THE EFFICACY OF SOLAR-POWERED RECHARGEABLE HEARING AID BATTERIES

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"When the power of love overcomes the love of power
the world will know peace."
-Jimi Hendrix

This is dedicated to my wonderful family and friends for their love and support throughout this project.

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ABSTRACT

THE EFFICACY OF SOLAR-POWERED RECHARGEABLE HEARING AID BATTERIES

by Erica M. Hansen

Rechargeable batteries offer the possibility of increased convenience, reduced cost, and a less negative environmental impact. There are few studies available to hearing professionals regarding the efficacy of currently marketed rechargeable hearing aid batteries in addition to information provided by the product manufacturers. In this study, the electro-acoustic characteristics of analog and digital hearing aid products were measured when powered by solar-charged nickel metal hydride (NiMH) rechargeable hearing aid batteries. The NiMH-powered hearing aids were exposed to television designed to simulate the "real world" everyday noise during the day and turned off at night. The NiMH-powered hearing aids were found to maintain gain, equivalent input noise, and total harmonic distortion that was compliant with the 1996 American National Standard Institute (ANSI) specifications throughout their lifespan regardless of the type of hearing aid technology. Shortly before the hearing aids lost power, a sharp decrease in gain and a sharp increase in THD and EIN were seen. The lifespan of the NiMH rechargeable batteries varied from approximately 8 to 25 hours depending on the hearing aid circuitry. The results of this study indicated that hearing aid wearers could use NiMH rechargeable batteries powered by a solar-powered charger without any effect on the sound quality of their hearing aids. This knowledge may increase the use of NiMH rechargeable batteries and solar-powered chargers, especially among economically-disadvantaged and environmentally-conscientious patient populations.

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CHAPTER I

INTRODUCTION

Rechargeable batteries offer the possibility of increased convenience, reduced cost, and a less negative environmental impact. However, little research is available for hearing professionals concerning the use of rechargeable batteries in hearing aids. Besides the information provided by the product manufacturers, there are few studies regarding the efficacy of currently marketed rechargeable hearing aid batteries. Many hearing professionals and hearing aid users in the United States are not even aware of the existence of these products or have negative associations with rechargeable hearing aid batteries.

Nickel-metal hydride (NiMH) is one type of rechargeable battery that has been commercially used since the 1970s and can be recharged hundreds of times (Lin, 2005). Godisa, a Botswana-based company, manufactures NiMH rechargeable hearing aid batteries and solar-powered battery chargers. The solar-powered hearing aid battery charger can be used instead of a conventional electric charger.

The purpose of this project was to explore the effectiveness of NiMH solar-powered rechargeable batteries in different types of hearing aid circuits. This study assessed the electro-acoustic characteristics of hearing aids powered by solar-charged nickel metal hydride (NiMH) rechargeable hearing aid batteries over the lifespan of the batteries. The measurements obtained were compared to the 1996 American National Standard Institute (ANSI) specifications. In addition, the lifespan of the batteries when used with various technology levels of hearing aids was recorded.

CHAPTER II

METHODS

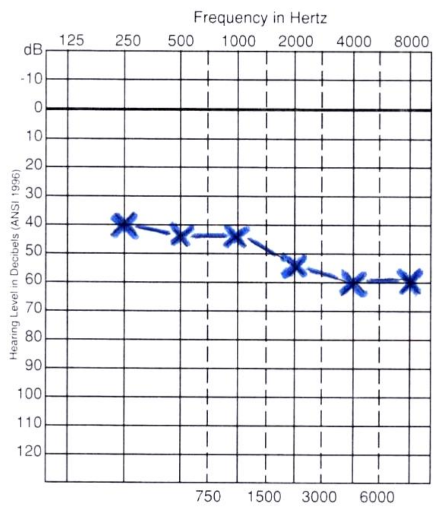
Materials

Hearing aids of varying technology levels were obtained for this experiment. The hearing aids consisted of conventional, basic digital, and advanced digital behind-the-ear (BTE) hearing aids from various manufacturers. The hearing aids used included the following: Phonak PicoForte PP-C-P (analog), Unitron Sound F/X 4 (analog), Phonak Maxx 311 Forte (basic digital), Siemens Infinity Pro Dir (basic digital), Phonak Savia 311 dSZ (advanced digital), and Siemens Acuris S (advanced digital). Each of the six hearing aids were new or in good working order and met the specifications established by the American National Standard Institute (ANSI).

