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DEPARTMENTS

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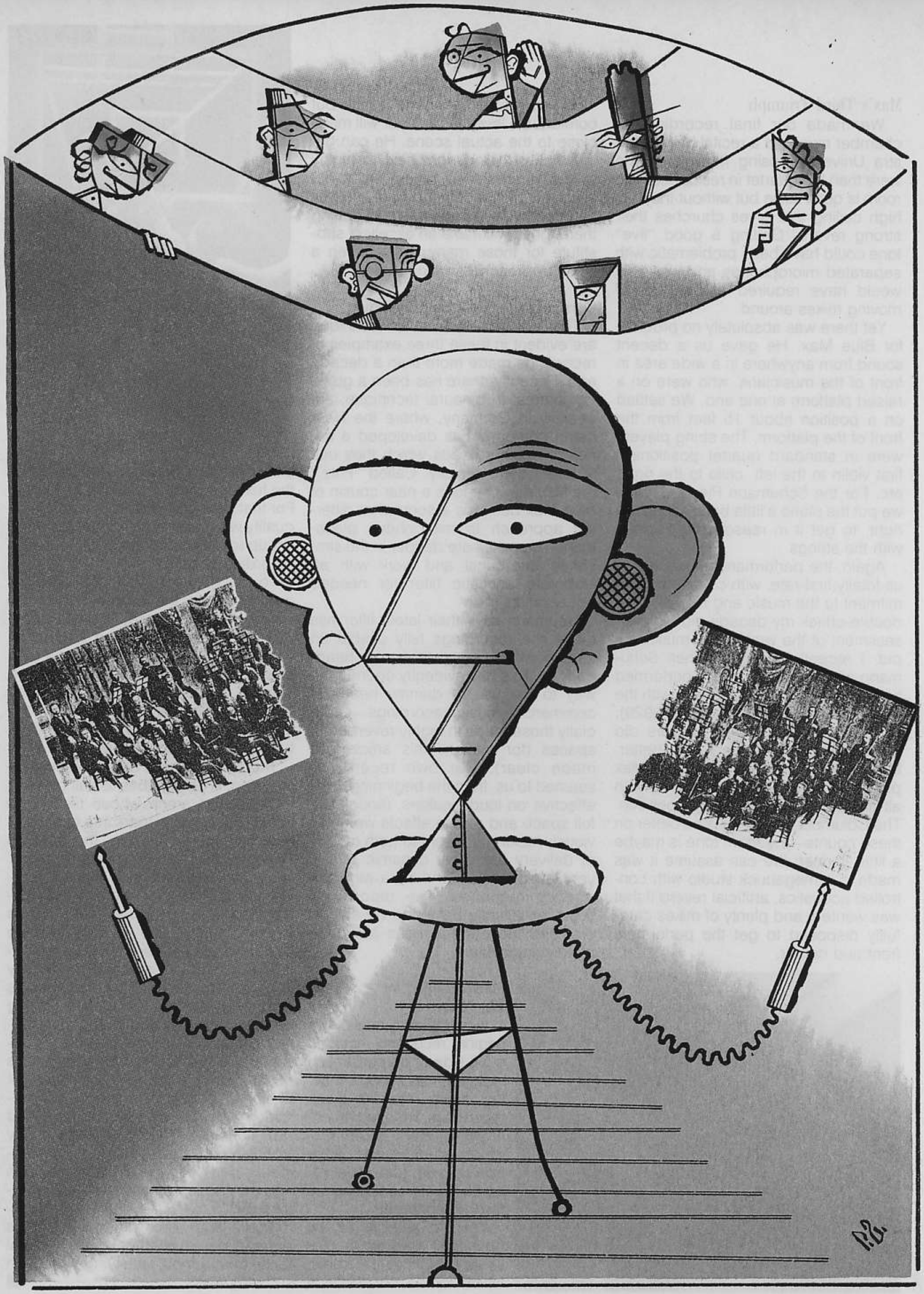


EARS WHERE THE MIKES ARE

PART I

JOHN SUNIER

In the last decade, more than 200 million stereo headphone sets have been sold in the U.S. alone. While the majority of these 'phones are attached to Walkman-type portable cassette, CD, or FM units, improvements in larger, home-type stereo headphones have made headphone listening an important part of many home music systems. Yet none of the source material being listened to by these headphone wearers was recorded for proper playback via 'phones! Standard recordings usually suffer from an exaggerated separation which concentrates sounds at the two ears and *inside* the head, rather than providing a natural placement *outside* the head, across the stereo stage. Further, ordinary two-channel recording fails to take into account the complexities of human hearing, especially the transfer function characteristics of the pinnae—i.e., the frequency-response and arrival-time differences caused by the outer ears.

For those unfamiliar with the concept, I'll start by defining binaural sound. It is a system employing two microphones, preferably mounted in an artificial or dummy head but often merely spaced the same distance apart as human ears or placed on or in the recordist's own ears. Two completely independent channels are used, and the two signals are fed, at the end of the chain, to the separate sides of a pair of stereo headphones worn by the listener; the original left mike feeds the left ear, and vice-versa.

At heart, this is the simplest possible method of reproducing sound (after, perhaps, the tin-can telephone). And this may be why it was invented only a few years after the phonograph: In 1881, Clement Ader experimented with transmissions from the Paris Opera using pairs of early telephone transmitters. Lately, binaural recording has benefited from the interest in spatial aspects of psychoacoustics that has led to such developments as Dolby Surround, Carver Sonic Holography, Hughes/Sony SRS, and various ambient-surround systems.

