

Field Measurements of Electromagnetic Interference in Hearing Aids

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Abstract

This investigation was a preliminary field study to determine the acoustic and perceptual characteristics of hearing aid distortion generated by digital wireless telephones, the usability of the telephones under field conditions, and the extent of bystander interference under field conditions. A two-channel analog-to-digital converter was used to monitor voltages generated by an acoustic (real-ear) and electromagnetic probe. Digital recordings of interference and speech plus interference were made on a laptop computer. Fifty-three hearing aid wearers listened to interference and speech plus interference through personal communication service 1900 and time division multiple access digital wireless telephones and rated them in terms of annoyance experienced and usability of the wireless telephone. Ratings of annoyance were also done for the bystander condition. Approximately 80 percent of the sample rated the telephones as unusable; on the other hand, 70 to 90 percent experienced no annoying interference from telephones being used by another person seated nearby (bystander condition).

Key Words: Hearing aids, telephones

Abbreviations: BTE = behind the ear, CDMA = code division multiple access, EM = electromagnetic, PBX = private branch exchange, PCS = personal communication service, RF = radio frequency, TDMA = time division multiple access

The primary objectives of this investigation were to (1) determine the acoustic and perceptual characteristics of hearing aid distortion generated by digital wireless telephones, (2) determine the usability of the telephones under field conditions, and (3) determine the extent of bystander interference under field conditions. It was considered important to measure this distortion with human subjects in conditions representative of actual use as concurrent and previous research have been done under laboratory conditions (Le Strange et al, 1995; Ravindran et al, 1996). The motivation for this research was the considerable concern among consumer groups about the imminent intro-

duction of new digital wireless telephones that might interfere with hearing aids in daily life.

The problem of digital wireless telephones' interference with hearing aids is a complex and dynamic one. Wireless telephones contain a radio transmitter that generates electromagnetic (EM) signals at very high frequencies, in the order of 900 or 1900 MHz. In the case of digital wireless telephones, these signals are switched on and off systematically so as to allow for several communication channels to operate simultaneously on a single carrier frequency. Three basic types of switching are in current use: (1) periodic switching at the rate of 50 times per second, (2) periodic switching at 217 times per second, and (3) nonperiodic switching. Different telephone companies use different forms of these three methods of switching. The personal communication service (PCS) 1900 (a service using the "J" standard 0007 of time division multiplexing) technology, for example, uses a 217-Hz switching rate, whereas the time division multiple access (TDMA) technology typically uses a

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50-Hz switching rate, and the code division multiple access (CDMA) technology uses a quasi-random, nonperiodic form of switching.

If an audio amplifier containing one or more nonlinear circuit elements is placed in one of these EM fields, the switching modulations will be demodulated and amplified, resulting in an audible interference. As a consequence, the PCS 1900 and TDMA technologies will generate audible interference with a strong harmonic structure, the fundamental frequency being either 50 or 217 Hz, depending on the switching rate. The CDMA technology will also introduce audible interference but without the strong harmonic structure.

Hearing aids are wearable, special-purpose audio amplifiers that are particularly prone to picking up (i.e., demodulating) EM interference from digital wireless telephones because of the close proximity of the telephone antenna to the hearing aid amplifier. There are two basic forms of interference. The more serious form, known as user interference, occurs when a person using a hearing aid places the telephone near the hearing aid to place or receive a call. Bystander interference may occur when a digital wireless telephone is used by someone else, close to a hearing aid user (e.g., as on a bus or train).

The intensity of EM interference in an audio amplifier usually decreases in inverse proportion to the square of the distance between the source of EM energy (i.e., the antenna of the wireless telephone) and the audio amplifier (e.g., hearing aid). This rule holds if there are no large metal or other materials in the vicinity that may cause additional EM energy to be reflected to the audio amplifier. As a consequence, bystander interference can be reduced substantially by increasing the distance between the wireless telephone and the hearing aid. (For example, a person using a wireless telephone sitting next to a hearing aid user should, as a courtesy, use the ear that is further away from the hearing aid user.)

