LUND UNIVERSITY
Faculty of Medicine
Department of Logopedics, Phoniatrics and Audiology
Faculty of Medicine, Lund
Department of Otolaryngology
Stanford University

Communication between hearing aids and external devices

Marianne Philipsson

Program of Audiology, 2008

Master's thesis, 30 higher education credits

Supervisor: Gerald Popelka

ABSTRACT

New technology makes it possible for existing hearing aids to communicate with each other to make a true binaural fitting and give all of the experiences and advantages of binaural hearing to the user. This project includes electro-acoustic measurements done on one system available on the market. The questions to be answered by this paper were: How does this new technology fit into the ANSI standards and how does the technology affect the audibility? Measurements have been done on the hearing aids individually, together and combined with the additional communication interface, the streamer. Conclusions were that the standards are hard to apply on this new technology and that the streamer adds some noise and distortion. This study is a first step and more research on real subjects is called for. Qualitative data will be needed in order to rule out effects on the audibility at an individual level.

TABLE OF CONTENTS

INTRODUCTION

New technology makes it possible for existing hearing aids to communicate with each other to make a true binaural fitting and give all of the experiences and advantages of binaural hearing to the user. The communication possible between two devices is both exchange of control data and transmission of the audio signal itself. With an additional communication interface, referred to as a streamer, the technology gives the user the choice to connect the hearing aids to a range of external devices. This makes all of the latest electronic devices such as cellular phones, iPods and mp3 players accessible and beneficial even if you have a hearing loss. The external devices can be connected to the streamer both wirelessly, through Bluetooth technology, or with an audio cable. In figure 1a below the communication between the hearing aids and the streamer is shown. Figure 1b shows the communication with external devices available in the hearing aids and the streamer.

Figure 1a and b. This figure shows the combination of the communication available in the hearing aid and their streamer.

This technology is fairly new and has only recently been applied to hearing aids; therefore we do not know much about how well this technology works or which benefits it actually can give to the user. Wireless technology is known to benefit the hearing impaired in some circumstances yet it also can add noise to the signal which may create a worse problem for persons with a hearing impairment.

This project included basic electro-acoustic measurements on one system available on the market, performed on each of the hearing aids individually as suggested by the current standards. There were also performed measurements on the hearing aids when connected to each other and to the streamer.

The current standard of how to measure a hearing aid is published by the American National Standard Institute, Inc and the latest version was published in 2003 (American National Standards Institute, 2003). In 2005, Frye came to the conclusion that there were more to add to these standards as technology moves along.

The technology and its application are new and there have not been many publications. Therefore the literature to be found is limited. Most of the information is found online and the findings rely on the information provided by the manufacturers and other sources on the internet.

Purpose

The purpose of this paper is to get an understanding of how this new hearing aid technology allows communication between two hearing aids and between the hearing aids and their streamers. There is a range of questions to be answered. Does the new technology affect audibility in a positive or negative way? How can you look at the streamer and its technology? Are current measurement standards appropriate for this new type of product?

Other wireless application has been known to add noise and therefore there is reason to believe that so will this application. Earlier assessment of the ANSI standards showed that there was a need of update. Another hypothesis is that this still is the case for these devices.

BACKGROUND

Technology

The different wireless technologies used in the devices

We have reached long beyond a hearing aid as just being an amplification system. Hearing aids today incorporate a range of different technologies and the accessories and possibilities are today more than ever before. Along with these individual features, the systems can employ different methods of electronic communication. The devices in this project use near-field magnetic and Bluetooth technology for communicating with each other and external devices.

Near-field magnetic communication

Hearing aids have been able to communicate through magnetic fields for several years. By having a loop of wire installed around the walls in an assembly hall or theater, a magnetic field is created. An audio signal can then be converted into electrical current running through the wire. Most hearing aids today are equipped with an internal coil of wire, called a telecoil, which picks up the signal through the magnetic field and generates an electrical voltage that is amplified by the hearing aid and converted back to an audio signal (Dillon 2001).

The technology used for communication between the hearing aids and their streamer is also based on magnetic field induction but in a smaller limited quasi-static field. The technology requires two devices, one transmitter and one receiver, the transmitter contains a transducer that generates a magnetic field and a similar transducer in the receiver picks up the information in the field. Some of the energy from the transducer will flow away but most of it will be concentrated in a close range around the transducer. The magnetic field is generally not affected by its surroundings or attenuated by obstacles such as the human body; it is very limited in range and is only suitable for communication within a close range, a maximum of one meter (http://www.auracomm. com. 2008-03-03).

Bluetooth

The communication between the streamer and the external devices is based on Bluetooth which is a patented wireless technology used for communication between devices in close range. It claims to be robust and immune to interference from other electromagnetic signals since the signal uses what is referred to as adaptive frequency hopping. The transmission frequency is within the 2.400 to 2.485 GHz band which is an unlicensed frequency band used for industrial, scientific and medical purposes. The Bluetooth technology operates on three different distances, from 1 to 100 meters depending on the device's class. The hearing aids and streamers belong to the second class allowing communication over a range of up to 10 meters (www.bluetooth.com, 2008-03-11).

Hearing devices communicating with each other

The main concept for two hearing aids communicating with each other is that instead of being two separate devices attached on each ear, hearing aids can operate together as one system. They communicate with each other to give the user the complete sensation and benefit from a binaural fitting. The basic features allow the user to control volume and program settings for both hearing aids from one side alone to make sure that the hearing aids are synchronized at all times. In other more advanced systems the two hearing aids work completely together when analyzing the surrounding acoustic environment. An even more advanced system allows connections to a communication interface, called a streamer, which allows interaction with external compatible devices that have audio output.