In the March 1986 issue of *Audio*, I presented a history of binaural sound. In Part I of this article, I'll look at the inherent problems of binaural sound, research projects going on now, some still-unanswered questions, and various approaches to dummy head design, including the most recent improvements. In Part II, I'll explain the effects of differences in headphones, equalization, and noise-reduction methods (not to mention differences in listeners' hearing); new methods of achieving binaural reproduction via loudspeakers and binaural effects with ordinary, two-channel material on headphones; binaural motion-picture sound, and some suggestions for do-it-yourself improvements in binaural listening.

The biggest drawback to binaural sound is obvious—one normally has to wear stereo headphones, with their logistical problems and their limitation of the number of listeners who can hear the same source. Loudspeaker playback of standard binaural recordings results in a distant, off-mike sort of sound with a lack of stereo spatiality. There is too much ambience, which seems to muffle the original sounds, and the bass lacks fullness. A second limitation: Only recordings that have been binaurally made can be heard binaurally—and very few recordings have been made this way. Bert Whyte has pointed out how simple and inexpensive it would be for most recording companies to set up a dummy head and make a binaural recording at the same time they make the main stereo master; with multi-track sessions, it could even be placed on two spare tracks of the master tape. However, the only label that has done this, to my knowledge, is Sonic Arts.

ILLUSTRATION: PHILIP ANDERSON

THE IDEA OF BINAURAL SOUND IS TO PUT

MADE, FOR A TOTAL SOUND

A basic binaural recording, made with a standard, unimproved dummy head, poses a number of problems for a totally realistic portrayal of the sound field at the recording location. The idea of binaural sound is to put your head where the recording was made—a total sound-recollection experience. Yet direct front and rear spatial localization is not as accurate as lateral localization (Fig. 1). Frontal sounds also usually seem elevated from their placement at the original recording. These effects differ from one listener to another; many people, in fact, have difficulty locating natural sounds that are in the same plane.

The ability to distinguish locations in the vertical direction is also relatively poor with basic binaural recordings. When a moving sound—such as a person walking by in a straight line in front of the dummy head—is played back, many headphone listeners hear the sound describing an arc in front of them, rather than the accurate straight line. Discrepancies of frequency response sometimes cause not only audible deviations from flat response but also confused spatial cues. Differences in headphones, equalization, and hearing are all factors. All of this has been summed up as the problem of the compatibility of production and reproduction in binaural sound.

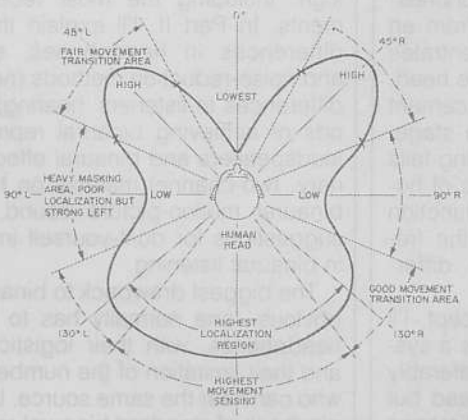


Fig. 1—Localization and movement sensitivity plot, showing asymmetry in natural binaural hearing process. (After Ron Cole.)

Standard stereo recording and reproduction are based on the theory, held for many years, that the relative positions of sound sources are cued by interaural (between the ears) differences in the time of arrival, intensity, and phase. The phase differences are used to localize sounds between about 200 and 700 Hz. Above 1,500 Hz, amplitude differences are felt to be the main contributors. Between 700 and 1,500 Hz, both phase and amplitude differences are used to determine direction of sounds. In fact, most mixing consoles work only with intensity differences to place sounds in the horizontal plane between the speakers. Work with four-channel sound, in the 1970s, made it clear that intensity cues alone were not sufficient to give proper side and rear images.

Localization cues by means of amplitude were found by investigators to be insufficient to define source positions such as "directly in front" or "directly behind," where the sounds produced at each ear have the same phase, intensity, and arrival time. Out of this came research showing that additional localization cues are created as the incident sound is reflected by the convolutions of the pinna of the ear. The theory is that these convolutions act as minute reflectors to create short time delays, causing a comb filter effect in the frequency response (Figs. 2 and 3). More information about these pinna transfer functions has been the goal of many researchers trying to fully understand auditory imaging, the cocktail party effect, the Haas or precedence effect, and other phenomena. Not all of these efforts are directed toward improving binaural recording and reproduction, but they all make useful contributions toward the recording arts.

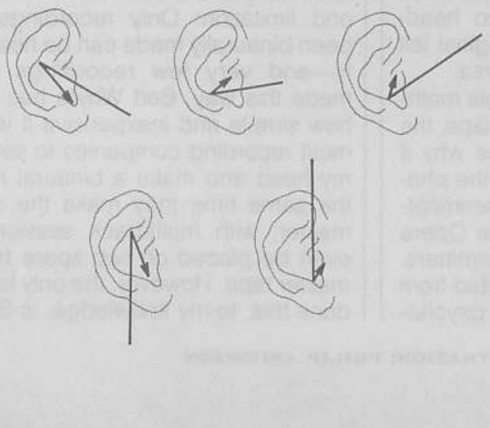


Fig. 2—Paths of first major coherent reflection in pinnae for sounds from various elevations. (After Rodgers.)

Another discovery was the importance of the envelope of the signal as a localization cue. It was found that transients are more easily localized than continuous sounds. Some of the cues could also be omitted without serious effects on localization as long as other cues were present. The problem of in-head localization was shown to be not limited to headphones; it could also be created with loudspeaker reproduction by preventing the listener from learning the

YOUR HEAD WHERE THE RECORDING WAS
RECOLLECTION EXPERIENCE.

acoustics of the listening room—i.e., confusing his short-term memory. Three Japanese researchers found that this effect can be greatly reduced during headphone listening by simulation of the room's acoustic properties through delaying a portion of the input signal.