The above inverse square rule does not hold for user interference. In this case, the hearing aid and telephone antenna are so close that near-field effects dominate. Under these conditions, small changes in the position of the telephone antenna relative to the hearing aid will produce large changes in the level of the interference in a complex way. It should be noted that the EM field generated by a telephone antenna consists of both an electrical field and a magnetic field. The electrical field is strongest at the tips of the antenna, whereas the magnetic

field is strongest at its midpoint. Moving the wireless telephone handset (which contains the antenna) relative to the hearing aid will thus change the strength of the EM interference but not always in the desired direction.

The fact that there are two types of fields, both changing rapidly with small changes in position, makes it very difficult to gauge from the telephone alone what the effect will be on a hearing aid in field conditions. The route we chose, therefore, was not to measure what is coming out of the telephone but what is coming out of the hearing aid.

METHOD

Instrumentation

A system was developed for monitoring both the EM field at the ear and the resultant acoustic interference in the ear canal of the hearing aid wearer. The system was configured around a Gateway 2000 notebook computer. A two-channel analog-to-digital converter (16-bit precision at a sampling rate of 22,050 Hz) was used to monitor voltages generated by an acoustic and an EM probe, respectively.

The acoustic probe consisted of a 3-inch plastic tube, the open end of which was placed in the ear canal along with the hearing aid, according to standard audiologic practice. The diameter of the tube is small enough to fit between the earmold of the hearing aid and the wall of the ear canal. The far end of the tube terminates in a miniature microphone, the output of which is fed to a matched preamplifier. The output of the amplifier, which was calibrated, was fed to one of the two input ports of the two-channel analog-to-digital converter. All metal components of the system had radio frequency (RF) shielding.

The EM probe initially used was the behind-the-ear (BTE) detector developed by Mead Killion. The unit consisted of a hearing aid microphone mounted in a BTE hearing aid case. The EM field is demodulated by a nonlinearity in the microphone. The demodulated signal is superimposed on the bias voltage of the microphone, which, in turn, is conveyed to the analog-to-digital converter using leads made of carbon-impregnated Teflon. These leads have high resistance at RFs so as not to pick up any unwanted RF signals. They also do not disturb the EM field to any significant degree. The BTE detector primarily monitors the electrical (E)

component of the EM field. The BTE detector was mounted behind the ear as if it were a BTE hearing aid. If the subject was wearing a BTE hearing aid, the two units were mounted alongside each other behind the ear. Later, a high-frequency diode was substituted for the BTE detector. This diode was more sensitive in monitoring the modulations of the EM field.

In addition to the above, an RF probe (NARDA model 8718) was used to measure the far-field intensity of the RF signal. This probe uses a heating element to measure the true rms value of both the electrical (E) and magnetic (H) fields and has a relatively long time constant. As a consequence, the unit was insufficiently responsive in the time domain for useful measurements under field conditions, and these data were not used.

Calibration data indicated that, effectively, the EM field was not affected by the instrumentation and that the instrumentation, in turn, was not affected adversely by the EM field. The acoustic probe thus provided an accurate indication of the acoustic interference in the ear canal.

Experimental Procedures

Data were collected in the Washington, DC, area in the summer of 1996, when digital wireless service was quite new. Three brands of telephones were used on two types of digital systems: the PCS 1900 (J STD 0007) service, then available under the brand Sprint Spectrum, and the TDMA IS-54, then available as Cellular One. The TDMA system was not at that time completely built, and some TDMA calls were completed in analog mode because the system automatically switched calls to an analog channel when a digital one was not available. Note that CDMA service was not available in the Washington area at the time of the study; therefore, data were not obtained for that technology in the initial study. Data on CDMA technology have been obtained in an ongoing subsequent study. Telephones and subscriptions to digital telephone services were purchased at retail outlets in the greater Washington area.

Subjects were recruited from the mailing list of Self-Help for Hard of Hearing People (SHHH). Two locations, one in the District of Columbia and one in Bethesda, Maryland, were used for data collection. Two locations were used as a way to vary the transmission strength and thereby vary the power of the telephones. Data were collected in quiet, windowless rooms so as to

avoid the intervening effects of ambient noise in interpreting the results.

During the experiment, subjects used the wireless telephones with the ear normally used for telephone calls. Subjects were asked to set their hearing aids to normal-use gain for the experiments.

