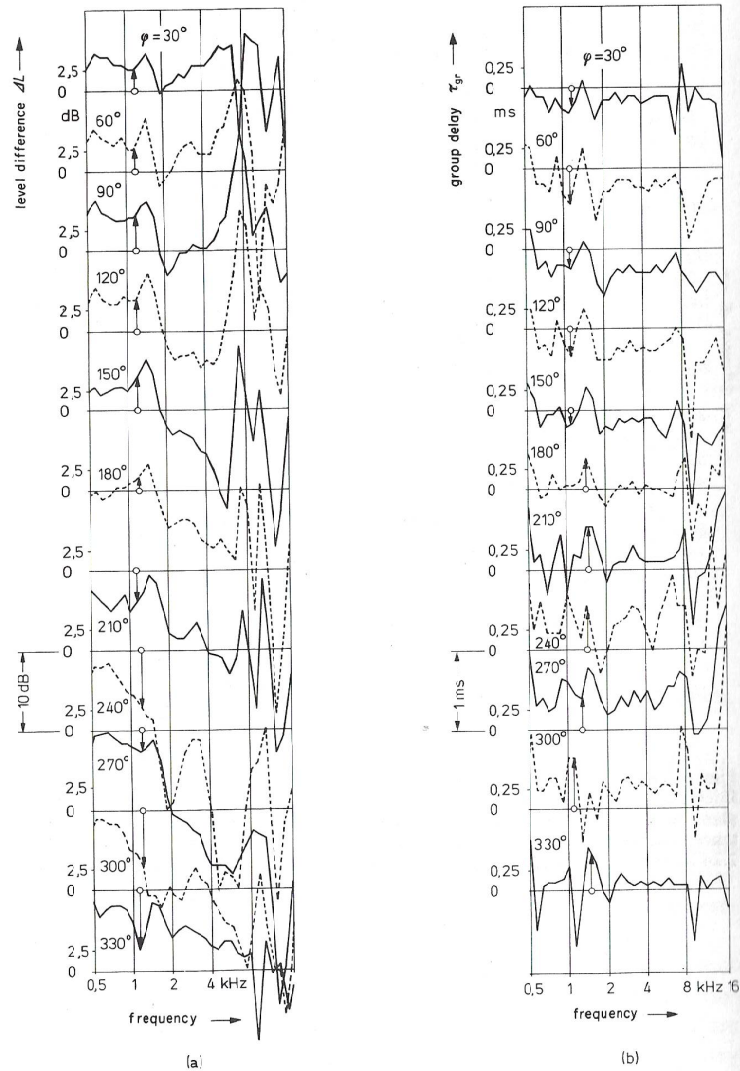


Figure 2.37
Monaural transfer functions of the left ear for several directions in the horizontal plane, relative to sound incident from the front ($\phi = 0^\circ, \delta = 0^\circ$), anechoic chamber, 2 m loudspeaker distance. Impulse technique, 25 subjects, complex averaging.

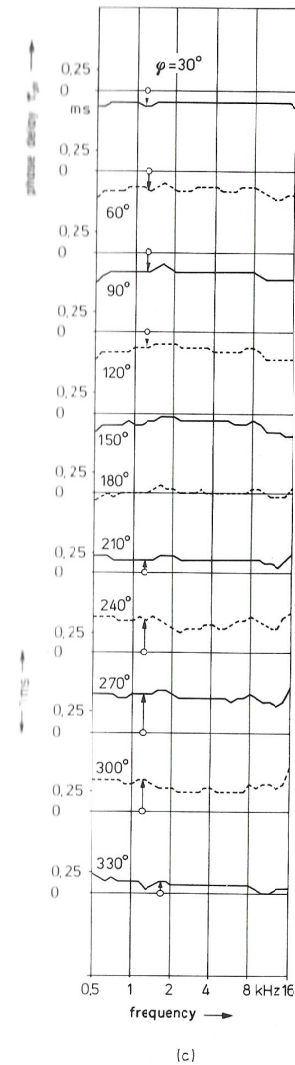


Figure 2.37 (continued)

their reflectances realistically. In general, however, it does not make sense to build highly detailed ray-tracing or image-source models. First, the reflectance of small wall elements (small when compared with the wavelength) cannot easily be specified. Second, the spatial and temporal selectivity of human hearing is limited. In the case reported here, an auditorium of about 1800 m³, excited with speech, 238 specified planes and 7000 detected mirror-image sources led to reasonably authentic percepts.