G. Plenge, at the Institut für Rundfunktechnik in Munich, found bone conduction within the head to be one of the causes of in-head localization. It occurs during recording with some dummy heads and all human heads but does not occur during playback with headphones.

Another researcher in Germany, where the greatest interest in binaural sound exists, developed what he has called the Association Model (Fig. 4). Gunther Theile, who is also with the Institut für Rundfunktechnik, assumes a two-stage function of the hearing process. His model builds on the fact that each hearing event has two different aspects: The sound source itself and the location of the source. These two aspects, therefore, have two correlates in the perception of sound: The location determination stage and the determination of the source itself (i.e., recognizing its gestalt). Without these two stages of signal processing by the brain, our sense of hearing would be unable to determine whether details of spectra are due to the transfer functions of the pinnae or to the sound source itself.

Theile found that the spectrum of a sound source changes depending on its location so that, together with the time delay between the two ears, there is a binaural correlation pattern set up. These patterns can be compared with others stored in the brain during the acquisition of hearing ability. One researcher even investigated the changes in these patterns during childhood: As the child's head grows, the distance between the ears, as well as around the head, increases, and the brain has to readjust the binaural correlation to maintain correct localization.

Theile's work is just one of many efforts during the past quarter century to demonstrate the importance of the localization cues provided by pinna filtering, as well as their role in establishing out-of-the-head character of sounds in the environment. Experimental manipulation to reduce or remove pinna cues was carried out by scientists (at some discomfort to subjects!), including filling the pinna folds with putty, covering them with blocks, and inserting tubes into the ears. All researchers, as expected, reported various degradations of localization acuity following pinna deformation. Wightman and Kistler recently conducted more precise tests simulating the free-field listening experience, using digital techniques to synthesize headphone-presented stimuli. They measured their subjects' free-field-to-eardrum transfer functions deep in the subjects' ear canals using tiny probe microphones (Fig. 5). The measurements obtained were shown to be consistent with previous data.

In addition to the pinna's frequency-contouring effect, the auditory canal, through which sound must pass on its way to the eardrum, also constantly filters the sound (Fig. 6). This gross coloring of the spectrum is common to all that we hear. Our brains make allowance for it with a sort of multiband automatic gain control.

Jens Blauert pointed out, in his 1983 book, *Spatial Hearing*, how we associate certain directions with certain timbres (Fig. 7). The

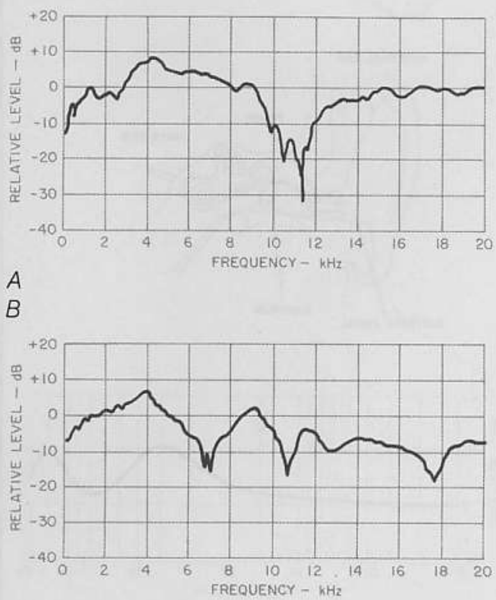


Fig. 3— Pinna response for sound source at 90° azimuth and 15° above ear level (A) and at 180° azimuth (directly behind the head) and below ear level (B). Note the high-frequency attenuation in (B). (After Rodgers.)

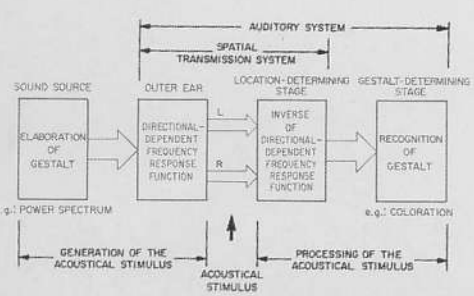


Fig. 4— Gunther Theile's Association Model of binaural hearing; see text.

AFTER THE TIN-CAN TELEPHONE,

OF THE SIMPLEST TYPES OF AUDIO AND

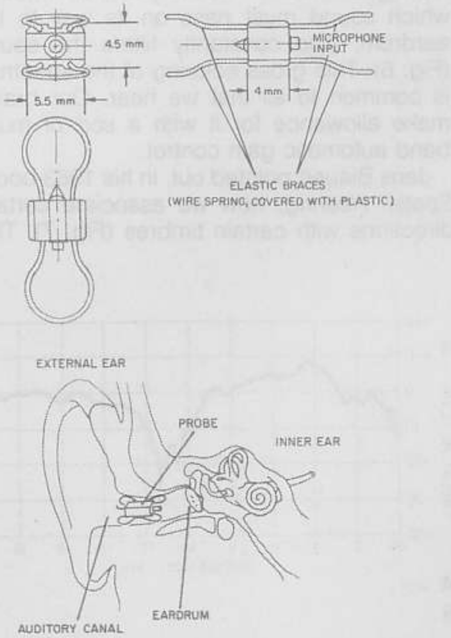
perception of a sound's location can be changed just by changing its equalization. The most familiar example of this is adding "presence" to a sound by raising the frequencies in the vicinity of 2.5 kHz. The plots clearly show that the main characteristic of frontal sounds is just this peak—the strongest frequency in the sounds we perceive from the front. So a peak at that pitch increases our feeling that the sound is close in front of us—increases, in other words, its "presence." Similarly, a peak at about 7.5 kHz in the sound source will be heard as coming from above one's head, no matter where the actual sound is located.