The first to release this type of product were Siemens. In 2004 they released ACURIS™ a technology that allows wireless communication between two hearing aids. The hearing aids transfer control information from one hearing aid to the other at rate of 215 bits/second. The feature exchanges information about control settings and implemented automatic changes depending on the user's present acoustic environment. Siemens refers to their technology as e2e, standing for ear-to-ear and it is currently available in three of their devices: CENTRA™, ACURIS™ and ARTIS™ (Powers, Burton 2005, www.siemens-hearing.ca, 2008-03-06).

In 2007 the Epoq by Oticon was released. The two hearing aids in this system communicate by magnetic induction technology with a rate of 120 000 bits per second. The high speed allows the two Epoq hearing aids to completely exchange control information and work together as one binaural system. They work together when it comes to compression in the two hearing aids and both directionality and noise reduction are synchronized (Lindley, 2007, www.oticon.com, 2008-02-28).

The Epoq Streamer is an accessory of this system that allows the two hearing aids to communicate with external devices such as iPods, cellular phones and other devices that the user wishes to receive as audio input through the hearing aids. The communication between the Epoq Streamer and the external devices is through Bluetooth wireless technology or by direct wired connection through an audio cable. The streamer transforms the signal into an electromagnetic stream that uses the same electromagnetic field as the two hearing aids. The streamer can also be used as a remote control, used for adjusting the volume or changing program (Lindley, 2007, http://www.oticon.com/com /Pro/OurProducts/HearingAids/Epoq/Downloads/91015310Epoq_whitepaper.pdf , 2008-02-28).

Also Phonak has similar devices that were released in 2008, the Exelia system, that also uses magnetic induction technology for communicating with one another. The interaction between the devices makes sure that the hearing aids are synchronized when it comes to controlling the volume control and program settings. The technique is not as comprehensive as in the Epoq and does not work together when it comes to the more advanced signal processing. Instead Phonak have put a lot of effort in their remote control, myPilot, which can be used for advanced settings of the hearing such as directional microphones and zooming in the interesting signal (www.exelia.phonak.com, 2008-02-29).

The iCom is Phonak's answer to the Epoq Streamer. Through the iCom the user can get audio input from a range of different digital devices such as mp3 players, GPS systems or television. The external devices connect to the iCom trough either Bluetooth or with standard audio cables. The iCom is also compatible with Phonak's FM systems to extend the use of the streamer to ease hearing from distance and in noise (www.exelia.phonak.com, 2008-02-29).

Summary

Devices communicating with each other have been available for several years, providing the market with hearing aids able to act synchronized when it comes to program- and volume changing. Only recently have hearing aids with the ability to connect to external devices through a streamer become available. Phonak is on their way to launch this kind of product, but when this project was done the only available device was the Epoq by Oticon.

Binaural advantage

The advantages with listening with two ears are many. Binaural hearing increases the ability to detect speech in a noisy environment and helps with sound localization and spatial hearing. A binaural fitting also provides the patient with better sound quality and through binaural summation the perceived sound is louder compared to the monaural case (Dillon, 2001).

The broadband communication in the Epoqs gives them not only the possibility to act synchronized at all time; the information exchange is also used for enhancing spatial hearing. The hearing aids analyze the loudness difference between the ears, if this is a natural difference due to that one ear is closer to the sound source the hearing aids maintain this difference. Other hearing aid not capable of this communication would let the active gain control act on the loudness difference, making the sound equally loud in both ears and thereby removing the user's naturally ability to localize sound through loudness cues (www.oticon.com, 2008-02-28).

METHOD

Devices

The hearing aid system tested consisted of two Oticon Epoq XW of receiver-in-the-ear (RITE) style plus a streamer. The two hearing aids were measured separately and together with the Oticon Epoq Streamer. Due to the marking on the receivers, the hearing aids are referred to as left and right even if though they were not fitted on a real subject. Initially, the project was planned to include testing on real subjects. Time contraints did unfortunately not make this possible.

Equipment and procedure

All electro-acoustic measurements were made using the Verifit® VF-1 Real-ear Hearing aid analyzer by Audioscan. The coupler connected to the analyzer was a HA1 2cc coupler. This kind of coupler better resembles the acoustic characteristics of the typical ear while wearing a hearing aid of the receiver in the ear style. This coupler does not include an earmold simulator such as the HA2 coupler. The hearing aids were first measured individually. Their receivers were connected to the coupler with the tip of the receiver placed in the center of the coupler's opening and even with the cavity wall. As suggested from the manufacturer the receiver was completely sealed to the coupler's opening by tacky wax. The coupler was then connected to the test microphone in the test box and the hearing aid positioned with its microphone within 2 mm distance from the reference microphone. See Figure 2 below.