Experimental Procedure

All of the hearing aids were programmed with a typical moderate to moderately severe hearing loss (Figure 1). The hearing loss had thresholds ranging from 40 dB in the low frequencies and sloping to 60 dB in the high frequencies. Each hearing aid was set to the default "first fit" in the manufacturer's software. The prescribed kneepoint thresholds and compression ratios differed among manufacturers. The Real-ear analysis using Audioscan Verifit equipment with a 2 cc. coupler was used to verify the fit of each of the hearing aids to this loss.

Figure 1. Hearing Loss Used to Program Hearing Aids



Once programmed each hearing aid was coupled to tubing and a comply tip that was covered with putty (Figure 2). The hearing aids were mounted on a wire basket and placed facing a television. The television was set at a normal conversational level (i.e. approximately 60 dB). A pre-recorded cassette tape was played in a continuous loop on the television. The tape consisted of talk shows, music, and background noises that are typically present in a real-world environment.

Figure 2. Picture of Hearing Aid Set-up

Nickel Metal Hydride (NiMH) rechargeable batteries and a Godisa solar-powered hearing aid charger were used to power the hearing aids (Figure 3a). The Godisa solar-powered hearing aid charger was charged with sunlight for six to ten hours as directed by the Godisa Instruction Manual. The sunlight consisted of both direct and indirect sunlight depending on the location of the sun and the amount of clouds in the sky at the time of charging. The charger was charged for up to ten hours on days when only indirect sunlight was obtainable. The NiMH rechargeable batteries were then charged using the "charged" Godisa solar-powered charger overnight. A RadioShack 15-Range Digital Multimeter (Figure 3b) was used to measure the voltage of the NiMH batteries after being charged in order to verify they had been fully charged. A minimal charge of

1.4 V was considered fully charged. The charger and batteries were fully charged prior to each trial.

Figure 3. Godisa Solar-Powered Charger and Digital Multimeter

a. b.

The NiMH powered hearing aids were exposed to the television designed to simulate the “real world” everyday noise for twelve hours per day. At night, the batteries were removed from the hearing aids and placed in an airtight container. At periodic intervals throughout the day, several measurements were taken. These measurements included: (1) a biologic listening check of the hearing aids, (2) electroacoustic analysis (EAA) of the hearing aids at user settings using Audioscan Verifit equipment, and (3) the voltage of the NiMH using a RadioShack 15-Range Digital Multimeter to the nearest thousandth. EAA included measurements of the total harmonic distortion (THD) at 500, 800, and 1600 Hz, gain at user settings, and the equivalent input noise (EIN). Measurements were taken at decreasing time intervals in order to increase the data obtained at the end of battery's lifespan.

A total of three trials were completed using the project design shown in Table 1.

During each of the trials, the rechargeable batteries were rotated among the hearing aids.

Table 1: Project Design

Trial #	A	B	C	D	E	F
1	R1	R2	R3	R4	R5	R6
2	R6	R1	R2	R3	R4	R5
3	R5	R6	R1	R2	R3	R4

Note: In this table, A-F represent each of the hearing aids used in this study. R1-R6 show the six rechargeable batteries that were used in correspondence to the hearing aids during each of the trials.

A = Phonak Savia 311 dSZ (advanced digital)
B = Phonak Maxx 311 Forte (basic digital)
C = Siemens Acuris S (advanced digital)
D = Siemens Infinity Pro Dir (basic digital)
E = Unitron Sound F/X 4 (analog)
F = Phonak PicoForte PP-C-P (analog)

Data Analysis

Data was recorded for each measurement taken. The voltage of the batteries was grouped according to hearing aid technology level and charted over time. In addition, the electro-acoustic data (i.e. EIN, THD, and gain) was examined with regards to 1996 ANSI specifications, grouped according by hearing aid technology, and charted over time. A summary of ANSI tolerance levels with regard to the manufacturers' specifications for each product is shown in Tables 2 and 3.