C. A. Rodgers observed that the spectral cues from pinna filtering were probably assisting the brain in resolving difficulties in differentiating sources directly in front from those directly in back. She also states that there is much yet to understand about the decoding mechanism of the pinna transfer functions. We do not know where the "location code" is contained—in the spectral nulls and peaks, or in a gestalt of the entire frequency spectrum. Also, it has been assumed that each person learns the localization cues provided by his own ears and localizes best with those specific cues. However, one study suggests that some pinnae provide more adequate cues than others. Will high-end binaural buffs one day actually cover their outer ears with putty and put on special headphones with flexible plastic "optimum ears" attached?

The pinna transfer functions are also felt by Rodgers to be important to better understand the Haas, or precedence, effect, which states: "If two sounds that are nearly alike follow each other in close consequence, they will be heard as one sound." She points out that the key phrase here is "nearly alike." Early reflections often come to the ears from many directions, and because of the spectral filtering of the pinnae, when they reach the eardrum, they are no longer nearly alike.

One study by Plenge went beyond the usual assumption that the subject's head would be fixed in hearing tests involving loudspeakers. He concluded that the listening sense does not use all arriving acoustic stimuli but makes a reduction by an appropriate choice process. It attaches the continuous information stream to gestalts, which it recognizes by using stored/learned perception patterns in the brain. Stimuli which cannot attach to these learned and stored patterns in a plausible arrangement with other stimuli are ignored. Another researcher's theory is that an entirely different process in the brain decodes recorded or broadcast binaural sound as compared to the process used in normal hearing.

The listener's brain is merely the final stop in the chain from the origin of the sound source to the experience of hearing its transmission or its delayed reproduction. There are variables in the transfer function at every step: The room in which the original sounds are made; the microphones in the dummy head; the construction of the head, pinnae,



A
B

Fig. 5— Probe using Knowles' miniature mike (A) and its placement in the ear (B). (After Theile.)

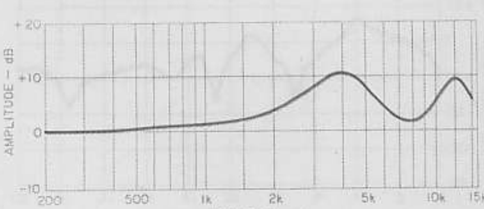


Fig. 6— Filtering effect of the ear canal, based on mean value of canal transfer functions measured by Shaw et al. The most effective frequency bandwidth for aural localization is from 625 Hz to 2.5 kHz; the point of greatest 360° imaging uniformity is 1.25 kHz, and the most sensitive point for image perception occurs from about 2.5 to 2.7 kHz. The resonance of the ear canal is at 7.5 kHz; the reference frequency (0 dB) is 315 Hz. (After Shaw.)

BINAURAL SOUND RECORDING IS ONE POTENTIALLY ONE OF THE BEST AS WELL.

and torso (if there is one) of the dummy head; the headphones placed on the dummy head and tested with probe microphones (preferably the same model headphones to be worn by the listener), and the transfer function with the listener's 'phones, pinnae, and ear/brain processing which concludes the chain.

A number of amateur binaural sound enthusiasts have made their own artificial binaural heads by using permafoam or wooden wig heads and drilling holes in the ears to mount small omnidirectional mikes. As we'll see, these two materials are just about the least suitable because they don't have any of the physical characteristics of the human head. Others have gone the route of mounting small electret mikes in, on, or near their own ears, sometimes using a spring headband such as that found on earmuffs.

For a time, JVC and Sony manufactured stereo headphones with built-in binaural mikes. This was a compromise solution because the low frequencies had to be filtered out to prevent feedback from the headphones. However, recording binaurally with small mikes in one's own ears often can provide the greatest realism, especially when the same person who made the original recording listens to the playback via headphones.

There are a number of obvious drawbacks to actually wearing the binaural mikes. Great care must be taken to keep the head perfectly straight and still during recording. If the head is turned to the side even a little, when one later listens to the recording, the entire musical group will seem to suddenly shift position in front of the listener! One must also be extremely quiet, since whispering, coughing, even heavy breathing will be clearly picked up by the mikes. A portable recorder is, of course, a necessity for this type of recording. I use a Sony Pro Walkman; others are having success with one of the portable DAT recorders. Since the recordist has to have the machine on his person, however, it cannot be a large studio model. *If* one can keep still, some astounding recordings of shorter musical selections and sounds can be made wearing the microphones.

However, for serious use, and especially for laboratory testing of the binaural hearing experience and improvements in the recording process, an artificial or dummy head is a necessity. In Germany, this is known as a *Kunstkopf* (*Kunst* is German for "artifice," *Kopf* for "head"). A number of such artificial heads are available for experimental, acoustic research, and recording purposes.