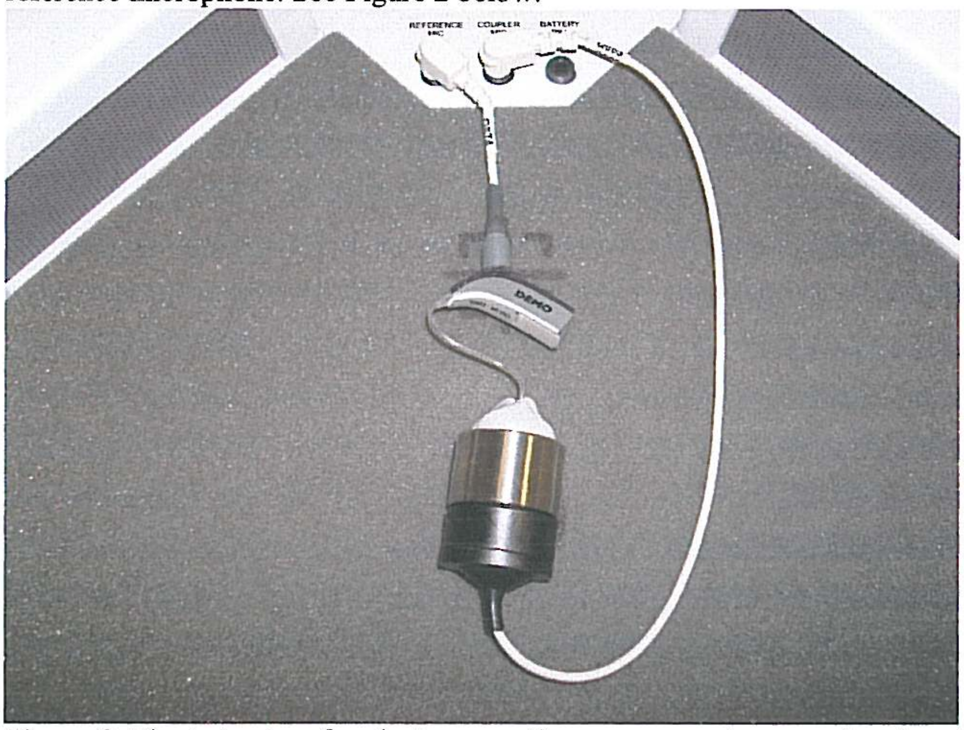


Figure 2. The test set-up for electro acoustic measurements on one hearing aid.

The sealing of the receiver to the coupler opening could be discussed since this does not resemble the real fitting of the hearing aid on a true ear. In other acoustic analyzers such as the Fonix 7000 by Frye electronic there is a specialized open coupler for measuring hearing aids with open fittings (Baum, E, Valente, M, 2008). However this is not a standardized coupler and can not be used together with other systems. Since it was suggested by the manufacturer to seal an HA1 coupler and the way the specifications was obtained the measurements were performed this way. Figure 3 and 4 below show how the receiver was connected to the coupler.

Figure 3 and 4. Shows how the hearing aid's receiver was connected to the coupler.

Measurements

Basic electro-acoustic measurements

Basic electro-acoustic measurements were performed to determine the acoustic properties of the hearing aids on each of the two hearing aids separately. These measurements were performed according to the ANSI standards. The results were compared to the specifications distributed by the manufacturer to make sure that the hearing aids worked properly and to have a baseline to compare further measurements. The measurements were:

- Output sound pressure level (SPL) for a constant 90 dB SPL input (OSPL90) with the hearing aid set on full on gain as a function of test frequency. A curve of SPL versus frequency (200Hz-5000Hz) was developed and the maximum SPL was shown. The high frequency average-OSPL90 (HFA-OSPL90) refers to the average SPL at the frequencies 1000, 1600 and 2500 Hz obtained in the coupler with a 90 dB input.

- Full on gain (FOG) was obtained with the hearing aid set to its full-on position and the coupler SPL measured with a 50 dB input. HFA full-on gain (HFA-FOG) refers to the average full-on gain at 1000, 1600 and 2500 Hz.

For OSPL90 and FOG the devices were set to full on gain position by using the programming software's technical measurements feature for full on gain.

- A frequency response curve was obtained with 60 dB SPL input with the hearing aids in a reference test setting position. Reference test setting (RTS) of the gain control is when the gain control is set to a position where the hearing aid produces an HFA-gain which equals the HFA-OSPL90 minus 77dB within +/- 1.5 dB.

- Total harmonic distortion (THD) was noted as presented by the acoustic analyzer. The THD expressed by calculating the ratio between the power of the unwanted distortion components and the wanted signal (Dillon, 2001).

- Equivalent input noise (EIN) was calculated as EIN= L_0 – HFAG50 dB SPL, according to the ANSI standards, where L_0 is the level in the coupler with the hearing aid turned off. Due to ambient external noise interfering with the measurement the microphones of the hearing aids were covered with putty when obtaining the L_0. In the specifications the EIN was presented as an EIN A which according to Dillon (2001) is when the SPL is obtained with an A-filter cutting out the low frequencies. Therefore the L_0 was first obtained with an A-filter setting on the analyzer to be able to compare it to the manufacturer's specifications. The L_0 was also obtained with a C-filter setting on the analyzer. The A-filter cuts out the low frequencies whilst the C-filter is almost the same as an un-attenuated filter (Gelfand 2001).

According to the ANSI frequency response, THD and EIN should be obtained with the gain control in a reference test setting. This occurs when the output SPL HFA-gain for a 60dB input equals the HFA-OSPL90 minus 77dB within +/- 1.5 dB. The software's technical measurements feature provides a reference gain setting that can be used for this test. This level was checked by the electro-acoustic analyzer before running the test to make sure the hearing aids were at the reference test gain position.

The remainder of the measurements specified by the standard including induction coil response, automatic gain control (ACG) functions and battery current drain were not tested.

Measurements on hearing aids when in simulated test settings

Because communication between the hearing aids is not implemented in the technical measurements mode the hearing aids were then programmed to imitate the full on gain and reference gain settings. A patient profile was created with an audiogram simulating a 120 dB flat loss. The hearing aids were then programmed with three programs. The first program set all controls as high as possible to imitate the full on gain position. The second program set the controls with a gain that equaled the reference test gain. This level was determined by the electro acoustic analyzer before testing the hearing aids to make sure that the gain was correct for the measurements. The third program implemented the t-coil. The noise managements and the special feature "my voice" which identifies the user's own voice and acts upon it were disabled and the hearing aids were set into a locked omnidirectional mode. The OSPL90 and FOG was obtained using the program one that simulating the full on gain setting and THD and frequency response were obtained using program two that simulating the reference test settings. The measurement results were compared to the specifications and served as the baseline for the following measurements.

