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The Australian Experience: Global System for Mobile Communications Wireless Telephones and Hearing Aids

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Abstract

A digital, wireless telephone system, the Global System for Mobile Communications (GSM), was introduced in Australia in 1993. Studies were conducted at the National Acoustic Laboratories to determine how the use of GSM mobile telephones (i.e., wireless telephones) causes interference in hearing aids and how hearing aids could be made more immune to such interference. A measurement system was developed, and measurements are presented for a variety of standard and treated hearing aids. Effective treatments include the addition of shunt capacitors to the hearing aid circuit and shielding by applying a conductive coating to the hearing aid case. Some recently produced microphones also increase immunity. High immunity levels can be achieved in future hearing aids, sufficient to prevent interference from other people's use of a wireless telephone and that often permit use of digital mobile telephones by hearing aid users. Audiologists will have an increasing role in advising hearing aid wearers on the use of wireless telephones or other communications equipment.

Key Words: Global System for Mobile Communications interference, hearing aid immunity, wireless telephones

Abbreviations: BTE = behind the ear, EMI = electromagnetic interference, GSM = Global System for Mobile Communications, IEC = International Electrotechnical Commission, ITE = in the ear, NAL = National Acoustic Laboratories

In Australia, there are over 300,000 hearing aid users, which adds up to well over 400,000 hearing aids as many fittings are bilateral. About 200,000 of these hearing aid users are clients of Australian Hearing. Australian Hearing standard-issue hearing aids are from a programmable range, and, currently, well over 90 percent of Australian Hearing clients have recently designed programmable hearing aids. The majority of the other hearing aids in Australia are in the ear (ITE) or in the canal. These facts are relevant because the biggest interference problem is with the older types of behind-the-ear (BTE) hearing aids, and, fortunately, these comprise only a small proportion of the aids currently in service in Australia.

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Wireless Telephones in Australia

Australia had an analog wireless telephone system for many years, and a digital system was introduced in mid-1993. This was the Global System for Mobile Communications (GSM), which has a carrier frequency in the 900-MHz band and a 217-Hz repetition rate. Everything reported here pertains to that system and is not necessarily applicable to other systems. Also, 900-MHz wireless telephones in Australia operate on a higher power level; they are 2-watt telephones compared with the 1-watt telephones used in the United States. It is uncertain whether this has had any effect on the subjective measurements to be reported here because it is not known whether the telephones were operating on full power or not.

It has been said that, in Australia, the use of wireless telephones is second only to Scandinavia and that the market is growing at 50 percent per year. Furthermore, the analog system was discontinued in Australia in 2000. This was not just for technical and economic reasons; it was announced as government policy that there would be no analog wireless telephone system after the year 2000. The implication of this for Australian hearing aid users who wish to use a wireless telephone is that they are now placed in a position where their only option is to use a digital wireless telephone.

Initial Concerns about Interference Problems

The possibility of interference problems became known when the National Acoustic Laboratories (NAL) was approached early in 1993 by engineers from the research laboratory of Telstra, which is the largest Australian telephone company. They were concerned that there could be some problems of electromagnetic interference (EMI) in hearing aids and other devices such as cochlear implants and various sorts of medical equipment.

An initial investigation was conducted as a combined effort between NAL and Telstra engineers, using simulated GSM transmissions. It was soon recognized that there was an interference and access problem, or, to use the common American terminology, there were potential problems with bystander and user interference.

Figure 1 shows some of the results from the initial investigation. This is a worst-case situation in that the hearing aids were not worn and there was nothing between the hearing aids and the emitting device. What is shown is the distance at which interference is approximately 10 dB above the noise level. This could be readily detected by a listener with normal hearing.

The left panel shows the results for BTE aids that were measured for both microphone and telecoil input. The first hearing aid (model VHK) is a BTE aid that had been in service since about 1985. On microphone input, it would pick up interference at 10 meters and, on telecoil input, at about 17 meters. VHK was a high-powered BTE hearing aid of what is now reasonably old technology. The other BTE hearing aids picked up interference at about 2 to 3 meters. The results can be different for telecoil and microphone. Depending on the particular hearing aid, interference may be worse for either telecoil or for microphone, or it may be much the same. These are the only telecoil results that will be shown in this article; in all of the following figures, the results are for microphone input.