Recordings of acoustic output in the ear canal were taken for the following conditions:

- Baseline measures on microphone and telecoil settings (where available) to determine the noise floor levels and to check for ambient interference in the system.
- Interference alone on microphone and telecoil settings, with the operating telephone as close as practicable to the hearing aid without causing discomfort.
- Interference plus speech on an actual telephone call. The calls were made from the wireless telephone to a wireline (PBX) station to which was attached a tape recorder and telephone interface. Recorded speech was used. Volume control on the telephone was set to maximum. The telecoil setting was not used because the telephones were not hearing aid compatible. As a consequence, subjects who normally use the telecoil input (roughly three-quarters of the subjects) were required to use the microphone input. Subjects rated the intelligibility and usability of the telephones while listening to speech on the live call.
- Steady-state interference (with the telephone in test mode, not on a live call) out of the line of sight of the subject (bystander condition). Measurements of bystander interference included the distance between the telephone and hearing aid at which interference is (a) just detectable, (b) annoying (mid-range rating), and (c) unbearable. (The latter condition was not always obtained.) Subjective assessments included
 - Annoyance ratings of interference alone (using a 5-point scale, from no interference to unbearable interference).
 - Intelligibility and usability ratings for speech with interference from operating wireless telephones.
 - Annoyance ratings when the telephone was used for a live call by a research associate seated beside the subject. These conditions were intended to approximate two commonly encountered conditions: that of a telephone user sitting next to a person wearing a hearing aid with (a)

the telephone on the side of the head closest to the hearing aid (ipsilateral) and (b) the telephone on the side of the head farthest from the hearing aid (contralateral). The midpoint of the subject's chair and that of the research associate's chair were 30 inches apart. Vinyl chairs were used.

Analysis

Signal Analysis

Digitized recordings of the acoustic signal in the ear canal were obtained for each test condition. These recordings are currently being analyzed to determine their power, spectral structure, speech-to-interference ratio, and other relevant variables. A time window consisting of 2048 samples (approximately 93 msec) is used for the spectral analysis and for measuring short-term fluctuations in signal level. This time window was chosen because it encompasses four to five periods of the lowest frequency interference (50 Hz), thereby allowing for a reasonably stable spectral analysis with good frequency resolution of this interference. A time constant of 93 msec is also comparable to the averaging time of the human ear. Two time windows were of particular interest in each recording: the window containing the highest short-term power and the window containing the lowest short-term power. In addition, the average short-term power averaged over all time windows was obtained.

Ratings and Distances

Frequency distributions of the subjective ratings have been graphed and descriptive statistics computed. The distances between the telephone and the hearing aid in the bystander condition have been analyzed using descriptive statistics.

RESULTS

Data were collected on 53 subjects ranging in age from 28 to 89 years, with a mean age of 60. All subjects reported using their hearing aids for voice telephony. Two-thirds of the subjects used BTE hearing aids on the ear used for telephone conversations. Three-quarters reported using the telecoil for wireline telephone conversations. Ninety-five percent of the subjects had used hearing aids for more than 2 years. For the ear used with the telephone, the three-frequency

pure-tone averages ranged from 8 to 102 dB, with a mean of 60 dB, based on the most recent audiogram. Eleven brands of hearing aid were represented in the sample.

The potential annoying effects of interference from wireless telephones used by others standing nearby has been of some concern to consumer advocates. Two methods were used to measure bystander interference. In the first, the researcher moved the telephone in horizontal arcs behind the subject on the same horizontal plane as the hearing aid but out of sight of the subject. The subject indicated given levels of interference (threshold, mildly annoying, annoying, very annoying, unbearable) by raising a hand. Distance measures were taken between the telephone and the hearing aid. Based on this method, the results indicated that some hearing aid wearers (25–38%, depending on the wireless technology) did detect wireless telephone interference at distances greater than 2 feet from the aid (Fig. 1). A smaller percentage (8–14%) received a level of interference that they considered annoying at more than 2 feet away.