One of the most ingenious and, at the same time, affordable to advanced amateurs, is the Sennheiser MKE 2002 (Fig. 8). Recognizing that a professional head with quality mikes mounted in it is very expensive, Sennheiser came up with their triaxial stereo microphone, which looks something like the acoustic headphones used on airlines. The two sensitive condenser mikes at the end of the "Y" yoke fit close to the ears but do not actually enter them. The power supply is in a

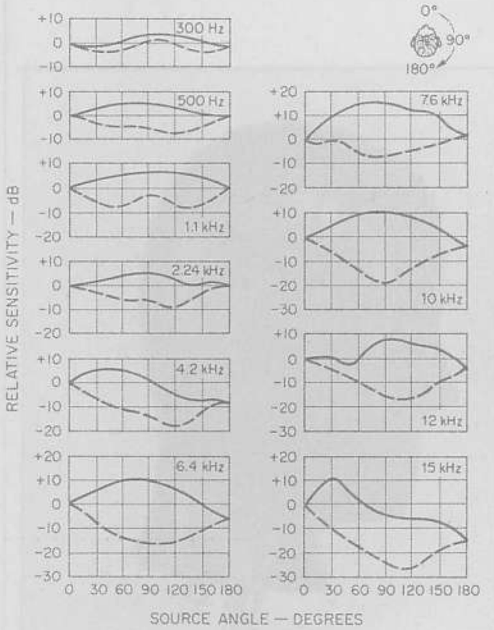


Fig. 7— The association between timbre and perceived source location can be inferred from these graphs, which show variations in the ear's sensitivity, at various frequencies, for source locations from front to back along one side of the head (top right). Solid curves represent the near ear, dashed curves the far ear. Note that the ears' responses do not mirror each other. (After Hiraga.)

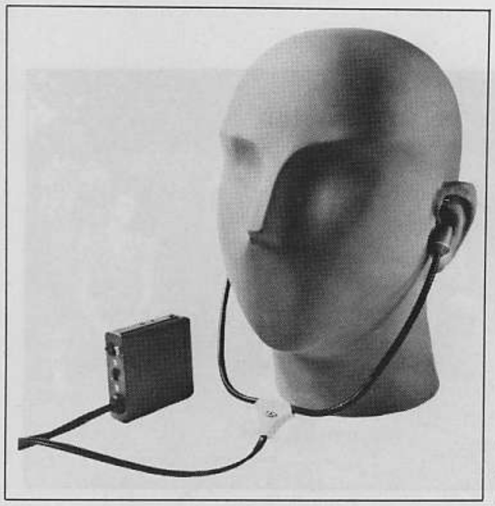


Fig. 8— Sennheiser's MKE 2002 triaxial stereo mike.

ORDINARY TWO-CHANNEL RECORDING OF OUR HEARING, ESPECIALLY

small attached box with leads running to a portable recorder.

The developers of this system, which has been available unchanged for over a decade, recognized that the binaural effect would not be as good when this mike is used with the dummy head they supply for concert recording and other situations where the mike cannot be worn by the individual.

While the gray, rubbery-surfaced head with mike-stand screw mount has an appropriate consistency, the pinnae are not detailed and cannot be expected to give the same sophisticated location cues as your own ears.

To use the Sennheiser dummy head, the "Y" yoke mikes are simply fitted into the ears just as on your own head. There seems to be greater high-frequency content when recording with the dummy head as opposed to wearing the mikes; perhaps this is due to the lack of hair and finished pinnae. Sennheiser urges binaural listeners to employ open-air-type headphones for best results, but as we'll see later, equalization factors seem to affect results more strongly than differences between closed- and open-ear designs.

The Neumann KU 81i (Fig. 9) has been widely used by professionals for binaural recording, as well as some lab work, for a number of years. The original models had the condenser mikes buried deep in the head, which was split side to side to access the mikes. However, it was learned that locating the mikes at the end of the artificial ear canal, where the human inner ear would be, caused equalization anomalies: In the listening process, the sound passed through the ear canals twice instead of just once! So most dummy heads now mount the mikes with their diaphragms as close as possible to the plane of the human eardrum.

A number of improvements have been made in the Model "i" version, primarily based on Theile's Association Model. Its improved pinna forms have all the pleats and cuts of actual human ears, as well as a similar texture and consistency. The head is equalized for flattest response as measured in a diffuse field, which is a different concept from the free-field approach of some other binaural researchers.

Free-field measurements of audio transducers are frequently made in an anechoic chamber—one which is free of all reflected sound. Only direct, frontal, acoustically flat sound is dealt with. In a pinch, measurements are sometimes made outdoors, where due to the lack of reflections, the results are similar to those obtained in a free-field environment. Adherents of this approach feel that dummy heads and mikes equalized for the free field provide the correct tonal character of sound for images directly in front. They also believe that for loudspeaker reproduction, these binaural recordings are superior to those made with diffuse-field EQ.

Fig. 9—Neumann's KU 81i professional artificial head with condenser microphones.

Kalifi, an ensemble from Ghana, being recorded with a Neumann dummy head for a West German CD on the AudioStax label.

TENDS TO IGNORE THE COMPLEXITIES

THE ROLE OF THE PINNA.

Diffuse-field conditions take into account not only the direct sounds but also their reflections. The further away the mikes are from the sound sources, the more diffuse the sound is because the ratio of reflected to direct sound increases Followers of this method point out that natural hearing conditions are nearly always diffuse-field and that this approach thus seems more realistic when listening on properly equalized headphones. A gentler equalization is required than with free-field, which means that many standard headphones are closer to diffuse-field parameters than to free-field. These 'phones require an adjustment in their high-frequency response to flatten the sound arriving from some directions.