It is doubtful if the EIN is an accurate way to determine the internal noise of the hearing aids when the hearing aids are programmed, as opposed to the technical measurement setting. The output level is affected by the automatic gain control, and the EIN is based on HFA50, Therefore only the L_0 was obtained and used as an indication of the internal noise of the hearing aids.

Measurements with two hearing aids involved

The two hearing aids were turned on using the same programs when measured individually. This allowed them to be used with binaural broadband communication between them. The measurements were then performed when the two hearing aids were communicating with each other.

Measurement setting

To determine if the presence of the magnetic field used for communication changed the acoustic properties of the hearing aids, the right hearing aid was positioned in the test box and the left hearing aid was placed outside with a distance of 15 cm from each other.

The two hearing aids placed on separate sides of the measurement box should not interfere with the communication between the hearing aids since the magnetic field is not affected by the plastic cover of the measurement system. The OSPL90 and FOG was obtained when the hearing aids were set to program one simulating the full on gain setting. When the THD, EIN and frequency response were obtained, the hearing aids were set to program two, to simulate the reference test settings just as above.

This procedure was also performed with the streamer connected and the hearing aids as before, one inside the box and the other outside, and the streamer within 0,5 meters from the two hearing aids.

Measurement involving the streamer

The left hearing aid was set to program two and was with covered microphones placed in the box. The L_0 was first obtained without having the streamer on to see that it matched the previous measurements, which it did. The iPod was connected to the streamer through audio cable that came with the streamer. The streamer was then placed outside the box. The audio streaming, without any input from the iPod, was turned on. This way the L_0 from the hearing aid with the audio streaming active was obtained. The measurement was repeated at 10 cm, 20 cm, 30 cm, 40 cm, 50 cm and 60 cm range between the hearing aid and the streamer.

To determine the audio communication between the streamer and the hearing aids sinusoidal tones were created (Sound Studio software on a Macintosh computer). They were stored with no compression in a file format known as AIFF which stands for audio interchange file format on a 4GB iPod mini of the second generation. The tones matched the test tones of the analyzer and were 200, 250, 315, 400, 500, 630, 800, 1000, 1250, 1600, 2000, 2500, 3150, 4000, 5000 and 6300 Hz. Each tone was 5 seconds long and had an on and off ramp time of 20 ms to avoid clicks in the signals. The amplitude of the signals was at the full output of the iPod digital to analog converter which allowed the full 96 dB dynamic range without peak clipping.

The volume control of the iPod was then set to half its gain and the tones were presented to the streamer and measured in the analyzer resulting in a frequency response of the coupler output SPL. This was repeated when the volume control of the iPod were at lowest possible gain and at ¼ of its gain. The frequency response for each tone was inspected for peaks other than at the pure sinusoid which would indicate distortion. Peaks had to be 6dB over the noise floor to be considered distortion peaks.

The distortion of the tones was then calculated by the formula $\% \text{ THD} = 100 \sqrt{(p^2_2 + p^2_3 + p^2_4 + \ldots) / (p^2_1 + p^2_2 + p^2_3 + p^2_4 + \ldots)}$ as suggested in the ANSI standards. It should be noted that this formula is used for harmonic distortion but was used also for the case of sub harmonic distortion.

The output SPL from the coupler was converted into sound pressure in pascal through the relation $SPL = 20 \log_{10}(p/p_0)$ which give $p = p_0 \text{ antilog}_{10}(SPL/20)$ where p_0 is the reference sound pressure of 20 μPa.

RESULTS

Results from the basic electro acoustic measurements

Right hearing aid

In table 1 the results from the basic measurement performed according to the ANSI standards on the right hearing aid are shown. The ANSI tolerance column shows how much the obtained values are allowed to differ from the specifications.

Table 1. The result from the basic measurements performed according to the ANSI standards on the right hearing aid.

	Obtained values	**Specifications**	**ANSI tolerance**
OSPL90 Peak	108dB SPL	109dB SPL	+3dB
OSPL90 HFA	101dB SPL	104dB SPL	+/-4dB
FOG Peak	46 dB SPL	47 dB SPL	Not listed
FOG HFA	39 dB SPL	38dB SPL	+/-5 dB
Harmonic distortion 500Hz	0%	0.20%	+3%
Harmonic distortion 800Hz	0%	0.40%	+3%
Harmonic distortion 1600Hz	0%	0.40%	+3%
EIN A Omnidirectional mode	18-19 dB	19dB	+3 dB
EIN Omnidirectional mode	18-19 dB	19dB	+3 dB

Left hearing aid

In table 2, the results from the basic measurements performed according to the ANSI standards on the left hearing aid are shown. The ANSI tolerance column shows how much the obtained values are allowed to differ from the specifications.

Table 2. The result from the basic measurements performed according to the ANSI standards on the left hearing aid.

	Obtained values	**Specifications**	**ANSI tolerance**
OSPL90 Peak	108dB SPL	109dB SPL	+3dB
OSPL90 HFA	101dB SPL	104dB SPL	+/- 4dB
FOG Peak	48 dB SPL	47 dB SPL	Not listed
FOG HFA	38 dB SPL	38dB SPL	+/-5 dB
Harmonic distortion 500Hz	0%	0.20%	+3%
Harmonic distortion 800Hz	0%	0.40%	+3%
Harmonic distortion 1600Hz	1%	0.40%	+3%
EIN A Omnidirectional mode	19-20 dB	19dB	+3 dB
EIN Omnidirectional mode	19-20 dB	19dB	+3 dB

Frequency response

Figure 6 shows the frequency response for the right hearing aid when running the test according to the ANSI standards.

