Clinical Evluation of a Verification Strategy for Personal FM Systems and Nonlinear Hearing Aids

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The primary aim of this study was to characterize the problems that may arise when following the ASHA 2002 guideline for fitting of FM systems to conduct electroacoustic verification of the FM advantage provided by nonlinear hearing aids. Electroacoustic output of FM systems coupled to nonlinear digital hearing aids was determined using the ASHA recommended procedure. When the ASHA recommended +10 dB FM advantage was not obtained, gain of the FM receiver was adjusted and additional electroacoustic measurements were conducted to illustrate changes in output, distortion, and equivalent input noise that may occur when increases in FM receiver gain are provided.

Introduction

The use of a frequency-modulated (FM) system is an effective method to improve speech recognition in noise for children and adults using personal hearing aids (HAs) (Boothroyd & Iglehart, 1998; Hawkins, 1984; Lewis, Crandell, Valente, & Horn, 2004; Pittman, Lewis, Hoover, & Stelmachowicz, 1999). Additionally, personal FM systems can alleviate difficulties associated with communication in reverberant environments and in situations in which the signal of interest is located at a distance from the HA user (Nabelek & Mason, 1981). Children and adults alike can benefit from the use of a personal FM system, but the most widespread application of FM technology is for children in academic settings.

With most types of personal FM systems, an environmental microphone is active on the users' HAs or FM receiver to allow access to signals in the immediate environment, particularly for situations in which the microphone of the FM system is located at a relatively great distance from the user. The system can typically be configured to operate in one of three modes: (1) HA only: the output only includes signals delivered to the environmental microphone, (2) FM only: the output only includes signals delivered to the FM microphone, and (3) HA + FM: the output includes signals delivered to the environmental microphone and to the FM microphone.

Using a personal FM system in the "FM only" mode typically results in an improvement of 20 dB or greater in the signal-to-noise ratio relative to the HA alone (Dillon, 2001). However, the wearer has limited audibility for his/her own voice or to sounds originating from the immediate environment, especially if the FM microphone is located at a relatively great distance from the wearer. In a classroom setting, the "FM only" mode offers access to the teacher's voice (assuming the teacher is using the FM transmitter), but it may limit a child's access to the responses of other children in the class. As such, personal FM systems are frequently used in the "HA + FM" mode, allowing the user consistent audibility for all sounds in the environment. In the "HA + FM" mode, the signal-to-noise ratio decreases significantly from that obtained in the "FM only" mode. Hawkins (1984) showed that the typical improvement in the signal-to-noise ratio obtained when using an FM system in the "HA + FM" mode was 4 to 7 dB, a decrease of approximately 13 dB from that obtained in the "FM only" mode. Furthermore, Hawkins found no difference in speech-recognition-in-noise scores between the "HA only" mode and the "HA + FM" mode. The lack of difference between these two conditions may be due to the fact that the relationship of the FM signal to the HA signal was not optimized.

Audiologists are responsible for setting the electroacoustic parameters of personal FM systems so that the signal of interest becomes audible in the presence of noise and reverberation, as well as when the signal originates from a great distance. While the main focus is on the signal of interest, the system should also enable access to other important environmental sounds. The American Speech-Language Hearing Association (ASHA) Ad Hoc committee developed guidelines to assist audiologists in the electroacoustic evaluation and fitting of personal FM systems (ASHA, 2002). The ASHA Guidelines for Fitting and Monitoring FM Systems refers to the FM advantage as the difference in output of the HA for a typical input to the FM microphone (i.e., 80 dB to 85 dB SPL) compared to the output of the HA for a typical input to the HA microphone (65 dB SPL). The guideline recommends an FM advantage of 10 dB, so that the output of the HA for a typical input to the FM microphone is 10 dB greater than the output of the HA for a typical input to the HA microphone.

To evaluate the FM advantage, ASHA (2002) recommends that a series of electroacoustic measures be conducted. Calibrated real speech is the preferred choice of signal for the assessment of digital hearing aids. First, the output of the HA is measured for an input signal of 65 dB SPL presented to the HA microphone. This measure is made without the FM receiver coupled to the HA. Then, the FM receiver is coupled to the HA, and the output of the HA is measured for a 65 dB SPL signal delivered to the FM microphone only. ASHA recommends that the outputs of the HA be identical for these two measures. It may also be prudent to measure the output of the HA for a 65 dB SPL signal presented to the HA microphone while the FM receiver is coupled to the aid. Once again, the output should be identical to the first measurement. This measure is important, as the addition of the FM receiver to a HA may change the output characteristics of the HA if a significant impedance mismatch exists between the HA and FM receiver. Finally, an 80 dB SPL signal is presented to the FM microphone and the output of the HA measured (while the FM receiver is coupled to the aid). It should be noted that the intensity of the signal may vary depending upon the placement of the FM microphone, with a higher level typically chosen if a boom microphone placement is employed. Ideally, the output of this measure should be 10 dB greater than the previous measures. Contemporary personal FM systems are coupled directly to users' personal HAs by way of direct-auditory input (DAI). Some systems allow the audiologist to adjust the gain of the FM receiver to maximize the FM advantage, providing greater flexibility to optimize audibility.