The right panel of Figure 1 shows the results for three ITE hearing aids. Interference would be audible at distances ranging from 0.6 m to about 0.15 m. The first two aids (models Sonata and Serenade) had been in use for several years. The other aid (model IT312), the one that is relatively immune to interference, was one of the programmable aids used by Australian Hearing. It is not significant that it is programmable; it is just that it is newer technology, with more compact circuitry and less wiring to act as an antenna that could pick up unwanted interfering electromagnetic emissions.

This preliminary investigation indicated that there were grounds for concern and resulted in a report that was widely circulated (Joyner et al, 1993). Consequently, the interference problem was widely publicized, and there were various meetings of government, industry, and consumer groups concerned with telecommunications or hearing aids. The final result was that a technical group was formed to carry out a more comprehensive investigation of the problem and to devise means of measuring EMI and making hearing aids more immune to EMI.

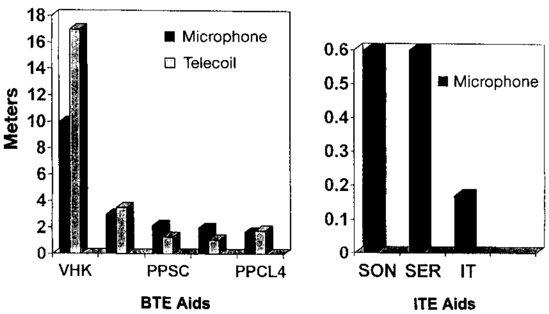

Figure 1 Initial study of interference to hearing aids from simulated GSM transmissions: maximum distance at which interference was detectable for five BTE aids (*left panel*) and three ITE aids (*right panel*). BTE results are for microphone (*left bar*) and telecoil (*right bar*) inputs.

MAIN STUDY

Aims and Methods

The study had several aims. One was to develop a measurement system that was accurate and would be practical for hearing aid designers and manufacturers. Other aims were to measure interference over a wide range of hearing aids and to devise ways of increasing the EMI immunity of the hearing aids. It was also desired to derive a basis for EMI immunity standards and to formulate some suggestions for improving wireless telephone designs to reduce EMI in hearing aids. All of these aims were achieved. In particular, a measurement system was developed, and EMI was measured on a range of standard and treated hearing aids. The technical measurements were related to the perceptibility of the interference by people with normal hearing. The perceptibility of the interference was also tested for hearing aid users.

Tests with Hearing Aid Users

Procedure

The hearing aid wearer sat on a stool at one end of a large office, and stretching out from the stool was a 4-m length of tape marked at 10-cm intervals. A telephone recorded message service was used to activate the wireless telephone and provide continuing acoustic output. The telephone was moved closer to and away from the hearing aid wearer to find the distance at which the interference was just detectable. The orientation of the hearing aid wearer to the telephone was varied systematically. It was found that the interference was nearly always greatest for the side-on position with the hearing aid closest to the telephone. All of the measurements reported here are for that orientation.

At least four and usually seven or eight hearing-impaired people were tested with each type of hearing aid. These were people who had hearing losses appropriate for the hearing aid. The hearing aids were not prescriptively fitted, but the high-powered hearing aids were tested on people with severe hearing loss, the medium-powered hearing aids on people with moderate loss, and the low-powered hearing aids on people with mild loss.

BTE Results

For hearing-impaired listeners, Figure 2 shows the distance at which interference could be detected for the BTE aids (left panel) and for the ITE aids (right panel). Some hearing aids were treated, and some were untreated. As individuals varied a good deal in how much they could detect interference, the figure shows the maximum distance at which interference could be detected by the most sensitive and by the least sensitive individual. Thus, two results are shown for each aid.

For the first aid on the left (VH), which is the fairly old technology untreated BTE, the majority of people could detect interference at 4 m, which was the maximum distance tested. However, contrary to this general finding, there was one person who could not detect interference until the telephone was within 0.3 m of the aid.