Table 2: Summary of ANSI Tolerances

Test	Tolerance
Percent total harmonic distortion (THD)	Max is specified value + 3 dB
Equivalent input noise (EIN) level	Max is highest specified value + 3 dB
Reference test gain (RTG)	None (information purposes only)

Table 3: Manufacturers' Specification

Hearing Aid	THD .5K Hz	THD .8K Hz	THD 1.6K Hz	EIN	RTG
A	2.5%	1.5%	1.0%	19 dB SPL	50 dB
B	1.0%	0.5%	0.5%	22 dB SPL	45 dB
C	3.0%	2.0%	1.0%	18 dB SPL	44 dB
D	3.0%	2.0%	1.0%	22 dB SPL	47 dB
E	1.0%	1.0%	1.0%	28 dB SPL	40 dB
F	1.6%	1.1%	0.2%	28 dB SPL	40 dB

CHAPTER III

RESULTS

Battery Life

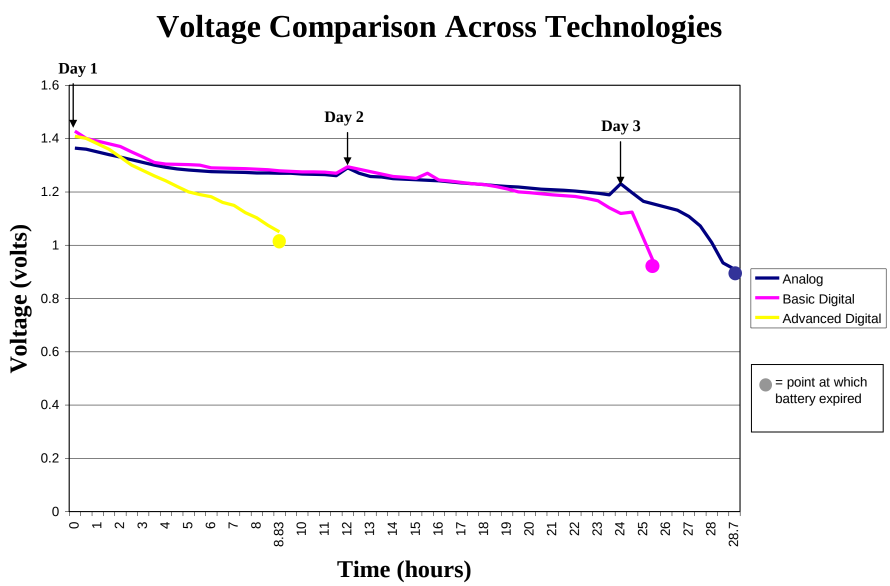
As the functionality of the hearing aid increased, the battery life decreased. The battery life was shown to be the longest for the analog hearing aids and ranged from 27.58 to 29.5 hours with an average of 28.66 hours. The battery life for basic digital aids ranged from 11 to 26.5 hours with an average of 22.6. The battery life was shortest for the advanced digital hearing aids and was six to twelve hours with an average of 8.93 hours.

Electro-acoustic Analysis

Voltage

The voltage was shown to steadily decline throughout the lifespan of the batteries. After periods of rest, such as the beginning of a new day after the hearing aid had been off for several hours, the batteries showed an increase in gain. This slight recovery pattern was evident regardless of the hearing aid technology and was consistently found for each of the trials. The following graph shows the voltage vs. time that was characteristically seen for each of the hearing aid technologies.