Prior to the publication of the 2002 ASHA guidelines, most HAs provided linear amplification. Because the same amount of gain was applied to the input signal until the point of output limitation, measurements of output using sequential inputs (ASHA procedure) were appropriate for determining FM advantage. For example, for a HA that provides 30 dB of gain, a 65 dB SPL input to the HA alone should result in an output of 95 dB SPL. When the FM receiver is coupled to the same HA, and an 80 dB SPL is provided to the FM transmitter microphone, the HA output should be approximately 105 dB SPL . Subtracting the two outputs (105-95) results in an FM advantage of 10 dB.

Currently, most HAs possess nonlinear amplification so that the gain may vary across a wide range of input levels. Nonlinear amplification has a varied effect on signals delivered at different intensities in a sequential test format; therefore, the FM advantage may be compromised. A 65 dB SPL input to a HA that provides 30 dB of gain (2:1 compression ratio) will have an output of 95 dB SPL, while an 80 dB SPL input to the transmitter microphone will result in an output of 100 dB SPL. Effects of the nonlinear amplification allow for a 5 dB FM advantage as measured in a sequential test approach. However, in realistic use, the signal from the hearing aid microphone and the signal from the FM transmitter are processed at the same time, and each receives the same amount of compression (the amount of which is determined by the signal with the greatest intensity). As such, nonlinear amplification seems to decrease the FM advantage when evaluated with sequential measurements, but it does not affect the FM advantage of a personal FM system in realistic use. This is because input signals arriving at the FM microphone and HA microphone simultaneously receive the same amount of compression.

Several researchers have noted the limitations of using a sequential test protocol (i.e., the ASHA procedure) to assess the FM advantage provided by contemporary HAs (Hostler, 2004; Lewis & Eiten, 2004; Platz, 2004). In fact, Lewis and Eiten (2004) have noted that when using the sequential test approach with nonlinear HAs, the attainment of an FM advantage of at least 5 dB is appropriate and will correspond to a larger FM advantage when signals are delivered to the FM microphone and hearing aid microphone simultaneously (which occurs in realistic use). Platz (2006) and Lewis (2006) have demonstrated that nonlinear hearing aids that provide a 10 dB FM advantage in realistic situations (with simultaneous presentation of inputs to the HA microphone and FM microphone) may provide anywhere from a +3 to +10 dB FM advantage when measured with the sequential approach. Furthermore, Hostler (2004) has indicated that attempts to increase the gain of contemporary FM transmitters to provide a 10 dB FM advantage frequently results in substantial increases in distortion and equivalent input noise (EIN). This may be particularly concerning for users who have severe to profound hearing loss and a narrow dynamic range in which to present amplified speech. There are, however, no reports that quantify the effects of using the ASHA 2002 procedure for verification of personal FM systems with contemporary hearing aids.

Given the concerns of previous researchers regarding sequential electroacoustic procedures (Hostler, 2004; Lewis & Eiten, 2004; Platz, 2004), the primary aim of this study was to characterize the problems that may arise when following the ASHA 2002 guidelines for electroacoustic verification of the FM advantage provided by nonlinear HAs. Electroacoustic output of contemporary personal FM systems coupled to nonlinear HAs at default settings was determined using the ASHA recommended procedure (2002). When the ASHA recommended +10 dB FM advantage was not obtained for these systems, the gain of the FM receiver was adjusted (as suggested by the ASHA procedure), and additional electroacoustic measurements were conducted to illustrate changes in output, distortion, and EIN that may occur when increases in FM receiver gain recommended by the ASHA procedure are provided.

Method

Equipment

Electroacoustic measurements were performed for 12 digital HAs coupled to two FM systems. The HAs were from four manufacturers as shown in the Appendix (designated as Aid A, B, C, and D). Within each manufacturer, three types of digital HAs were selected: low-end, high-end, and power-digital model. For example, within the Manufacturer A group, there were three hearing aid types: "LowA," "HighA," and "PowerA." Two personal FM systems (FMTx1 and FMTx2) were selected, and boots or DAI shoes were obtained so that every HA but one (the "HighB") could be assessed with each FM system. The "HighB" HA could not be coupled to the FMTx1 system; therefore, no data were obtained for this configuration. The measures were made with each HA programmed for two degrees of hearing loss: a flat moderate sensorineural hearing loss (45 dB HL pure tone thresholds from 250 to 4000 Hz) and a flat severe sensorineural hearing loss (80 dB HL pure tone thresholds from 250 to 4000 Hz). Because one of the HAs used in this study could only be coupled to transmitter "FMTx1," 46 series of measurements were conducted.