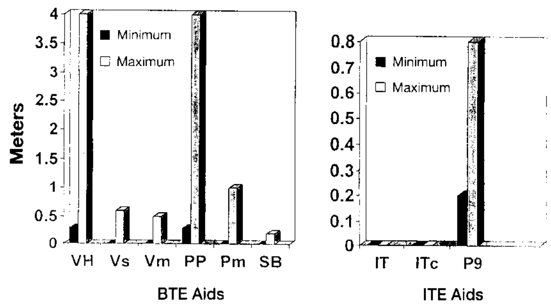

Figure 2 Distance at which GSM interference was detectable by hearing-impaired listeners (four to eight listeners for each aid) for three standard and three treated BTE aids (*left panel*) and two standard and one treated ITE aid (*right panel*). The left bar for each aid shows the least distance at which interference was just detectable by any listener, and the right bar shows the greatest distance at which interference was just detectable by any listener. (Maximum distance tested was 4 m.)

This shows how variable the effects can be for people with similar hearing losses tested with the same hearing aid. The aid labelled "PP" is another high-powered BTE aid. The results look as bad as those for VH, but, in fact, there were not as many people who could detect the interference at the maximum distance. The aid on the right of the panel (SB) is a medium-powered BTE aid from the newer programmable range. This aid was much less susceptible to interference; none of the listeners could detect any interference at distances greater than 0.2 m. This result is owing mainly to the more compact design.

The letters m, s, or c indicate that the hearing aids have been treated to reduce interference. An m indicates that the hearing aid case has been impregnated with metal fibers, an s indicates that a silver conductive coating has been applied to either the inside or outside of the hearing aid case, and a c indicates that shunt capacitors have been added to the hearing aid circuits so as to attenuate the high-frequency electromagnetic signals picked up by the hearing aid.

Vs and Vm are treated versions of the model designated VH. Also, Pm is a treated version of model PP. For both models, the treated versions significantly improve the immunity of these hearing aids to EMI.

ITE Results

The right panel of Figure 2 shows the results for two standard ITE aids and one treated aid. For the aid on the right (P9), some people could detect interference at about 0.8 m. This was a custom ITE aid similar to most of those that were in service a few years ago.

For the IT aid (a programmable aid of recent design), the interference was not detectable even when the telephone was within a few centimeters of the hearing aid. Some hearing-impaired listeners (and all people with normal hearing) could detect interference if the telephone was held over the hearing aid in the normal-use position. Some (but not all) of the hearing-impaired listeners could use this hearing aid with the telephone, using the microphone input and holding the telephone slightly away from the aid to avoid acoustic feedback. The same aid was treated by adding shunting capacitors (ITc).

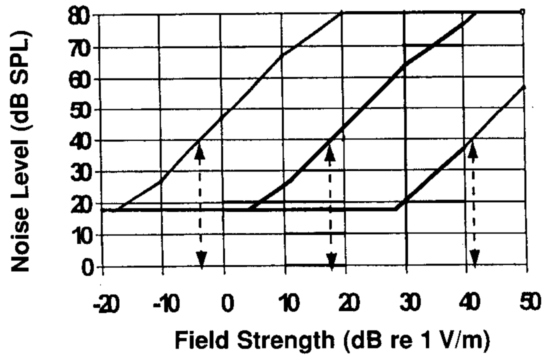

Figure 3 Immunity measurements for *(left to right)* one low-immunity hearing aid, one medium-immunity hearing aid, and one high-immunity hearing aid. The immunity level is the input (field strength) required to produce a noise level (equivalent input referred sound pressure) of 40 dB SPL.

Technical Measurement Methods

The measurement system and methods are described in detail in the report of the main study (Le Strange et al, 1995). There are two special items of equipment. One is a waveguide that is used in conjunction with suitable signal-generating equipment to create a well-controlled electromagnetic field as an input to the hearing aid. The waveguide is a rectangular tube of length 2 ms, height 250 mm, and width 125 mm. The other special item of equipment is a manipulator consisting of a cradle for holding a hearing aid and a gimbal arrangement for rotating the aid around three axes. The manipulator is fitted into the waveguide through a hole in the top. The purpose of this is to enable the hearing aid to be turned in any direction to find the orientation that maximizes interference. The rest of the measurement system is standard equipment for generating radio frequency signals and for measuring the noise output of the hearing aid. A computer is used to control all acoustic and radio frequency–generating equipment used with the waveguide, allowing full automation of the EMI test procedures.