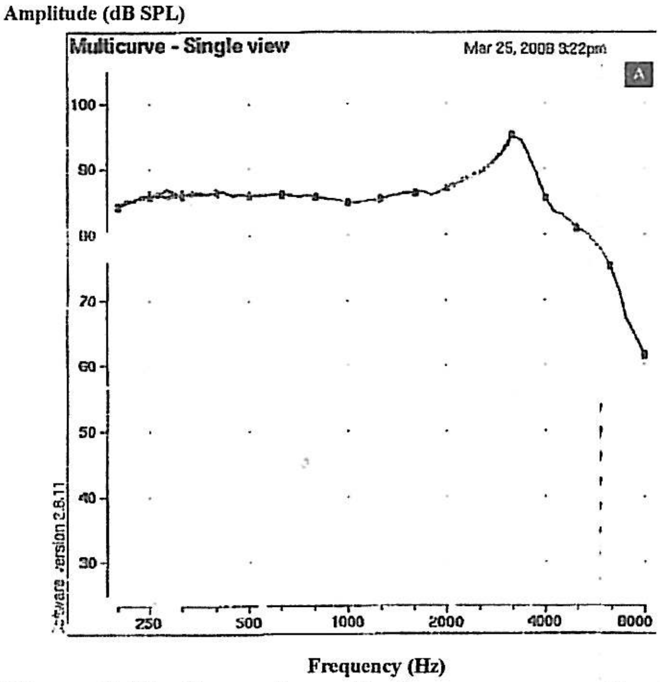


Figure 6. The figure shows the frequency curve for right hearing aid.

The curves have similar shape to the curves from the manufacturer's specifications. According to the ANSI standards the frequency range should be determined by subtracting 20dB from the HFA obtained from the specifications curve. Further, a line is drawn parallel to the frequency axis. The intersection of this line should be marked as f_1 (the lower limit of the frequency range) and f_2 (the higher limit of the frequency range). The same thing should then be performed on the measured frequency response curve to compare f_1 and f_2. The manufacturer's specifications gave a frequency range of <100-9000 Hz but since the bandwidth of the analyzer is only 200-8000 Hz it is not possible to obtain this range. However looking at the frequency curve it should be safe to estimate the frequency range for left and right hearing aid to be somewhere around 100-9000Hz.

All together the results of these measurements showed that both left and right hearing aid worked as specified by the manufacturer because all result were within the tolerance limit of the ANSI standard.

Simulated reference settings measurements results

Right hearing aid

In table 3, the results from the measurements performed according to the ANSI standards on the right hearing aid when set to the simulated test settings, are shown.

Table 3. The results from measurements performed according to the ANSI standards on the right hearing aid when set to the simulated test settings.

	Obtained values	Specifications	ANSI tolerance
OSPL90 Peak	103dB SPL	109dB SPL	+3dB
OSPL90 HFA	98 dB SPL	104dB SPL	+/-4dB
FOG Peak	36 dB SPL	47 dB SPL	not listed
FOG HFA	35 dB SPL	38dB SPL	+/-5 dB
Harmonic distortion 500Hz	0%	0.20%	+3%
Harmonic distortion 800Hz	0%	0.40%	+3%
Harmonic distortion 1600Hz	0%	0.40%	+3%
L_0 Omnidirectional mode	45 dB A	-	-
L_0 Omnidirectional mode	45 dB C	-	-

Left hearing aid

In table 4, the results from the measurements performed according to the ANSI standards on the left hearing aid when set to the simulated test settings are reported.

Table 4. The results from measurements done according to the ANSI standards on the left hearing aid when set to the simulated test settings.

	Obtained values	Specifications	ANSI tolerance
OSPL90 Peak	103dB SPL	109dB SPL	+ 3dB
OSPL90 HFA	97dB SPL	104dB SPL	+/-4dB
FOG Peak	37 dB SPL	47 dB SPL	not listed
FOG HFA	35 dB SPL	38dB SPL	+/-5 dB
Harmonic distortion 500Hz	0%	0.20%	+3%
Harmonic distortion 800Hz	0%	0.40%	+3%
Harmonic distortion 1600Hz	1%	0.40%	+3%
L_0 Omnidirectional mode	45 dB A	-	-
L_0 Omnidirectional mode	44 dB C	-	-

Frequency response

Figure 7 shows the frequency response for the right hearing aid when in simulated test settings, program 2.

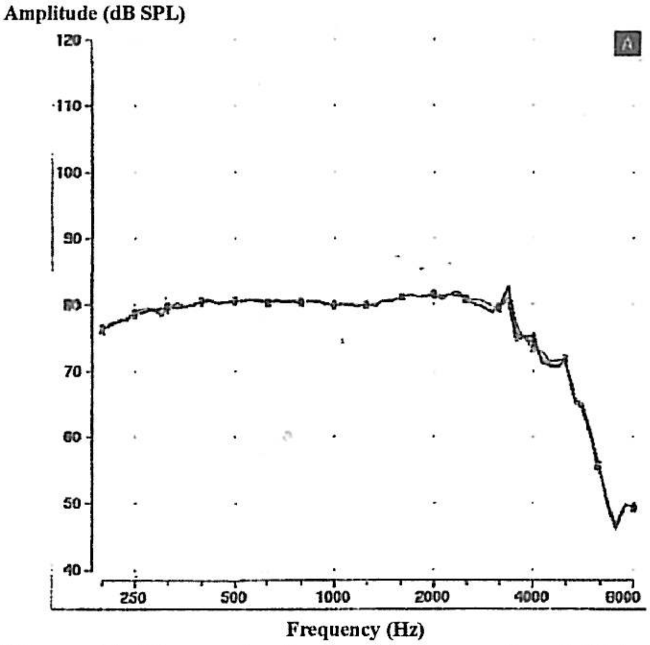


Figure 7. Shows the frequency curve for right hearing aid when in the simulated test settings, program 2.