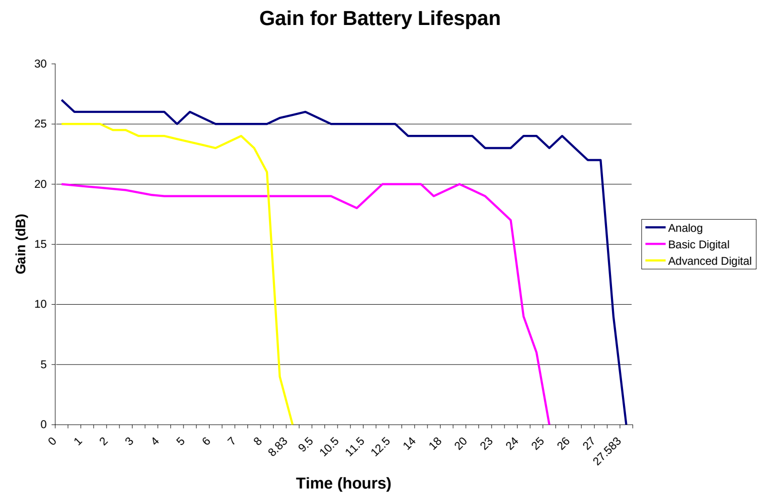
Figure 4. Comparison of voltage during the lifespan of the solar-powered NiMH batteries for different technologies



Gain

The gain was constant for the majority of the life of the hearing aid. Shortly before the battery expired, a sharp decrease in gain was noted. This pattern was evident regardless of the hearing aid technology and was consistently found for each of the trials. The following graph shows the gain vs. time that was characteristically seen. The gain varied across manufacturers as seen in the graph below.

Figure 5. The gain over time for different hearing aid technologies when powered by the solar-powered NiMH batteries

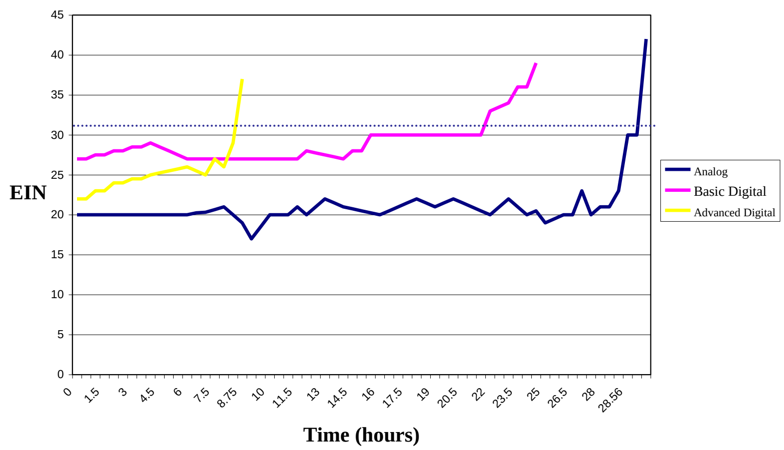


<u>Equivalent Input Noise</u>

The equivalent noise input was constant for the majority of the life of the hearing aid. Shortly before the battery "died," a sharp increase in EIN was noted. This pattern was evident regardless of the hearing aid technology and was consistently found for each of the trials. The following graph shows the EIN vs. time that was characteristically seen for each of the hearing aid technologies.

Figure 6: The equivalent input noise over time for different hearing aid technologies when powered by the solar-powered NiMH batteries

EIN for Battery Lifespan



Total Harmonic Distortion

The total harmonic distortion was low for the majority of the life of the hearing aid. Shortly before the battery expired, a sharp increase in distortion was noted especially at 500 Hz. This pattern was evident regardless of the hearing aid technology and was found for each of the trials. The following graphs (Figures 7 through 9) show the THD vs. time that was characteristically seen for each of the hearing aid technologies. The dotted lines show the ANSI specifications for each of the frequencies. The total harmonic distortion was within the percentages specified by the ANSI specifications until

shortly before the hearing aids expired.