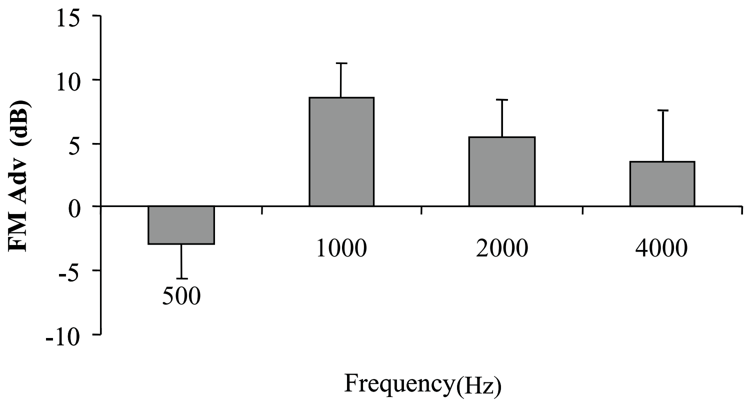
The electroacoustic assessment of the FM advantage was conducted with the Audioscan Verifit HA analyzer and a HA-2 coupler. Measures of EIN and total harmonic distortion (THD) were also conducted. The microphone of the HA and FM system were placed next to the reference microphone in accordance with the recommendations of the test box manufacturer.

Procedures

A modified version of the ASHA electroacoustic verification protocol was used to assess the FM advantage. First, the output of each HA was measured for a 65 dB SPL input signal presented to the HA microphone using the speech-shaped signal available within the Audioscan Verifit system. The output of each HA was adjusted to match the Desired Sensation Level (DSL) I/O 4.1 target (Cornelisse, Seewald, & Jamieson , 1995) for average conversational level speech, and the maximum output of each HA was set so as not to exceed the predicted uncomfortable loudness level as indicated by DSL I/O 4.1. The signal processing characteristics and compression parameters of each HA were set to manufacturer defaults for the hearing loss entered into the programming software. Secondly, an FM receiver set to the manufacturer default (+10 FM advantage) was coupled to the HA, and the output of the HA was measured for a 65 dB SPL speech-shaped signal presented to the HA microphone. This measure was conducted to ensure that the addition of the FM receiver did not change the output of the HA for inputs delivered to the HA microphone. Finally, an 85 dB SPL speech-shaped signal was presented to the FM microphone, and the output of the HA was measured. An 85 dB SPL was the default signal level for assessment of FM systems in the Audioscan Verifit system, and Dillon (2001) suggested that 85 dB SPL represents a typical input level to an FM microphone positioned 6 to 8 inches from the speaker's mouth. All measures were made with the hearing aid in the FM +HA mode.

Measurements for each FM and HA combination were conducted at octave frequencies from 500 to

Figure 1. Mean FM advantage (Adv) obtained across all hearing aid and FM transmitter combinations (forty-six conditions) with FM receivers set at default settings.



4000 Hz. The FM advantage was defined as the difference in output averaged at 1000 and 2000 Hz between each measurement (Formula: average output at 1000 and 2000 Hz for 85 dB SPL signal delivered to FM microphone – average output at 1000 and 2000 Hz for 65 dB SPL delivered to HA microphone while coupled to FM receiver = FM Advantage). The FM advantage recorded with the FM receiver set to default settings was noted as FM Advantage 1. The 1000 and 2000 Hz criteria were selected given their importance for speech intelligibility (French & Steinberg, 1947) and their test-retest reliability (Lewis, 2006). In addition, the EIN and THD were measured for each HA while the FM receiver was coupled to the aid.

If the measured FM advantage (average at 1000 and 2000 Hz) did not meet or exceed 9.5 dB, then the gain of the FM receiver was increased in an attempt to achieve the ASHA recommended +10 dB FM advantage. If the recommended +10 dB FM advantage was not be obtained, the maximum FM advantage for the HA was recorded. The FM advantage recorded after necessary adjustments were made was denoted as FM Advantage 2. Finally, EIN and THD measures were repeated with the FM receiver gain set at the revised setting.

Results

FM Advantage 1

The mean FM advantage for all octave frequencies from 500 to 4000 Hz of the 46 measurements is provided in Figure 1. The minimum FM advantage occurred at 500 Hz (-3 dB), while the maximum FM advantage occurred at 1000 Hz (8.6 dB). Analysis of variance (ANOVA) was conducted and showed a statistically significant difference in the FM advantages as a function of frequency ($p < .0001$). Post-hoc analysis (Tukey) indicated a significantly lower FM advantage at 500 Hz relative to all other frequencies, and a significantly higher FM advantage at 1000 Hz relative to other frequencies. No significant difference was detected between the FM advantages at 2000 and 4000 Hz.

FM Advantage 1: Comparisons across Aids, Manufacturers, and Severities of Hearing Loss

An analysis of variance (ANOVA) was used to examine four main effects: HA manufacturer (Aid A, B, C, and D), HA type (power, high-end DSP, and low-end DSP), hearing loss (45 or 80 dB HL), and FM system manufacturer (FM1 or FM2). The two dependent variables were FM Advantage 1 (mean FM advantage at 1000 and 2000 Hz with FM receiver at default settings) and FM Advantage 2 (mean FM advantage at 1000 and 2000 Hz obtained after necessary adjustment of FM receiver).