The shape of the frequency curve differs from the curve obtained when the hearing aids were in the technical measurement mode. When calculating according to the ANSI standards it showed that programming the hearing aids had limited the frequency range. The range was now from to <200 Hz to 6000 Hz.

These results do not match the manufacturer's specifications, and according to Oticon's representative it is not possible to obtain the values of the specifications any other way than to have the hearing aids set into full on gain and reference test setting through the technical measurements feature in the software. These results were as close as possible and will therefore be used as a baseline.

Measurements with the broadband for communication turned on

Right hearing aid + left hearing aid

Table 5 shows the result from measurements made according to the ANSI standards and obtained from the right hearing aid when in a 15 cm range from the left hearing aid. The hearing aids were set into the simulated test settings and the broadband turned on.

Table 5. The results from measurements done according to the ANSI standards obtained from the right hearing aid when in a 15 cm range from the left hearing aid.

	Obtained values	**Specifications**	**ANSI tolerance**
OSPL90 Peak	105dB SPL	109dB SPL	+3dB
OSPL90 HFA	98 dB SPL	104dB SPL	+/-4dB
FOG Peak	36 dB SPL	47 dB SPL	Not listed
FOG HFA	35 dB SPL	38dB SPL	+/-5 dB
Harmonic distortion 500Hz	0%	0.20%	+3%
Harmonic distortion 800Hz	0%	0.40%	+3%
Harmonic distortion 1600Hz	1%	0.40%	+3%
L_0Omnidirectional mode	45-46 dB	-	-
L_0 Omnidirectional mode	44 dB	-	-

Right hearing aid + left hearing aid + streamer

Table 6 shows the results from measurements made according to the ANSI standards obtained from the right hearing aid when in a 15 cm range from the left hearing aid and a 0,5 m range from the streamer. The hearing aids were set into the simulated test settings and the broadband turned on.

Table 6. The results from measurements done according to the ANSI standards obtained from the right hearing aid when in a 15 cm range from the left hearing aid and a 0,5 m range from the streamer.

	Obtained values	**Specifications**	**ANSI tolerance**
OSPL90 Peak	104dB SPL	109dB SPL	+3dB
OSPL90 HFA	97 dB SPL	104dB SPL	+/-4dB
FOG Peak	36 dB SPL	47 dB SPL	Not listed
FOG HFA	35 dB SPL	38dB SPL	+/-5 dB
Harmonic distortion 500Hz	0%	0.20%	+3%
Harmonic distortion 800Hz	0%	0.40%	+3%
Harmonic distortion 1600Hz	1%	0.40%	+3%
L_0Omnidirectional mode	45-46 dB	-	-
L_0 Omnidirectional mode	45 dB	-	-

None of these measurement results differed from the basic measurements done on the hearing aids individually when set into the simulated test positions, nor did the frequency response curve.

Measurements involving the streamer

The L_0 of the hearing aid without the audio streaming was measured to 45 dB A and 44 dB C. In table 7, the results of the L_0 measurements when the audio streaming was turned on, are shown.

Table 7. The table shows the results of the L_0 measurements when the audio streaming was turned on.

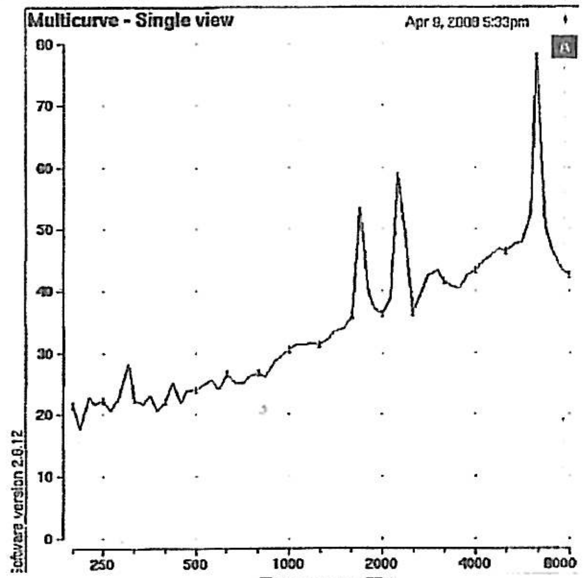
Distance	**A L_0 in dB SPL**	**C L_0 in dB SPL**
10 cm	50	49
20 cm	50	49
30 cm	50	49
40 cm	50	49
50 cm	50	49
60 cm	no steady level	no steady level

When moving the streamer out of the 50 centimeters range from the hearing aid the analyzer was not able measure a steady level since the level ranged from 41 dB SPL up to 70 dB SPL.

Results of the audio streaming when the streamer is connected to the iPod

When presenting the tones from the iPod the frequency responses showed several peaks at both higher and lower frequencies than the one being presented as can be seen in figure 8 and 9.