Figure 3 is a simplified version of some figures in Le Strange et al (1995). It illustrates the nature of the measurements. It is like an input/output graph, such as used in many hearing aid measurements. The input is the electromagnetic field strength inside of the waveguide. This input can be varied to see what variations result in the noise output of the hearing aid. However, so that the immunity performance of both low- and high-powered hearing aids can be compared, the hearing aid output is referred back to an equivalent input level that would produce the measured output level for the hearing aid. This equivalent input referred sound pressure level is easily obtained by subtracting the gain of the hearing aid from the measured output level. The figure shows three measurements. From left to right, these are for a low-immunity hearing aid, a medium-immunity hearing aid, and a high-immunity hearing aid. Consider the middle graph, for example.

If there is no input, the equivalent input referred noise level of the hearing aid is owing to the internal noise of the aid. If a relatively weak radio field is generated—less than 11 dB in this example—the noise level remains at a low value, but when the field strength increases beyond that point, the noise level rises. For each 1-dB increase in radio field strength, the noise increases by 2 dB until the hearing aid is saturated.

For the low-immunity hearing aid, only a low-level input (field strength) is required to produce an increase in the aid's noise level. (The increase comes about when the EMI is added to the aid's internal noise.) For the high-immunity hearing aid, the noise level will increase only when the field strength reaches a high level. An important feature of these measurements is that for hearing aids operating in the linear mode, the graphs always form a straight line, showing a 2-dB increase in output for each 1-dB increase in input. It is thus completely predictable how the noise will increase when the field strength is increased once the field strength is sufficient to cause an increase owing to interference. Therefore, a measurement at one point on the graph can give an accurate picture of the aid's immunity.

A convenient measurement for comparing the immunity performance of hearing aids involves determining the electromagnetic field strength that produces a noise output equivalent to that produced by an acoustic input of 40 dB SPL. When using a ⅓-octave filter, this is a convenient level for measuring hearing aids ranging from very low to high immunity. Thus, the immunity levels for microphone setting, designated ILM40, for the three examples in Figure 3 are about –3 dB, 18 dB, and 42 dB relative to 1 V per meter.

Immunity Levels for Standard and Treated Hearing Aids

Figure 4 shows immunity levels for a range of standard and treated aids. (The treated aids are labelled "s" or "m," as explained earlier.) Because these are immunity levels, the higher the number is, the greater the immunity. If the immunity level is less than about 5, and the GSM telephone is at a meter from the hearing aid, a person with normal hearing will hear a loud and annoying buzz. If the immunity level is greater than about 20, the buzz will probably not be audible. For immunity levels between 5 and 20, the buzz will be audible but will not necessarily be annoying. Considerably higher immunity levels are required to permit telephone use. If the immunity level is 36 or more, it should be possible to use a wireless telephone (with the aid's microphone input) without any detectable interference. If the immunity level is 22 or less, the aid almost certainly will not be usable because of the loud, audible interference. For intermediate levels, interference will probably be noticeable but may not necessarily exclude telephone use.

Now consider the measurements starting with the standard aids from left to right of Figure 4. The first one (IT) is the relatively modern, compact ITE, with a good immunity level of 28. As mentioned earlier, some hearing-impaired people could use this aid with a digital wireless telephone, but others could not. The next standard aid (SB) is the modern (programmable) medium-powered BTE. It has an immunity level of 11, enough to avoid most but not all serious bystander interference problems but certainly not enough to permit telephone use. The next standard aid (PP) is one of the older high-powered BTEs. It has an immunity level of only 8 and will, therefore, pick up a moderately loud buzz from a wireless telephone 1 meter away. The next aid is the one marked 67. Although it is a standard, production model aid, it could also be regarded as "treated." It is a high-powered programmable BTE that was designed with knowledge of the GSM problem. It has shunt capacitors in the circuit specifically to reduce interference. This has achieved a moderately high immunity level (over 20). It is sufficient to prevent any bystander interference, although still not enough to permit telephone use.