Overall, the mean FM Advantage 1 for conditions assessed was 6.98 dB (SD = 1.96), with a range of 2.5 to 10.5 dB. Of the 46 conditions evaluated, eight had an FM Advantage 1 of 9.5 dB or greater. The ASHA recommended +10 dB FM Advantage 1 was obtained for six HA and FM system combinations in the 45 dB HL hearing loss group and two HA/personal FM system combinations in the 80 dB HL group.

Mean FM Advantage 1 for each level of the four main effects is provided in Figures 2a-2d. Analysis of variance for FM Advantage 1 indicated that the only statistically significant main effect was HA manufacturer ($F = 31.88$, $p < .0001$). Additionally, a statistically significant interaction was found between HA manufacturer and HA type ($F = 9.65$, $p < .0001$).

The mean FM Advantage 1 for the different HA types across the four HA manufacturers is provided in Figure 3. Post-hoc tests (Tukey) were performed for HA manufacturers using reduced data sets where the HA type was held constant. The results of the post-hoc testing are provided in Figure 4 with non-significant differences between HA manufacturers denoted by connecting lines.

Although the primary dependent variable of interest was the average FM Advantage 1 obtained between 1000 and 2000 Hz, a statistically significant interaction occurred between personal FM system and frequency ($F = 16.6$, $p < .0001$). Mean FM Advantage 1 for each FM transmitter as a function of frequency are provided in Figure 5. Pair-wise comparisons indicated that the FM advantage 1 was higher for FMTx1 at 1000 Hz and below ($p < .0001$), while the

Figure 2. Mean FM advantage (Adv) 1 for 1000 and 2000 Hz with FM receiver set at default settings for each (a) degree of hearing loss, (b) type of hearing instrument, (c) FM transmitter, and (d) hearing aid manufacturer.

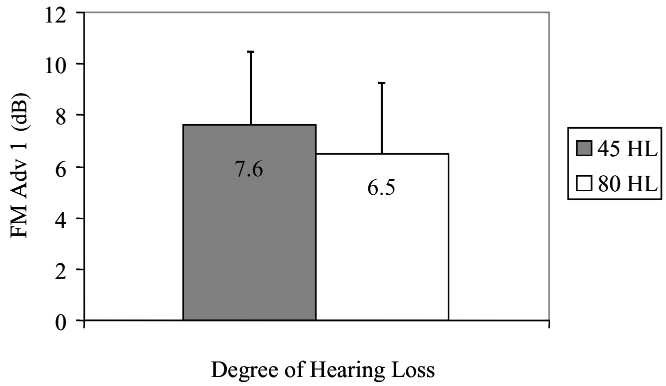


Figure 2 A.

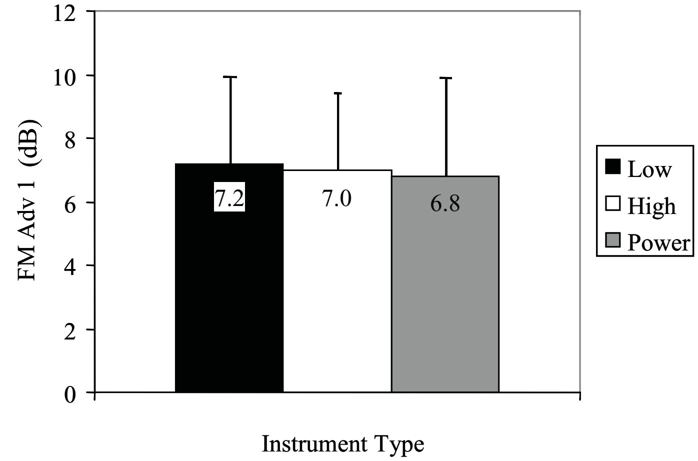


Figure 2 B.

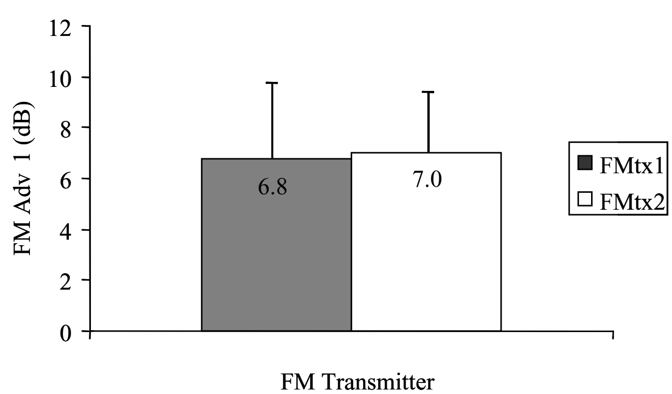


Figure 2 C.

