interfere with hearing aids from as far as 30 meters depending on the hearing aid model. At a range of 3 to 5 meters, hearing aid users may experience a 200 Hz humming noise overpowering all other signals. This is a particular problem for hearing aid wearers who wish to use wireless phones. The degree of interference immunity varies widely by hearing aid type with the in-the-ear (ITE) devices typically having higher immunity. The level of interference is also affected by the relative orientation of the hearing aid and the phone.

Physical Measurements

Quantification of the sensitivity of a particular hearing aid (HA) to wireless phone interference is the first step in the ultimate development of immunity standards. Physical testing of HA immunity requires an RF signal source for generation and propagation of the appropriate cell phone signal, a controlled RF environment, a means for mounting and orienting the HA, and instrumentation for measuring the level of the audio interference output.

RF Test Signal

Previous researchers have employed various RF test signals to represent the GSM RF signal, including:

1. 900 MHz pulse modulated carrier with a modulation frequency of 217 MHz duty cycle of 1:8 and 100% modulation (EHIMA, 1993; Joyner et al., 1993;
National Telecom Agency of Denmark, 1994), and
2. a 900 MHz carrier, 80% modulated by a 1000 MHz sine wave (IEC, 1994; Le Strange et al., 1995).

No reports have been located in which the physical measurement testing was conducted using actual wireless phones. Some subjective testing has been reported with actual phones (Le Strange et al., 1995).

This study will use actual wireless phones. Some models will be "hot wired " or programmed in a continuos transmission mode. Other models will communicate with an HP 8920A RF Communications Test Set functioning as a base station simulator. This approach provides the greatest realism in terms of actual signal structure including the format for control and voice traffic (e.g., paging, power control, channel changes). This approach requires an accurate means of measuring RF field intensities generated by the phones at various distances.

RF Environment

Previous researchers have employed or compared various RF test environments, including:

1. a radio frequency anechoic room (EHIMA, 1993; IEC, 1994; Le Strange et al., 1995),
2. "stripline" consisting of a ground plane, stripline conductor, and 50 ohm resistive matching network (EHIMA, 1993), and
3. a waveguide (Joyner et al., 1993; Le Strange et al., 1995).

RF field intensities have either been fixed at 10 V/m or varied up to 200 V/m.

None of the three previously used RF test environments have been selected for this study. Options 2 and 3 are precluded by the fact that actual phones along with their self-contained antennae will be used as the signal source. Testing will be conducted at

the AT&T Open Area Test Site (OATS) In Oklahoma City. A radio frequency anechoic room (Option 1) is not currently available at this facility. Therefore, testing will be conducted within the shielded room at the OATS facility. The possibility of using a GSM cell will also be explored.

Mounting and Orienting the Hearing Aid

The hearing aid must be positioned in the RF test field away from objects that could distort the field and in such a way that it can be manipulated for maximum interference. Previous protocols have used the following:

1. place HA in chamber in "normal use" position, rotate (clockwise) in 9O° steps in the horizontal plane, measure interference at maximum SPL (EHIMA, 1993; IEC, 1994; National Telecom Agency of Denmark, 1994),
2. use both horizontal and vertical polarization of the RF field (EHIMA, 1993),
3. gimbal style mounting device for positioning HA in the waveguide about three axes, rotate for maximum pickup (Le Strange et al., 1995), and
4. mount within the Kemar head (no reference found at present).

Discussions of the Study Design Group led to the conclusion that the Kemar head (Option 4) was not an effective means of mounting the hearing aids since it did not provide a good RF analog of the human head. Option 3 is unique to the waveguide approach which is not being used in this study. Options 1 and 2 will be combined through the user of a non-RF distorting mounting device for alignment of the HA and a *device for positioning of the phone.*

Measuring Hearing Aid Output

The output of the HA must be measured without introducing instrumentation that could distort the RF field. This has typically been accomplished by using small diameter (2 mm) plastic tubing with a length between 50 mm and 500 mm to distance the HA and the acoustic monitor (IEC, 1994). Specific examples include:

1. ear simulator (IEC 711)to audio test station, amplifier, and DAT recorder via 500 mm tubing (EHIMA, 1993; National Telecom Agency of Denmark, 1994), and
2). standard 2 cc acoustic coupler to measuring microphone (B&K4155) and measuring amplifier (B&K 2636) via 500 mm length of 2 mm Tygon© tubing (Le Strange et al., 1995)

Option 2 will be used in this study based on available models of audio monitoring equipment.