It is worth mentioning in passing – now that computer-based binaural room simulation is on its way to being accepted as a standard tool for planning acoustic spaces and audio systems – that an alternative method exists which is also capable of providing realistic auralization. This method makes use of scaled-down physical models of the space to be constructed (usually at a scale of 1:10 to 1:8). These models are driven by ultrasonic sound. Recordings are made with scaled-down dummy heads. Given that the laws of modeling are properly observed (including an adequate selection of materials and of the model atmosphere), these physical models produce very realistic binaural impulse responses, which, after adequate frequency transformation, can be used for auralization, as in the method described above. The scale-model method is well developed. For details the reader is referred to the literature (e.g., Blauert 1984a, Els 1985, 1986, Els and Blauert 1985, 1986, Xiang 1989, 1990, 1991, Xiang and Kopatz 1989, Xiang and Blauert 1991a,b, 1992, 1993).*

Binaural room simulation, as well as the scale model technique, model the static case, that is, sound sources and listeners at fixed positions and orientations in a fixed space. This leads to an unrealistic effect for the listeners, which is also typical for dummy-head stereophony in general. When the listeners move their heads, the signals at their two ears do not vary the way they would with natural hearing. As has been emphasized in section 2.5.1, listeners use the specific variation of the signals at the two ears as strong cues for localization in conjunction with their awareness of head position, orientation, and movement. If these cues are not available or are distorted, localization errors may occur, such as front-back reversals (e.g., along a cone of

* It goes without saying that binaural impulse responses can also be obtained from real, existing halls, that is, 1:1 models (Pösselt et al. 1988b, Tachibana et al. 1989)

confusion; see figure 2.94) and inside-the-head locatedness (section 2.3.2). Carefully measured external-ear transfer functions and individual adjustment to the specific listener reduce the problem, although they do not eradicate it completely. In cases where, because of a lack of individual adjustment, listeners are presented sound signals through somebody else's transfer functions (i.e., listening through somebody else's ears), the resulting localization errors sometimes seriously corrupt the auditory impression being aimed at.

Returning to figure 5.3, a possibility to resolve the problem emerges. As the auditory scene is generated by a computer rather than recorded by a dummy head, the actual computations can be performed for the actual head position and orientation. To this end, the current head position and orientation are tracked and the information is fed back into the computer. Position- and orientation-tracking sensors (six degrees of freedom) are readily available for this purpose, based on, for example, mechanical, optical, or magnetic principles (Meyer et al. 1992). If the adjustment of the input signals to the two ears of the listeners is performed in a realistic way, the localization errors clearly decrease, and individual adjustment of the external-ear transfer function may not be necessary in less critical applications. Furthermore, the perceptual space of the listener is now spatially fixed while the head is moving and no longer moves unrealistically in accordance with the head. This so-called perceptual space constancy provides the listeners with, among other things, an improved sense of involvement, as they now perceive themselves as moving in an otherwise fixed scenario.

As a matter of fact, the introduction of a head-tracking device into binaural systems is an important conceptual step in the development of binaural technology, as it introduces interaction of the system and the listener. By moving their heads, the subjects interactively control part of the simulation procedure. The introduction of interactivity into binaural simulation systems is actually an indispensable step to yet another branch of novel technology, namely, the field of so-called virtual reality. This widely used term, *virtual reality*, is obviously semantically inconsistent and, consequently, needs some explanation.

Virtual-reality technology aims to perceptually displace subjects into "virtual" environments which are different from the environments that they are actually exposed to. Ideally, the subjects feel "present" in