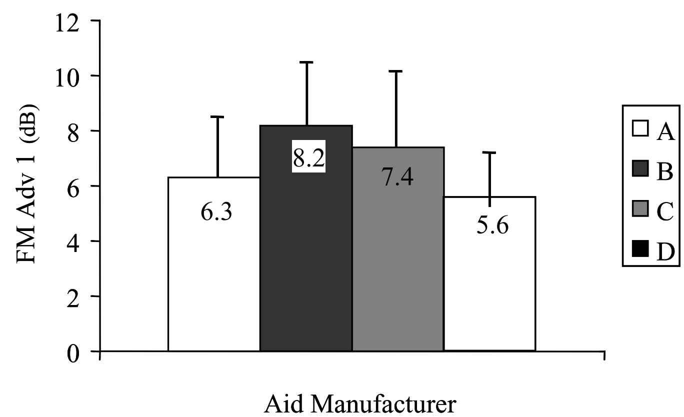


Figure 2 D.

FM advantage was higher for FMTx2 for frequencies higher than 1000 Hz ($p < .0001$).

FM Advantage 2: Comparisons across Aids, Manufacturers, and Severities of Hearing Loss

For the 38 conditions in which the ASHA recommended +10 FM advantage was not achieved, the gain of the receiver was increased in an attempt to achieve the desired advantage. The FM advantage measurements obtained after these adjustments were referred to as FM Advantage2. Twenty-five of these conditions did not achieve an FM advantage of +10 dB despite a maximum increase in FM receiver gain. The mean FM Advantage 2 with all aids included was 8.66 dB (SD = 1.92). An ANOVA was conducted for FM Advantage 2 and showed no statistically significant differences ($p > .05$) or interactions among the four main effects (hearing aid manufacturer, hearing aid type, FM system, or degree of hearing loss). The mean FM Advantage 2 is provided for each of the four main effects in Figure 6a-6d.

After the FM Advantage 2 measurements were completed, the change in EIN and THD at 500 and 800 Hz were determined by subtracting measurements from the default setting. The mean increase in EIN following adjustment of the FM receiver gain was 5.6 dB (SD = 4), while the mean increase in the THD was 9.7% (SD = 9.4) and 8.4% (SD = 12.9) at 500 and 800 Hz, respectively. The range of change in the EIN was zero to 15.4 dB, while the range for the change in THD was zero to 42.2% and zero to 48% at 500 and 800 Hz, respectively. An ANOVA indicated no statistically significant differences in the change in

EIN or THD from the default setting to the adjusted setting for any of the main effects ($p > .05$).

Discussion

FM Advantage as Measured with ASHA Verification Approach

A commercially available HA analyzer, the Audioscan Verifit, was used to measure the average FM advantage of several contemporary HAs possessing digital signal processing. Measurement of the FM advantage was accomplished using a sequential assessment protocol, as recommended in the ASHA Guidelines for Fitting and Monitoring of FM Systems (2002). The average FM advantage at 1000 and 2000 Hz did not meet the ASHA recommendation of +10 dB for 38 of 46 HA conditions when the FM receiver was set at the manufacturer default settings. No significant differences were detected in the average FM advantage at 1000 and 2000 Hz when the HAs were set for either a mild or severe degree of hearing loss. For the severe hearing loss programming used in this study, the dynamic range (range between threshold and loudness discomfort level) exceeded 30 dB. Therefore, average conversational speech could be amplified within this dynamic range (available headrowom). It is probable that a profound hearing loss, with a smaller dynamic range, would not allow for full audibility of average conversational level or the ability to achieve a +10 dB FM advantage.

No significant difference was detected in the mean FM advantage at 1000 and 2000 Hz between the two personal FM systems or for the various types of HAs that were evaluated (i.e., low-end, high-end, and power aid). There was, however, a statistically significant difference in the mean FM advantage between the various manufacturers of HAs used in this study, which was likely attributable to two factors. First, when evaluated at default settings, the HAs of Manufacturer B had higher FM advantages than the HAs of the other manufacturers. Two of the HAs of Manufacturer B had separate analog-to-digital (A/D) converters for the input from the HA and FM microphones, resulting in independent control of the output of each A/D converter. As such, the HAs were designed to maintain a difference (i.e., 10 dB FM advantage) for conversational speech between the HA and FM microphones. The output is maintained regardless of whether a sequential or simultaneous verification procedure is used. The HAs of the other manufacturers were designed so that the signal from the HA and FM system were processed by the same amplifier. Consequently, the compression of the two signals will likely be different for a nonlinear HA when using a sequential evaluation approach.

Another factor contributing to differences among HA manufacturers was the varying compression characteristics in the HAs. For example, Aid D possessed a relatively low compression threshold and high compression ratio, and it also possessed the lowest FM advantage amongst the four HA manufacturers. Therefore, the amount of compression for the FM signal is greater for this manufacturer compared to the other manufacturers. In a sequential verification approach, the increased amount of compression results in the appearance of a lower FM advantage. In realistic situations, however, the HA and FM system signals will be processed simultaneously, and the same amount of compression will be applied to each. Therefore, the FM advantage obtained when using a sequential test approach for nonlinear HAs may not be representative of what is achieved in everyday listening situations.