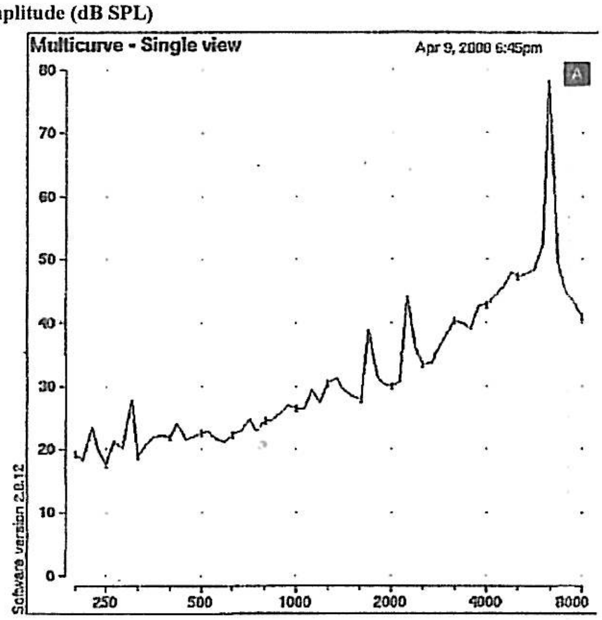
Amplitude (dB SPL)



Frequency (Hz)

Figure 8. Shows the frequency response for the 6300 Hz tone when the gain control of the iPod set to half of its gain.

Amplitude (dB SPL)



Frequency (Hz)

Figure 9. Shows the frequency response for the 6300 Hz tone when the gain control of the iPod set to ¼ of its gain.

When lowering the volume from half its gain to ¼ the peaks became fewer, therefore an attempt to lower the volume to minimum possible gain was made. The frequency responses for theses tones were however very irregular and increased the distortion.

Looking at the results when the iPod was set to ¼ and half gain it showed most distortion when presenting the two highest frequencies, especially when set to half its gain.

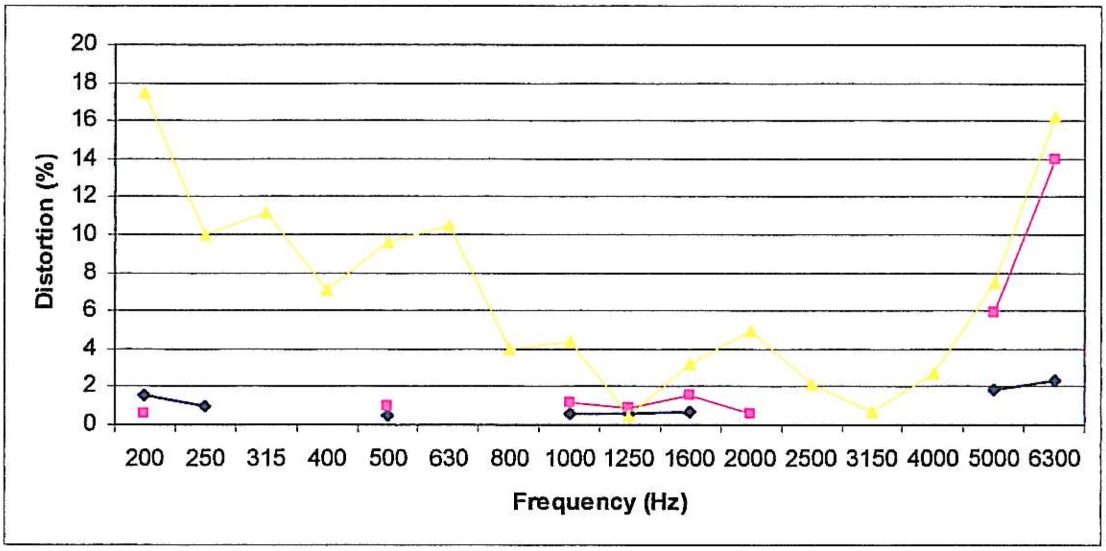


Figure 10. Shows the amount of distortion at every tone for the three different settings of the iPod's volume control. Triangles – volume control minimum on, squares– volume control half on and 'diamonds' – volume control ¼ on.

DISCUSSION

Standards

The technology connecting hearing aids has come a long way but the standards to measure the communication have stood still. In 2005 Frye stated that even if the standards should be renewed every five years, this is not done and the standards from 2003 do not differ that much from its predecessor from 1996. The author also suggested adding directionality, processing delay, phase and other special functions to the ANSI standard (Frye, 2005). As the technology moves along more is to ad to that list. We now have a completely new device, the streamer, but without any standards for how to measure the system.

All this new technology can give great benefits for the user but there are no methods for verifying that it really does everything it is supposed to do. The standards give us information on how to measure basic features of the hearing aids, we know how to measure and calculate the internal noise and harmonic distortion of the hearing aids. But these hearing aids are then connected and supposed to work together with the streamer which noise and distortion we can not measure. Therefore our knowledge about the system we provide to our patient is limited.

There was also a problem when determining the exact frequency range. This was due to limitations of the analyzer and also to the fact that the standards do not apply for hearing aids with this great a frequency range

Receiver in the ear has become a very popular fitting alternative during the last years but there are no standards for measuring this kind of fitting. There are special couplers out on the market for this purpose, however they are not standardized and therefore there is no standardized way to connect the receivers to a coupler. The way suggested from the manufacturer was to seal the receiver by putty which is a common way. However this does not at all resemble the real open ear fitting.

A problem through this project was that there is no test mode for testing the functions of the broadband; this way there is no way to test the streaming without having other functions in the hearing aids activated. When performing the basic acoustic measurements the test mode provided by the manufactures software also makes sure that all other functions are shut off. Since there is no such mode for all the measurements, except the initial basic measurements, measurements reported here were made with all functions activated. This may have influenced the results. To be able to test the streamer's features together with the hearing aids there is a need for a test mode which allows communication between the devices with other functions turned off.