The second method involved having the researcher place a call to the local telephone company's weather recording while seated next to the subject. When the telephone was used on the side of the head closest to the hearing aid (ipsilateral placement), the interference was inaudible or audible but not annoying to approximately 70 percent of the subjects, mildly annoying to 9 to 15 percent, and annoying or worse to 15 to 17 percent. When the telephone was used on the opposite side of the researcher's head (contralateral placement), interference was not detected at all by 85 to 90 percent of subjects, was mildly annoying to 4 to 6 percent, and was annoying to only 2 percent (i.e., only one of the subjects found the interference annoying). A number of subjects commented that they heard the interference only when the researcher moved the telephone from one side of the head to the other.

For user interference, 80 percent of subjects judged the digital wireless technologies unusable. The interference was such that many subjects had to hold the telephone away from the hearing aid to avoid discomfort. Speech through the digital wireless telephones was rated as unintelligible by 60 to 70 percent of the subjects, depending on the telephone, as illustrated in Figure 2. Note that telephone 3 on this figure frequently switched to analog transmission while being tested. As a consequence, the interference was much less using this telephone. On those

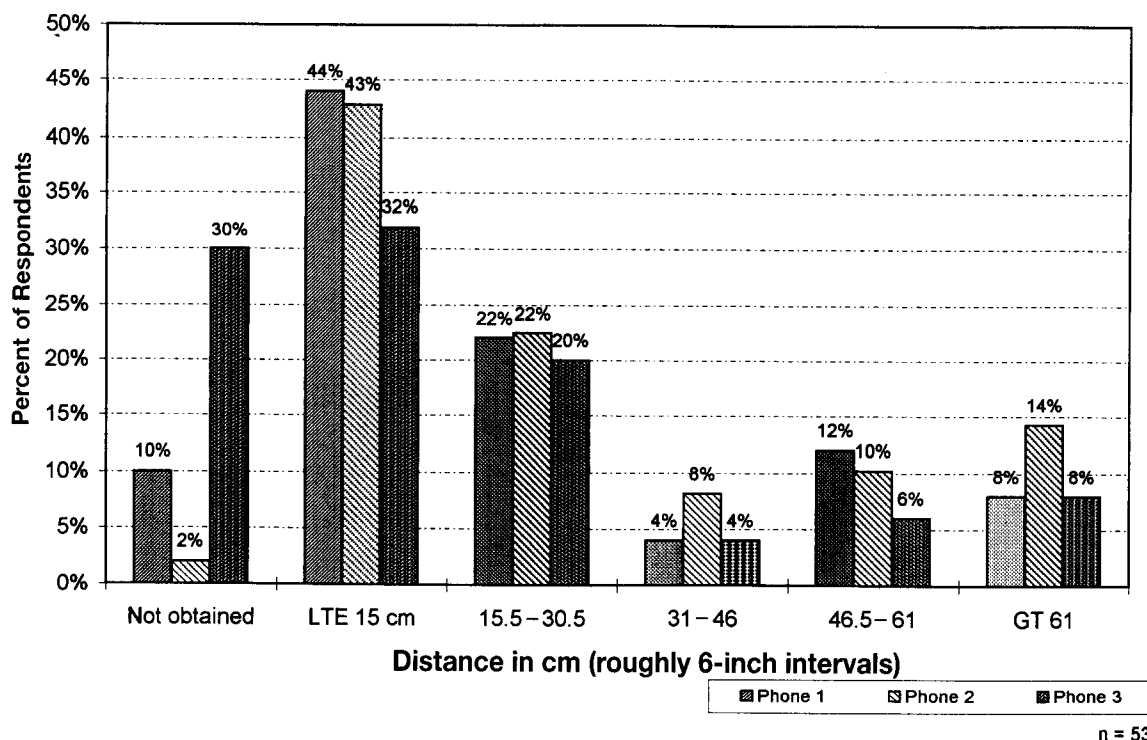


Figure 1 Annoyance as a function of distance. The vertical axis shows the percentage of respondents who found the interference annoying. The horizontal axis shows the distance between the wireless telephone and the hearing aid. Three telephones were tested. Telephone 3 frequently switched to the analog mode of operation while being tested. LTE = less than or equal to; GT = greater than.

calls in the analog condition, the ratings of usability and intelligibility were fairly evenly distributed across rating categories, which is more reflective of the variations in hearing loss of people in our sample. Thus, the poor ratings of usability and intelligibility cannot be attributed to subjects' hearing loss alone.