One way to achieve the desired +10 dB FM advantage is to use an adjustable gain feature available on some FM receivers. In this study, increasing the gain of the FM receiver occasionally produced detrimental outcomes. For instance, increasing the gain of the FM receiver typically resulted in an increase in the internal noise, which corresponded to the magnitude of the gain increase. Increases in EIN of at least 3 dB were observed in 27 of the 38 hearing aid/FM conditions in which the gain of the FM receiver was increased to achieve the ASHA recommended +10 dB FM advantage. The difference in the EIN following the adjustment in the FM

Figure 3. Mean FM Advantage (Adv) 1 for 1000 and 2000 Hz for each type of hearing aid across four different hearing aid manufacturers (FM receiver set at default settings).

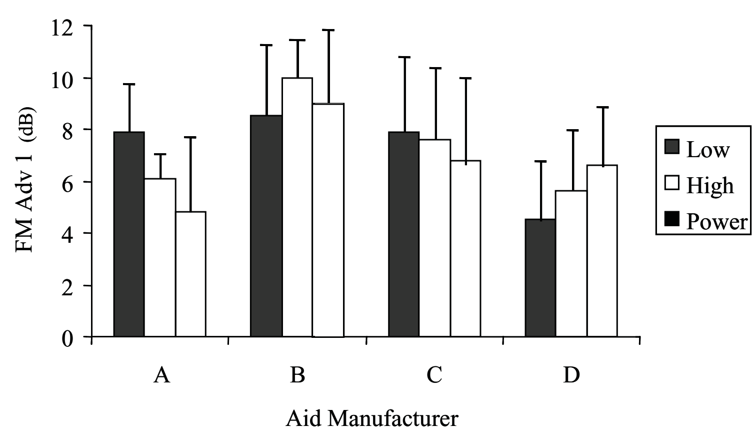


Figure 4. Results of Tukey analysis examining differences between hearing aid manufacturers across type of hearing aid.

Hearing Aid Type	Hearing Aid Manufacturer			
Low:	Aid C	Aid B	Aid A	Aid D
High	Aid B	Aid C	Aid A	Aid D
Power	Aid B	Aid D	Aid C	Aid A

Note. Non-significant differences are denoted by connecting lines

receiver gain ranged from no change to an increase of 26 dB. The mean increase in EIN was 5.6 dB (SD = 5.7 dB). A paired Student's t-test indicated that the difference in EIN measured before and after the adjustment of the gain of the FM receiver was statistically significant ($p < .001$). Larger increases in EIN were typically observed as larger increases in the adjustable gain in the receiver were implemented. This increase in internal noise may affect sound quality and potentially speech recognition in quiet environments. It should be noted that the ANSI S3.22-1996 standard for the measurement of hearing aid performance does express concern with the use of the EIN test with hearing aids possessing nonlinear signal processing. Specifically, the ANSI S3.22-1996 standard suggests that EIN values may be exaggerated when using nonlinear hearing aids. The possibility does exist that a portion of the increase in EIN observed with changes in FM receiver gain may be attributed to the exaggeration associated with nonlinear hearing aids.

Increases in THD were also observed for 31 of the 38 hearing aid/FM conditions in which the gain of the FM receiver was increased to achieve a +10 dB FM advantage. The increase in distortion was most severe when the FM receiver was set to the maximum setting. Also, this increase (mean increase of approximately 9%) often exceeded the acceptable THD level, as recommended by Dillon (2001). Comprehensive evaluation of the performance of an FM system should include not only an electroacoustic analysis but also a biologic listening assessment to check for artifacts or distortion that may elude the electroacoustic evaluation.

Effectiveness of ASHA Guidelines for Hearing Aids with Nonlinear Signal Processing

Several researchers have expressed concern regarding the limitations of using a sequential test protocol, such as the ASHA (2002) procedure, for the evaluation of contemporary nonlinear HAs (Hostler, 2004; Lewis, Feigin, Karasek, & Stelmachowicz, 1991; Platz, 2004, 2006). Indeed, this paper suggests that it is difficult to obtain the recommended 10 dB FM advantage when using the ASHA procedure with contemporary nonlinear hearing aids. Furthermore, attempts to attain the recommended 10 dB FM advantage through increases in the gain of the FM receiver may result in undesirable consequences, such as increases in internal noise and distortion. Finally, investigators have shown that attainment of a 10 dB FM advantage when using the ASHA (2002) procedure may result in an inappropriately high FM advantage in realistic situations (Lewis and Eiten, 2006). Keep in mind that attainment of a 10 dB FM advantage is still a reasonable goal with nonlinear hearing aids coupled to personal FM systems. In fact, Platz (2006) Lewis (2006) both showed that the 10 dB FM advantage is achievable with nonlinear hearing aids when signals arrive at the hearing aid microphone and FM microphone simultaneously. Because of this, there is a need for a new method to assess the FM advantage obtained with nonlinear hearing aids.