The calibration procedure for both approaches (after calibration of the dummy head) is to insert the small probe mikes 4 mm inside the ear canals of the listening-test subjects and, without their wearing headphones, to make an equalization chart. (For free-field calibration, the sound originates from directly in front; for diffuse-field, the source speaker is rotated in various directions around the listener's head.) The probes are then left in the ear canals, and the same equalization is carried out while the listener wears the headphones. The idea is to achieve the same flat response as without headphones—the total response must be as flat as possible. David Griesinger feels that the claims of free versus diffuse fields may be moot because of the wide range of equalization in individual listeners' hearing. In other words, if an overall average transfer function is decided on as a universal standard, it will be so generalized that the smaller differences between free- and diffuse-field conditions will be unimportant. Griesinger proposes a standard somewhere between the two, with an off-axis front angle from 0° to 20° as the important direction.

The Brüel & Kjaer Type 4128 head and torso simulator (Fig. 10) is an expensive unit designed for objective measurements on audio communications devices such as telephones, headsets, and hearing aids; evaluation of hearing protectors and noise-cancelling microphones; testing of headphones; investigation of room acoustics and speech intelligibility; evaluation of stereo sound fields, and motor-vehicle noise-control work. Its proportions are said to replicate those of a median adult human. Brüel & Kjaer ½-inch condenser mikes are mounted in the realistically formed silicone rubber pinnae. The unit even comes with a low-distortion "mouth simulator," used for testing communications mikes, telephone equipment, and sound-reinforcement systems.

While some of the dummy heads I've mentioned look like body parts for a *Star Wars* robot, the Knowles Electronics Manikin for Acoustic Research (KEMAR) is scary in its nearly human appearance (Fig. 11). It is an-

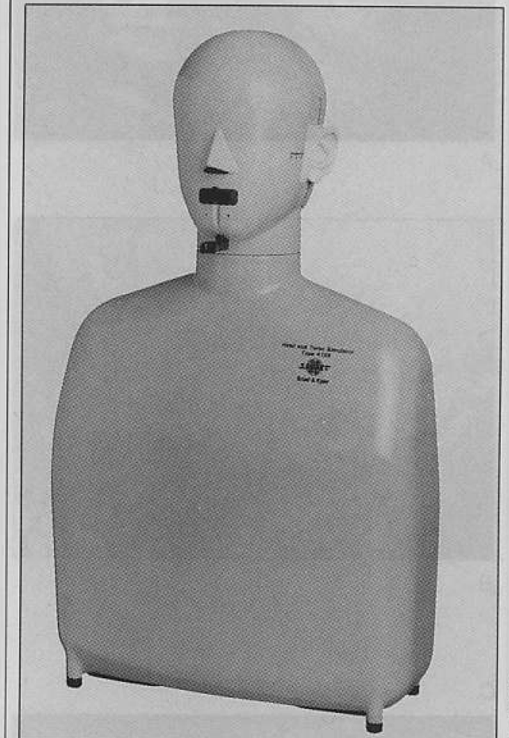


Fig. 10— B & K's Type 4128 head and torso simulator.

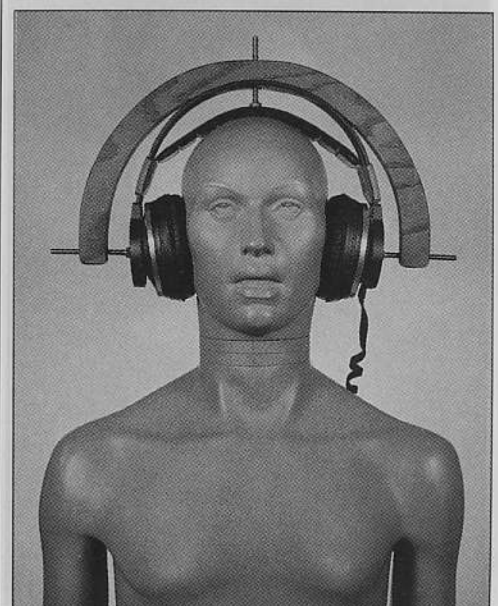
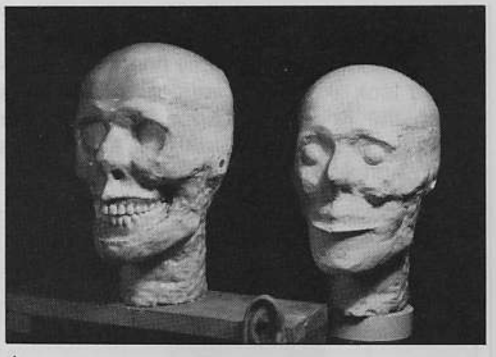


Fig. 11— The KEMAR mannequin, with a zero-static-force restraining yoke holding headphones under test. (From Russotti, Santoro, and Haskell.)

IN THE PAST 25 YEARS, RESEARCHERS

THE LOCALIZATION CUES GIVEN



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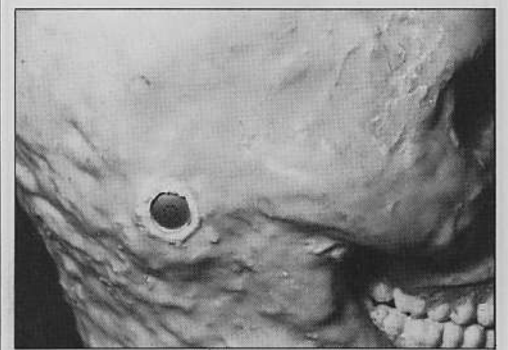

B

C

Fig. 12— Construction of the "Mr. Aural II" and the "Lady Aural" dummy heads. In overall view (A), the left skull has synthetic internal packing—brain, tongue, ported nostrils, and sinus cavities—in place. Right skull is plaster cast of skull on left, but with all open areas—nostrils, mouth, eyes, etc.—built up, to be used as a form for constructing an outer facial mask to be placed over head on left. The close-up (B) shows mike transducer in auditory canal area. Completed "Lady Aural" version, with microphones in place, is shown on its stand (C). (Photographs courtesy of Ron Cole.)

thropometrically proportioned in fiberglass-reinforced polyester; some of the interior is hollow to allow for cables, mikes, and other equipment, while the rest is coated with lead-pellet-filled resin to reduce resonances. The ears are removable, as with the Brüel & Kjaer unit, and there is also an ear-canal extension for tests requiring ear canal/eardrum simulation. The method of attachment permits other sizes and shapes of pinnae to be used if desired.