Now consider the treated aids. Four have had their cases treated with a conductive silver coating (Is, Ss, Ps, 6s). The immunity level of these aids has been increased substantially, sufficiently so that there should be no interference even with telephone use. Pm is an example of a metal-impregnated case that did not improve immunity. This treatment was effective in some but not all instances. The other treated aid (42) is a BTE in a decorative metal-plated case. It has good immunity but is not sufficient for telephone use. In summary, all of the treated aids (with the exception of Pm) were sufficiently immune to avoid bystander interference, and several should permit telephone use without any interference.

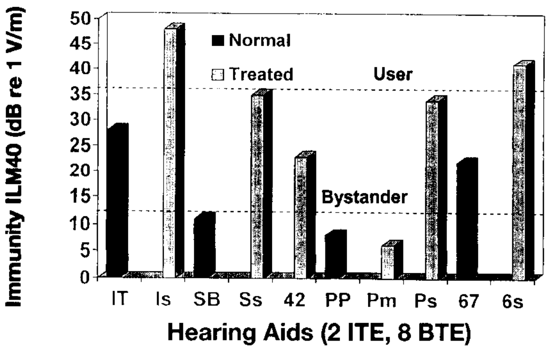

Figure 4 Immunity levels for a range of standard and treated hearing aids. Treated aids are Is, Ss, 42, Pm, Ps, and 6s (see text for details). Also shown are the Australian Standards for avoiding bystander and user interference.

Aided Telephone Use

It should be noted that achieving high immunity does not ensure that a hearing aid wearer will be able to use a digital wireless telephone. When using a hearing aid on microphone input, it is necessary to hold the telephone slightly away from or at an angle to the hearing aid to avoid acoustic feedback. This reduces the signal to a level that may be inadequate for some hearing aid users and also allows external noise into the hearing aid, resulting in a reduction in signal-to-noise ratio. To help overcome acoustic feedback problems, the volume of the digital wireless telephone should be increased to maximum, and, if practicable, the hearing aid volume control should then be reduced. The hearing aid labelled "IT" (which was marginal for telephone use in terms of its immunity level) was tried on several hearing aid wearers. Some could use the telephone, but a minority could not because the signal was inadequate when the telephone and hearing aid were separated sufficiently to avoid acoustic feedback. It was not possible to use the telecoil input because the coil picked up a type of interference, referred to as "baseband" interference, resulting from current flow within the telephone that generated a low audio frequency magnetic field that was picked up by the telecoil. This problem can only be overcome by redesigning the wireless telephone to reduce baseband interference.

STANDARDS

The data of this study have provided a basis for recommending Australian Standards on hearing aid immunity. The tests suggest that, to avoid bystander interference, hearing aids should have an immunity level somewhere between 11 and 24, and, to avoid user interference, the immunity level should be between 28 and 36. If the standard were set at the upper number, users should not experience any interference. If the standard were at the lower number, there would be some interference, but it just might be acceptable. The Australian Standards have, in fact, been set for microphone input to the equivalent of 12.5 for bystander interference and 36 for telephone use. These levels are shown in Figure 4. The immunity levels for bystander and user interference are more strict than those provided in the International Electrotechnical (IEC) Standard. The Australian Standard is based on a 1-meter protection zone for bystander interference rather than 2 meters used as a basis for the IEC Standard. Also, the Australian Standard provides interference-free reception for hearing aid users, whereas the IEC Standard does not meet this requirement when a 2-watt GSM mobile is transmitting at maximum power. The immunity level required in hearing aids to meet the Australian bystander requirement is readily achievable, and it is now possible to build production hearing aids at little or no extra cost that meet the Australian hearing aid user requirement.

CONCLUSIONS AND RECOMMENDATIONS

Hearing Aids

Future hearing aids can and should be designed to have high immunity to interference from wireless telephones. Even without specific efforts, this is largely the way that hearing aids are being developed with the new types of technology. However, hearing aids can be made immune using reasonably simple techniques, provided that the immunity issue is considered at the design stages. Methods include the use of more compact circuitry, the addition of shunting capacitors, and the use of various types of electrostatic shielding, such as the silver coating used in the NAL study. New types of microphones are available that increase immunity. Microphones from three manufacturers have been tested at NAL, and the tests have confirmed that these microphones do produce a significant improvement in immunity. The use of such microphones and compact circuit design would, therefore, be an alternative or supplement to the other treatments mentioned above. The development of hearing aids should include interference design criteria and measurements.