Several alternatives have been proposed and

Figure 5. Mean FM Advantage 1 obtained for two different personal FM systems across frequency with the FM receiver gain set at default settings

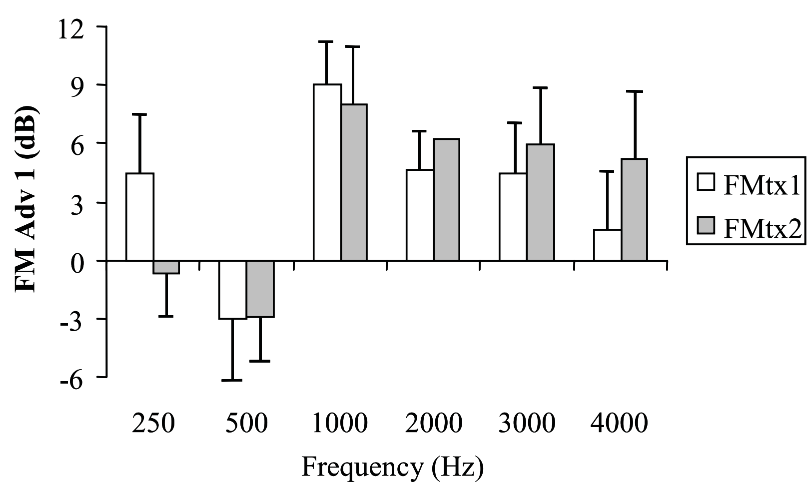


Figure 6. Mean FM Advantage (Adv) 2 for 1000 and 2000 Hz with FM receiver set at the adjusted FM receiver settings for each (a) degree of hearing loss, (b) type of hearing instrument, (c) FM transmitter, and (d) hearing aid manufacturer.

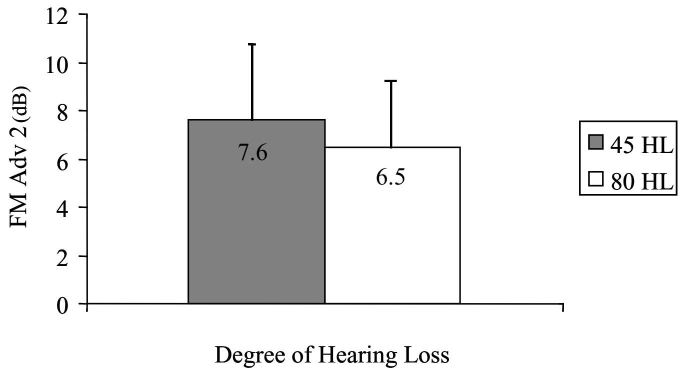
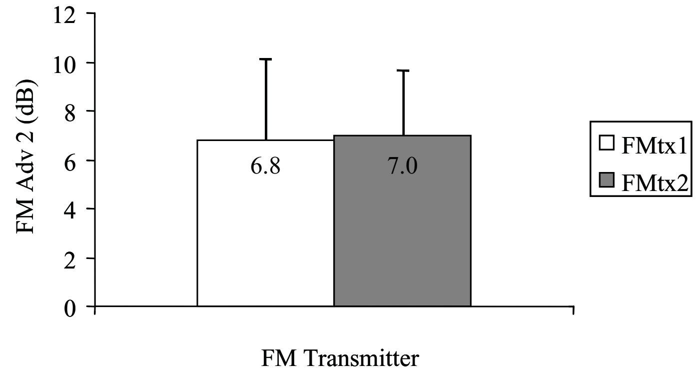


Figure 6 A.



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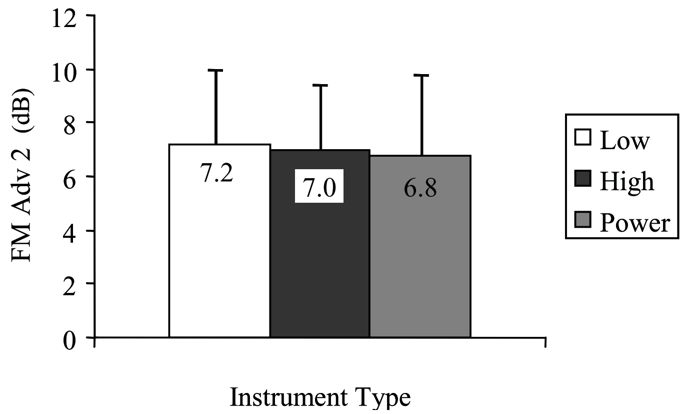

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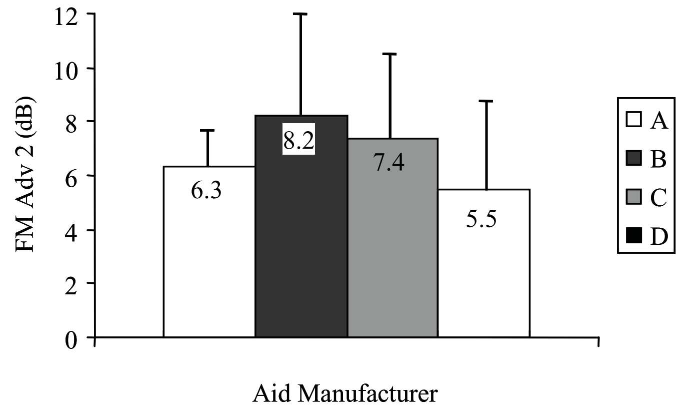


Figure 6 D.

focus on simultaneous presentation of test signals to the HA and FM microphones. These arrangements will provide a more valid testing situation and should theoretically result in the same amount of compression at each microphone. Until technology evolves to allow for that type of assessment, other approaches have been proposed.