In 1986, KEMAR was used by researchers at the Naval Submarine Medical Research Lab in Groton, Conn. to establish testing procedures for circumaural (on-the-ear) headphones. Prior to this, the only measurement standard was specifically for supra-aural (insert) headphones. Digital conversion-function techniques were used to measure the frequency response of several popular stereo headphones from Sennheiser and Stax. Even with this highly accurate dummy head and torso, it was found that the rubber pinnae did not compress under normal headphone headband pressures, as human ears do, so bass response was less accurate than could be expected in actual use.

Ron Cole, a researcher in Southern California, has been evolving dummy head designs for some years, calling his process Biophonic Sound. Cole's desire to replicate, as accurately as possible, the softness and hardness of various skull areas, as well as the head's interior density, led him originally to experiment with actual human skulls! (At the risk of being mundane, I should point out that Cole obtained his skulls from a medical supply house.) He soon found such wide variations in the real thing that he opted to start from scratch and build his own; he now uses a proprietary latex/polymer material, chillingly fleshlike to the touch, to cover his heads (Fig. 12). The interior is packed variously with polyurethane foam and cotton to imitate the brain and other tissues—all of which Cole feels contribute to the perfection of binaural localization.

Cole's latest Biophonic design, which has resulted in "Mr. Aural" and "Lady Aural" heads, exaggerates certain facial features to compensate for faults in the microphones and for phase anomalies in the recording electronics. This has resulted in lateral frontal imaging that is vastly improved over the elevated and indistinct frontal image of some other binaural systems.

Cole identifies several conditions for achieving the most effective binaural replica of actual hearing. First, the passive response characteristic of the ear canal must exist, but

HAVE SHOWN THE IMPORTANCE OF
BY THE PINNA, OR OUTER EAR.

the real time delay of the canal cannot. Second, phase mirroring must be used to cancel out phase summing in the listener's ear canal. (Cole accomplishes this by critical tuning of the passive-equalization amplitudes and responses.) Third, the surface travelling-wave effects of the cranium, together with the resonance of the ear canal, must act as a single, unified, tuned instrument at mid- and high frequencies (Fig. 13).

He has further learned that extremely flat phase response is vital to the binaural effect. For example, a 30° phase lag at 2 kHz can shift an overhead sound source in the rear to an unnatural, overhead-in-front location, while a 30° phase lead will create the inverse. Because of such phase sensitivities, Cole feels that transformers should not exist anywhere in the signal path.

Binaural recordings often begin with identification of the left and right channels; this is much more important than with ordinary stereo. Left and right orientation cannot be reversed between the making of a binaural recording and its reproduction. According to Cole, localization processing is "a function of differential level sensitivities between the two ears and brain, plus the associated phase relationships summing to the original amplitude differentials."

His tests involved 30 right-handed subjects (response patterns are different for left-handed subjects, though their brains make the proper correction). The top-view response sensitivities create a "Big D" pattern (Fig. 14) due to the right ear being about 7 to 7.5 dB greater in sensitivity. A similar plot for a dummy head would be quite different, correlating more closely on the left side but with a major "difference region" on the right and around the back, due to the sensitivity being mirrored on both sides equally.

The Aachen *Kunstkopf* (Fig. 15) of Dr. Klaus Genuit of Aachen, Germany uses a special processor whose circuitry removes the pinna's transfer function. Genuit's processor achieves flatter response and makes playback of binaural recordings successful through speakers. With exact free-field equalization, playback through headphones is even better, but for many 'phones, results are good without additional equalization.

The Aachen head is similar to the popular ORTF stereo microphone, which places two cardioids 17 cm apart, at an angle of 110°. (The 17-cm separation simulates normal spacing of the ears, while the angle simulates the ears' directional pattern.) Thus, ORTF recordings are well suited to listening with headphones and with speakers. The Aachen head equalization results in fewer errors in the low frequencies than does the ORTF, and the actual head reproduces all the phase and surface-wave characteristics pointed out by Ron Cole.

The *Kugelflachenmikrofon* (*Kugelflachen* is German for "spherical surface," *Mikrofon* for "microphone") is a spherical dummy head system developed by Gunther Theile to improve loudspeaker reproduction. It has neither features nor pinnae, and surface mikes are embedded in it. Its response is very close to that of a standard dummy head, without need for special equalization. Even with headphones, many listeners find it difficult to tell its recordings from those of a true dummy head.

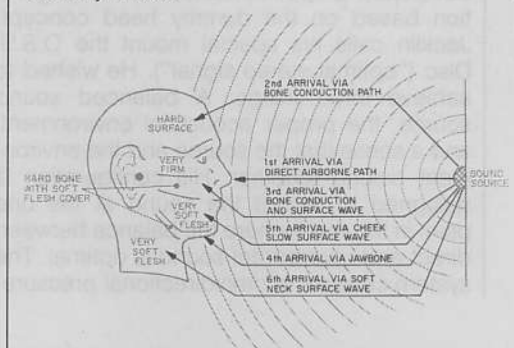

Fig. 13— Airborne and surface-wave sound paths to the ears and the order of arrival times. (After Cole.)