Distortion and noise of the streamer

The measurements showed that there was no increase of the noise when just transferring data. This means that when the user only uses the communication between the hearing aids for synchronized volume and program settings together with exchanging signal information it will not introduce any noise. This means that the benefits from the binaural fitting and collaboration between the hearing aids do not decrease audibility.

When the transmission of audio from the streamer is turned on it however causes an increasing of the noise by 5dB from 45dB to 50 dB. We know that individuals with hearing impairment have greater problems than individuals with normal hearing to hear in a noisy environment (Dillon 2001). Therefore the noise might be a problem for some individuals when listening through the streamer.

The result shows the least distortion when the iPod is set to ¼ of its gain, and the most distortion when set to minimum gain. The reason for the high level of distortion when set to minimum gain is the low level of the signal which is too low to differ from the noise floor. The testing of the streamer connected to the iPod was tested only when set to three different gain positions. It could be interesting to increase the volume of the iPod even more and see what it does to the signal. However it is safe to say that the volume settings of the iPod do make a difference and the user should be aware of the importance of not using the volume control of the iPod, but instead use the volume control on the streamer.

The possibility that the iPod contributes to causing the distortion has been considered. However this product should not provide any distortion. The authors subjective experience from listening was that the tones through the earphones sounded pure. But when listening through the hearing aid the distortion at 5000 and 6300 is clearly audible.

It should be noted that updates to the Epoqs and to the streamer are now available but these measurements were performed on previous versions of these devices.

How the distortion affects the audibility can not be stated through this project. Many of the distortion numbers are fairly low if you compare to some home entertainment systems for movies that have distortion numbers much higher than this. However these systems are made for individuals with normal hearing who want, for example, to have a sensation of a movie with great explosions and soundtracks. The devices measured are for individuals with a hearing impairment that wish to benefit from iPod or cellular phone to hear an interesting signal, for example an important discussion over a cellular phone.

The greatest amount of distortion is obtained at the highest frequencies and is then lower peaks. It is possible that there may be peaks at higher frequencies as well but the range of the electro-acoustic analyzer does not allow us see it. The distortion is probably not a problem for individuals with normal hearing or flat losses. However on a sloping hearing loss it can lead to a situation where the main tone is inaudible and the user only hears the peaks lower in frequency. What this does to the audibility is hard to tell but there may be a problem when combined with the extra noise the streamer creates.

This paper does not include any testing of the Bluetooth transmission to the streamer from a cell phone. However it is safe to say that the conditions do not get better. When connected to a cell phone you have to add the internal noise of that device and then there is a Bluetooth transfer which may also provide noise.

CONCLUSIONS

There will be more of these applications and devices as technology moves along since the use of iPods, cellular phones and other devices among hearing aid users will only increase. This is the future of hearing aid technology and we will see more and more of incorporating other technology and devices with hearing systems. It will become more and more complicated to verify hearing aid performance. There is still a need for standards so that we can determine what we actually provide our patients with. These standards need to be updated and applied to more features than they are today. The present work is a first step in trying to asses the benefit of these applications. Next step must be more qualitative research with testing on real subjects.

The system tested in this project may affect the audibility, but still has a lot of advantages and will provide the user with the possibility to benefit from iPods and mp3 players just as individuals with normal hearing. As these systems will become more and more common the manufacturers will hopefully also make them better and provide them with test modes and together with the market develop new standards.

ACKNOWLEDGMENTS

I would like to thank my supervisor Gerald Popelka together with all of staff at the department of Otolaryngology at Stanford University for all the help and support through this project. I would also like to thank the Swedish Audiologist association, the Swedish Audiology Society and The Sound Environment Centre at Lund University for financial support.

REFERENCES

American National Standards Institute (ANSI). *ANSI S3.22-2003-Specifications of Hearing Aid Characteristics.* Melville, NY: Acoustical Society of America

Baum, E, Valente M. (2008) *Using the FONIX 7000 to Verify Coupler and Real-Ear Performance to Adhere to the AAA Guidelines for the Audiologic Management of Adult Hearing Impairment.* Washington University School of Medicine

Dillon, H. (2001). *Hearing aids.* Sydney: Boomerang Press

Frye, J G. (2005). Understanding the ANSI Standards as a Tool for Assessing Hearing Instrument Functionality. *The Hearing Review* 2005; 5

Gelfand, S A. (2001). *Essentials of Audiology, second edition. New York: Thieme*

Katz, J. (2002). *Handbook of clinical Audiology, fifth edition.* New York: Lippincott Williams & Wilkins

Lindley, G. (2007). Accessing the "Far World": A New Age of connectivity for Hearing Aids. *The Hearing review* 2007; 5

Powers, T A, Burton, P. (2005) Wireless Binaural Synchronization in Hearing Aids: Questions and Answers. *The Hearing review* 2005; 1

Aura Communications. Near-field communications properties. White paper. Available at: www.auracomm.com/Downloads/webwireless.pdf. Accessed 2008-03-03

http://www.bluetooth.com/Bluetooth /Technology/Basics.htm. Accessed 2008-03-11

http://www.siemens-hearing.ca/hearing_aids /Technology/ aboutE2E.apsx. Accessed 2008-03-06

http://www.oticon.com/com/Pro/OurProducts/HearingAids/Epoq/Downloads/91015310E poq_whitepaper.pdf. Accessed 2008-02-28

http://www.exelia.phonak.com/fileadmin/user_upload/downloads/en/028_0338_02_Exeli a_Brochure_Professional.pdf. Accessed 2008-02-29