Figure 7. The total harmonic distortion over time for analog hearing aid technologies when powered by the solar-powered NiMH batteries

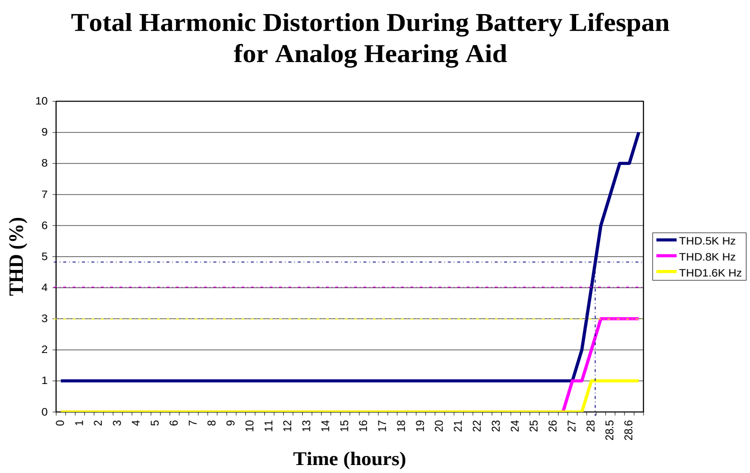


Figure 8. Total Harmonic Distortion in Basic Digital vs. Time

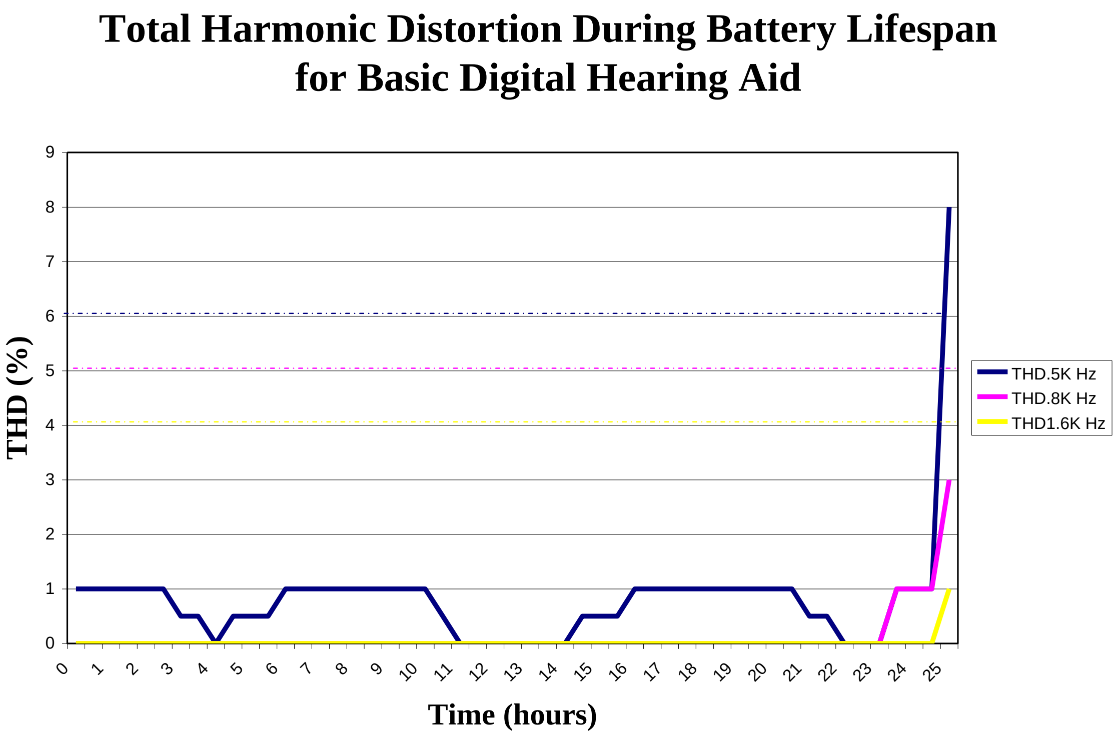
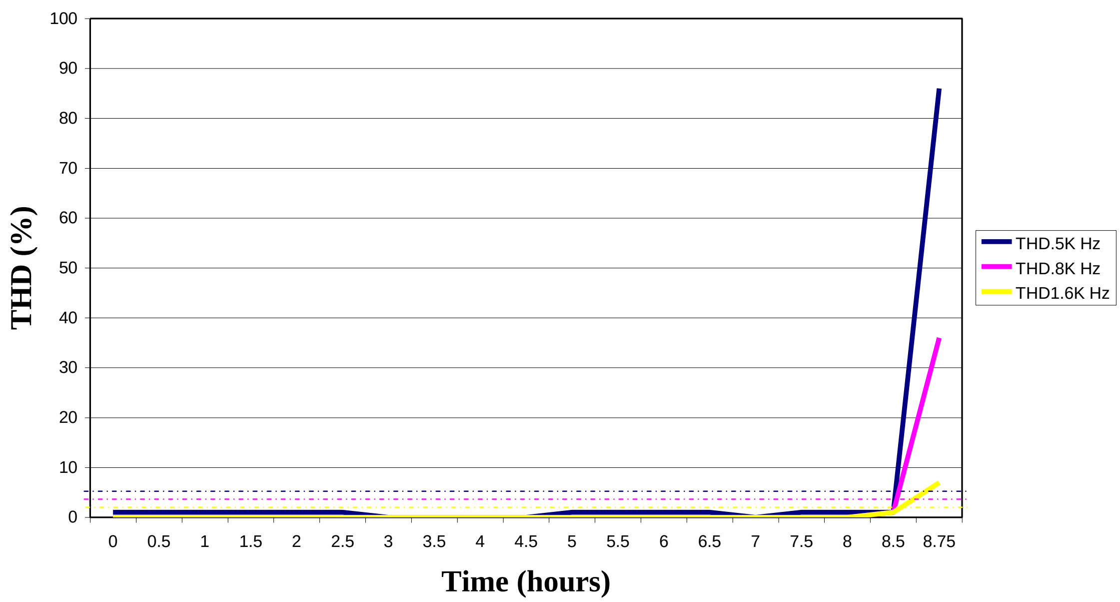