These data are currently being examined in more detail, along with new real-ear measures that we have collected in a second phase of research. We are interested in finding that critical speech-to-interference ratio at which the telephone is usable, where speech is sufficiently intelligible. The new experiment involved a "decoy" wireless telephone through which speech was played. The speech, a long conversation between two talkers, was recorded onto a digital recorder from a live call made over a digital wireless telephone. The recording was played through a hardwire connection to the decoy telephone, which uses an actual wireless telephone speaker. Thus, the conditions of wireless carriage of the call and use of wireless telephone components (including the vocoder) have been duplicated without the interference. In the new experiment, the telecoil was used by those subjects who normally use it for telephone calls. An

assistive listening device (HATIS) was plugged into the recorder and used for listening by the subjects. Interference was introduced via a test telephone for each of the three technologies, behind the subject and out of sight. Subjects were asked to listen to the speech and to indicate when the interference level reaches various levels of usability. At that point, the output of the hearing aid was captured by digital recording, using the same method used in the first experiment, and intelligibility ratings were obtained. The resulting output of the hearing aid was analyzed to determine the signal-to-interference ratio at various levels of usability.

DISCUSSION

The study reported here should be considered a preliminary field evaluation of digital wireless telephones and their effects on hearing aid wearers. PCS 1900 was evaluated in field conditions; the evaluation of TDMA was partially in test mode because the system had not been fully built out at the time of the study, and CDMA was not studied because it was not available at the time of the study. The sample in this study was skewed toward people with BTE

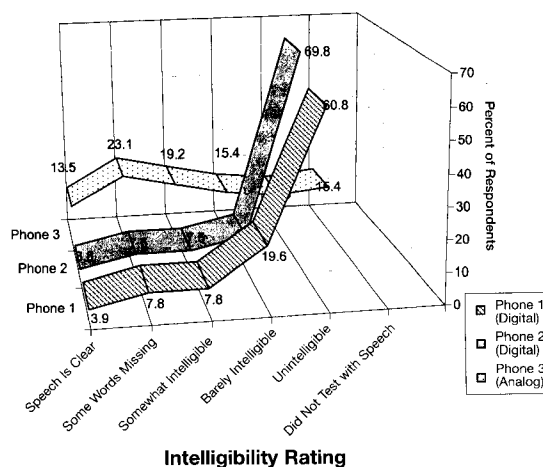


Figure 2 Intelligibility ratings for three wireless telephones. A five-category rating scale was used, ranging from “speech is clear” to “unintelligible.” The vertical axis shows the percentage of respondents for each category of the rating scale. The horizontal axis shows the five categories of the rating scale. The sixth entry on this axis applies to respondents who were not tested with speech. Three telephones were tested. Telephone 3 frequently switched to the analog mode of operation while being tested.

hearing aids, which have been shown in other studies to be relatively susceptible to digital wireless telephone emissions.

The results of the study showed that bystander interference is unlikely to cause a great deal of annoyance to most hearing aid users. Some hearing aid users will be exposed to increased bystander interference as the number of wireless telephone users increases and their use increases in public places. It is likely that the interference will be a temporary phenomenon, most noticeable when the bystander is in the process of placing the call and the strength of the EM field is greatest. It is advis-

able for hearing aid wearers to learn the characteristic sounds of this interference so that they can monitor the extent of it in their daily lives as wireless telephone use grows. Without knowing the acoustic signatures of various sources of interference, it is unlikely that hearing aid wearers will know where it is coming from. This will deter any action to rectify the situation—even to the extent of asking a wireless telephone user to move the telephone to the other side of the head.

User interference is a more serious problem because the telephone must be placed next to the hearing aid, thereby creating much more intense levels of interference. For many people using BTE hearing aids, the use of wireless telephones will be restricted to those telephones that can work with an assistive device that allows the telephone to be removed from the ear—at least until such time as emissions are reduced and the immunity of hearing aids is improved. Work is currently in progress addressing these issues by both the wireless telephone and hearing aid industries.

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