Wireless Telephone Design

Wireless telephones should have sufficiently high acoustic output so that they can be used without pushing the telephone hard up against the hearing aid. The acoustic receiver should be as far as possible from the antenna of the telephone. It would help to devise improved methods for coupling the telephone to the hearing aid. There is also the problem of reducing the unwanted magnetic fields produced in the telephone so as to make it possible to use the hearing aid's telecoil. This was not possible with any of the 2-watt GSM mobile telephone and hearing aid combinations that have been tested in the NAL studies.

Educating Hearing Aid and Telephone Users

Part of the process of avoiding or solving interference problems is the education of both hearing aid and telephone users. Hearing aid users need to be told about the interference problem, and, preferably, it should be demonstrated in quiet and in noise. If the hearing aid wearer wants to use a wireless telephone, then the issues involved should be explained and demonstrated, and the person should be advised to ensure that his or her particular hearing aid and telephone combination can be used together before purchasing the equipment. Users of wireless telephones should be educated about the problems that they can cause to hearing aid users and to display courtesy and consideration when using a wireless telephone near someone who has a hearing aid.

FINAL OBSERVATIONS

Interference

Serious bystander interference will probably not be a common problem. It seems likely that virtually all future hearing aids will have sufficient immunity to avoid significant bystander interference. Nonetheless, some bystander interference problems can be expected because, at the moment, there are many different types of hearing aids in service, and some of these are low-immunity models. Of greater concern is the problem of user interference.

In Australia, there have been relatively few complaints about interference so far, probably for a combination of reasons. The majority of hearing aids have reasonable or high immunity; digital telephones have only become common in recent years; some people may not recognize the nature of the interference; and some people may not know to whom to complain.

Telephone Access

Telephone accessibility is obviously a major concern. Wireless telephones are rapidly becoming an important part of modern living, and all wireless telephones in Australia now use digital transmission technologies. This trend is expected to be followed around the world in future years. At present, however, relatively few hearing aids set to either the microphone or telecoil mode can be used with a GSM digital wireless telephone. Currently, it is not difficult to improve the immunity of hearing aids operating in microphone mode by well-recognized techniques, making it possible to reduce interference to an acceptably low level, even below the hearing aid electrical noise level. The next step is to make wireless telephones hearing aid compatible so that they can be used with the telecoil of a hearing aid. This can only be achieved by a complementary effort on the part of the telephone manufacturers to reduce the unwanted stray magnetic fields, emanating from the wireless telephone, that are sensed by the telecoil within the hearing aid. The overall intent is to make digital wireless telephones as accessible to hearing aid users as modern wireline telephones.

Future Developments

Finally, we should be aware that GSM and other telephone technologies are not the end of the line. In the near future, there will undoubtedly be other communication technologies that hearing-impaired people need to use in conjunction with hearing aids or assistive devices. One implication of this is that audiologists and consumers must ensure that the telecommunications industry is aware of the needs of hearing-impaired people when introducing new technologies and designing communication systems and devices. Certainly, hearing-impaired people were not considered when GSM was introduced in Australia, but, hopefully, the investigations and the associated publicity will encourage more consideration of the requirements of hearing-impaired people in the future. The other implication of the development of new communication technologies is that consumers will have an increasing need for expert advice on how to live with and benefit from the new developments. Increasingly, audiologists will need to be able to advise their clients about choosing and using wireless telephones or other communication devices. They will also need to ascertain the client's needs for such devices and ensure that hearing aids are selected to be compatible with those needs.

Acknowledgments. The data reported in this article were drawn from the study reported in Le Strange et al (1995). The participants in that study were Ross Le Strange, Eric Burwood, and Denis Byrne (NAL); Ken Joyner and Mike Wood (Telstra); and Grant Symons (AUSTEL). The project was financed by three telephone companies in Australia (Telstra, Optus, and Vodafone), which also provided telephones for testing. The project was also supported by the hearing aid industry. In particular, the Phonak and Oticon companies supplied some of the treated hearing aids for testing.

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