Figure 9. Total Harmonic Distortion in Advanced Digital vs. Time

Total Harmonic Distortion During Battery Lifespan for Advanced Digital Hearing Aid



CHAPTER IV

DISCUSSION

Test Environment

The Godisa solar-powered charger and rechargeable hearing aid batteries were specifically designed for the sub-Saharan environment of Africa. This experiment was carried out during the winter months in the central Michigan region of the United States. The weather was overcast for most of the experiment. Direct sunlight for charging the solar-powered charger was not available, and it was necessary to rely on indirect sunlight to charge the solar-powered charger. Therefore, it is argued that the results obtained for this study represent worst case scenario performance of the products tested.

Efficacy

Based on the results found in this study, several inferences can be made about the efficacy of the use of solar-powered rechargeable hearing aid batteries. The hearing aids charged by the solar-powered rechargeable batteries were found to maintain gain, equivalent input noise, and total harmonic distortion that was compliant with the ANSI specifications for the majority of their lifespan, with the exception of shortly before the battery was about to expire. This implies that hearing aid wearers could use these products without any effect on the sound quality of their hearing aids.

Another consideration is the lifespan of the NiMH rechargeable hearing aid batteries was found to be considerably shorter when compared to zinc-air single use batteries. Estimates of the lifespan of the analog hearing aids when using zinc-air batteries was 213 to 392 hours (18-32.5 days). The estimated lifespan for basic digital hearing aids when using zinc-air batteries was 287 to 417 hours (24-35 days), and the estimated lifespan for advanced digital hearing aids when using zinc-air batteries was 98 to 172 hours (8-14.5 days). Based on the results found for this experiment, the worst case scenario lifespan of the rechargeable hearing aids was significantly shorter for each of the hearing aid technologies. This implies that hearing aid wearers using this product must be willing to change their battery more frequently than users of single-use batteries and must be willing to manage the solar-powered charger regularly to have fresh batteries. In addition, the lifespan varied with the hearing aid technology. The added functionality of the advanced digital hearing aids, including multi-channel digital sound processing and noise reduction systems, resulted in reduced battery life when compared to hearing aids with less complexity.