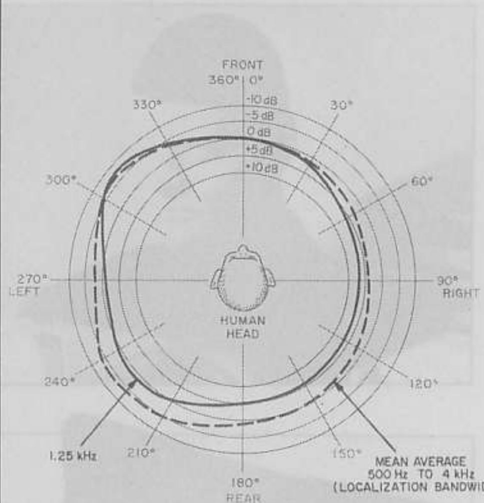

Fig. 14— Lateral-plane left/right sensitivity is shown for right-handed listeners. This curve's "Big D" shape, with the typical 7.5-dB difference in sensitivity between ears, shows why channels cannot be interchanged in binaural recording and listening. The shape would be different for a dummy head (because left/right sensitivity is basically mirrored the same on both sides) and for left-handed listeners. For this plot, from an average of 30 subjects tested in 1983 and 1984 by Cole, an acoustic source with a constant level of 0.25 watt at 1 meter was kept at a constant distance from the listener around the measurement circle. (After Cole.)

USING A PORTABLE TAPE RECORDER AND BINAURAL MIKE HEADSET, YOU CAN MAKE ASTONISHINGLY GOOD RECORDINGS.

There are several other quasi-binaural mike arrays in current use. One of these, from Crown International, was originally offered as a binaural microphone. In its latest version, however, it is referred to as a Stereo Ambient Sampling System (SASS) designed for highly localized stereo imaging in loudspeaker reproduction, with a successful summing to mono (impossible with widely spaced mikes). The SASS (Fig. 16), said to accurately convey the ambient environment, is available with either a pair of Brüel & Kjaer 4006 omnidirectional studio mikes or a pair of Crown International electret PZM mikes.

Swiss recording engineer Jürg Jecklin, the head of a small classical record label, has developed a special microphone configuration based on the dummy head concept. Jecklin calls his special mount the O.S.S. Disc ("optimal stereo signal"). He wished to achieve three things: A balanced sound source, the proper acoustical environment, and a sense that the source and the environment belong together. His configuration is designed to record the sound at the one point in the room where the balance between direct and reverberant sound is optimal. The system consists of omnidirectional pressure-zone mikes spaced 165 mm apart to produce the proper time-delay differences between channels. They are acoustically separated by a disc 280 mm in diameter, damped on both sides to avoid reflections. A similar, but rectangular, configuration was offered by Bang & Olufsen in the 1960s, with ribbon mikes in a figure-eight pattern. Both of these types would be considered quasi-binaural. A coherent, 360° stereo signal is the result, incorporating intensity, time-delay, and frequency-response differences between the channels. Other types of omnidirectional mikes may also be used with the O.S.S. Disc. Headphone listening is excellent, though not truly binaural. This configuration has found considerable use for recording classical music and jazz in France and Switzerland. I have found that European engineers sometimes refer to such a configuration as an artificial head pickup. In fact, it is not actually a dummy head.

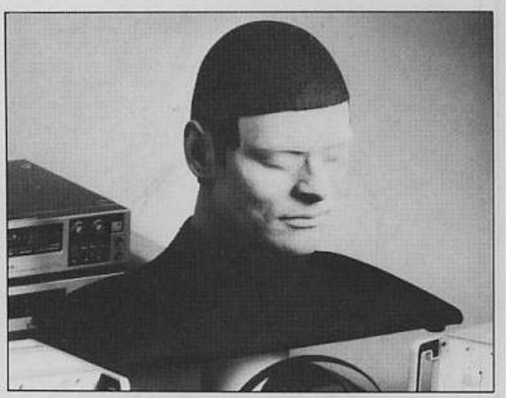

*Fig. 15—
The Aachen dummy head, which is compatible with loudspeakers, and its associated hardware.*

*Fig. 16—
Crown International's SASS quasi-binaural mike configuration, using PZM microphones.*

Some years ago, the French recording engineer A. Charlin used what he referred to as a *tête artificielle*, and some of his recordings are still available on CD. This "head" is actually two convex discs, much like shallow bowls, fastened together and covered with fur. The mikes are mounted on opposing sides, protruding some distance from the fur's surface. The Charlin head was used in 1958 for recording some of the first French stereo discs. The French label, Harmonic Records, uses the Charlin head in recording CDs. Headphone listening derives very little actual binaural localization from these recordings, but they sound fine on loudspeakers. French Harmonia Mundi reports that many of their recordings of early music are made with a basic artificial head system, often with judicious use of additional spotlight mikes for certain soloists.

If the *Audio* reader is moved to try his hand at building a dummy head—or binaural microphones to fit on his own ears—I suggest two do-it-yourself articles: Gene A. Nelson's "Build a Binaural Mike Set" (*Audio*, May 1976), in which Nelson uses a headband to hold two Panasonic electret mikes, and Thomas Krehbiel's "Build a Binaural Mike-set" (*Hands-On Electronics*, April 1987). Krehbiel's unit is mounted in a permafoam wig head, which Ron Cole's work suggests is unsuitable because its density is nothing like that of the human head. I would prefer to see Sony, JVC, or others bring back their simple binaural mike/headphone systems, given the current rebirth of interest in binaural sound.

In Part II, we'll delve further into the recording end of the binaural chain. 🅰