Subjective (Psycho-acoustic) Measurements

Subjective evaluation of wireless phone interference is important since the delectability and annoyance of the interference depend on the individual hearing acuity of each HA user. Delectability and annoyance levels should be determined for hearing-impaired people with hearing losses appropriate to each type of HA. Persons with normal hearing should also be included to represent worst case situations of delectability and annoyance. Delectability can be determined through the application of standard psychophysical techniques such as the method of limits or method of constant stimuli. The degree of annoyance is typically ascertained through the use of subjective scaling techniques.

Interference Source

Subjects may be presented with either actual or recorded interference signals. Specific examples include:

1. recorded interference signal together with pinknoise, "partysounds", or connected speech (EHIMA, 1993; National Telecom Agency of Denmark, 1994),

and

2. actual phone with call placed to pre-recorded message (Le Strange et al., 1995). A variation of Option 2 can be achieved through the use of the base station simulator and the cell phone loopback (talkback) mode or audio transmission from the base station.

Detectability

Interference can be recorded on DAT or generated directly with actual phones for evaluation of detectability. Any of the following schemes can be used:

1. samples of various levels of recorded interference can be replayed in random sequence at random intensity levels while subjects are asked to respond as to the presence or absence of interference,
2. subjects wearing hearing aids are tested by moving an actual phone across a number of test sites from far (4 m) to near and back while the subject indicates the presence or absence of a "buzz" (Le Stranize et al., 1995), and
3. subjects can listen through tubing to actual hearing aid output with the HA at various locations (e.g., close to phone as in listening to a call, one meter, and up to several meters). The acoustic level of interference is classified as: "not preceptible", "just perceptible", 'moderately perceptible", and "annoyingly perceptible" (Le Strange et al., 1995).

Annoyance/Usability

The interference signal is presented at random intensity levels and,/or varying distances while subjects are asked to respond with the corresponding level of annoyance. Examples of the scales used include:

1. "not annoying", "slightly annoying", "annoying", and "very annoying " (EHIMA, 1993), and
2. "usable", "sometimes usable", and "unusable" (Le Strange et al., 1995).

Tests for Detectability, and Annoyance will *be combined using a hybrid mixture of Options 2 and 3 above under detectability. This provides a more authentic test for the extent of the problem as determined by subjects listening to the actual interference.*

Experimental Variables

The experimental variables in the study consist of the independent variables which are manipulated, dependent variables which are measured, and control variables. The control variables are defined by the test environment ("test bed"), test apparatus and experimental procedure. The dependent variables include the physical measurements and characteristics of the interference levels and immunity "scores", and the subjective responses for delectability and annoyance. The independent variables represent those factors which are tested to determine their influence on the dependent measures (both objective and subjective). Potential factors in this study are presented in outline form in the following section labeled Experimental Design.

EXPERIMENTAL DESIGN

FACTORS AND LEVELS

Hearing Aids

Hearing aid types

Behind the ear (BTE)
In the ear (ITE)
In the canal (ITC)
Completely in canal (CIC)
(ITE, ITC and CIC comprise 80% of market)

New devices vs. current patients

Specific manufacturers, models, units/model (too many?)

Phones

Phone technology (in priority order)

1. TDMA (D-AMPS) @ 800 MHz (IS-54) and 1900 MHz (IS-136)
2. CDMA @ 800 MHz (IS-95) and 1900 MHz (J008)
3. PCS @ 1900 MHz (J007)
4. GSM @ 900 MHz
5. GSM @ 1900 MHz

Participating manufacturers

Test Procedure Variables

Distance between phone/simulator and HA

Side of head

Ipsilateral (same side) vs. contralateral (opposite side)use
(important because of Class I vs. Class II standards)
Phone use by others vs. phone use by HA wearer

Relative orientation

Antenna position/field polarization
Angle of coupling (HA orientation)

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