Cost and Environmental Considerations

The cost of the rechargeable batteries is less over time when compared to single-use batteries. Godisa sells the rechargeable NiMH hearing batteries for approximately

$1.50 a piece plus the cost of the charger while single use zinc-air batteries are approximately $1.00 each (United States currency). In addition, the users can benefit from increasing the elapsed time between battery purchases.

Unlike previous versions of rechargeable batteries including Nickel-Cadmium (NiCad), the environmental risk of NiMH batteries is considered low, and due to multiple reuses after charging, less waste is accumulated in the landfills over time compared to single use batteries (Lin, 2005). The freedom from electricity makes it possible for NiMH solar-powered rechargeable batteries to be used worldwide, including developing countries where electricity is not readily available. This is especially applicable when considering the World Health Organization (WHO) estimates that two-thirds of people with a disabling hearing impairment live in developing countries (WHO, 2005).

CHAPTER V

CONCLUSION

The hearing aids charged by the solar-powered rechargeable batteries were found to maintain gain, equivalent input noise, and total harmonic distortion that was compliant with the ANSI specifications throughout their lifespan regardless of the type of hearing aid technology. Shortly before the hearing aids lost power, a sharp decrease in gain and a sharp increase in THD and EIN were seen. This implies that hearing aid wearers could use NiMH rechargeable batteries powered by the Godisa solar-powered charger without any effect on the sound quality of their hearing aids. The lifespan of the NiMH rechargeable batteries was shown to vary with the hearing aid technology used and was shorter than zinc-air single use batteries. Therefore, NiMH users must change their batteries more frequently. The knowledge obtained during this study may increase the use of NiMH rechargeable batteries and solar-powered chargers, especially among economically-disadvantaged and environmentally-conscientious patient populations.

Appendices

Comparison of Batteries

Type	**Zinc Air**	**NiCd**	**NiMH**	**Lithium Polymer**
Commercial use since	1930	1950	1970	1990
Environmental Risk	Safe	Toxic	Low	Moderate to Low
Cycle Life	n/a	1500	300-500	Around 500
Self-discharge per month	≤0.5% (tab on)	20%	30%	5%
Cell Voltage (V)	1.2	1.2	1.2	3.7

(Lin, 2005)

BIBLIOGRAPHY

American National Standards Institute, Specifications of Hearing Aid Characteristics, ANSI S3.22 – 1996.

Chesser, B.J., and Dancer, J.E. (1985). The effects of vocational noise exposure on hearing aid battery subjective life. *Journal of Auditory Research*. 25 (4), 215-219.

Estancona, N.G., Tena, A.G., Torca, J., Urruticoechea, L., Munez, L., Aristimuno, D., Unanue, J.M., Urruticoechea, A. (1994). Solar recharging system for hearing aid cells. *Journal of Laryngology and Otology*. 108 (9), 768-769.

Edwards, B (2005). *The future of hearing aid technology*. Starkey Presentation, Minneapolis, Minnesota.

Godisa (2002). *Technologies for the Developing World*. Retrieved October 24, 2005 from http://www.godisa.org/

Knutsen, J.E. (1982). Power supplies for hearing aids. *British Journal of Audiology*. 16 (3), 189-191.

Lin, W. (2005, September 27). *Rechargeable batteries and power needs for hearing devices*. Starkey Presentation, Minneapolis, Minnesota.

Shull (2005). Care of New NiMH Rechargeable Batteries. Retrieved October 21, 2005 from http://thomas-distributing.com/

Sparkes, C., and Lacey, N.K. (1997). A study of mercuric oxide and zinc-air battery life in hearing aids. *The Journal of Laryngology and Otology*. 111(9), 814-819.

Vos Savant, M. (2005, October 16). *Ask Marilyn: Why do the batteries in my hearing aid last less than a week, while the batteries in my watch last two or three years?!***.** Parade Magazine. Retrieved October 17, 2005 from http://archive.parade.com/

World Health Organization (2005). *Prevention of Deafness and Blindness*. Retrieved October 29, 2005 from http://www.who.int/pbd/en/