Lewis and Eiten (2004) described an approach where the output of the HA and FM system are each determined in response to a 65 dB SPL signal. If the output is identical, then inputs to the transmitter and HA microphones are believed to be compressed by the same amount. In contrast, when output differs by more than + 2 dB, the FM advantage setting on the FM receiver should be adjusted until similar output is measured. Then, when the relative distances of the transmitter (3-6 in.) and HA microphone (3 ft.) are in place, an FM advantage should be present. In addition, an FM advantage of +5 dB may be sufficient to allow for a perceptual benefit in noisy environments. Lewis and Eiten compared the ASHA protocol (2002) to the newly proposed protocol for three HAs with different characteristics (A-high compression threshold/ low compression ratio, B-separate processing path for FM system and HA to maintain +10 dB FM advantage, C-low compression threshold/ high compression ratio). When using the ASHA protocol, the FM advantage for the three HAs programmed for a 45 dB HL hearing loss was 8, 10, and 4.5 dB, respectively. When the same HAs were evaluated using the approach suggested by Lewis and Eiten, all three HAs produced a similar output for a 65 dB SPL signal presented to both the HA and FM system microphones. Consequently, in realistic use, the three HAs provided a comparable FM advantage even though they appeared to be very different when using the ASHA approach.

Currently, the verification approach described by Lewis and Eiten (2004) presents an effective and clinically feasible approach for evaluating the FM advantage of personal FM systems coupled to personal HAs. Additionally, Auriemmo, Keenan, Passerieux, & Kuk (2005) described a well-designed protocol for electroacoustic verification of personal FM systems for use with contemporary digital hearing aids. Finally, Platz (2006) also described an innovative approach to assess the FM advantage of contemporary systems, but the approach requires multiple HA analyzers making it impractical for some audiology clinics. Recognizing the need for new procedures for the fitting and verification of FM systems, an American Academy of Audiology taskforce of researchers in the area of Hearing Assistance Technology (HAT) are in the process of developing new guidelines (Deconde Johnson, Anderson, Boothroyd, Eiten, Gabbard, Thibodeau , 2007). Until the new guidelines are published, the prudent audiologist must continually be aware of contemporary verification strategies for personal FM systems and sophisticated digital hearing aids, as well as changes and improvements in HA analyzer technology that will allow for a more direct assessment of FM performance.

FM Advantage as a Function of Frequency

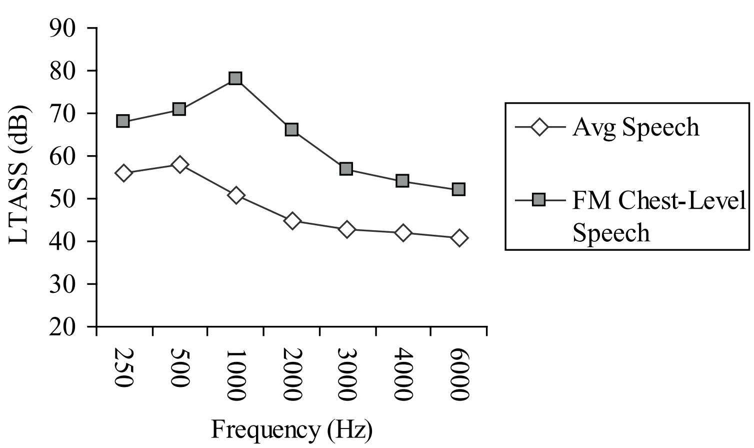
Results of this study showed that FM advantage varied as a function of frequency. Specifically, the FM advantage was greater between 750 and 2000 Hz relative to other frequencies. Differences may be attributed to input level, location of the microphones, and compression characteristics. First, the spectrum of the input stimulus at the two test levels, 65 and 85 dB SPL, is different (see Figure 7). Second, the intensity and the spectrum of the signal are altered at the two microphones because of the relative location of the FM system and HA. Finally, the compression characteristics of the HA will affect the FM advantage measured when using a sequential verification protocol. If compression ratios differ across channels of a nonlinear HA, then the FM advantage will be affected differentially across the frequency range.

In summary, the FM advantage obtained when evaluating contemporary HAs and FM systems with currently available HA analyzers using speech-like signals will vary as a function of frequency. It is most effective to focus FM advantage measurements to a specific area of the spectrum where FM advantages are often higher (750-2000 Hz). As previously noted, for this study, FM advantage was obtained at 1000 and 2000 Hz because the test-retest reliability was shown to be good at those frequencies relative to other frequencies (Lewis, 2006).

Conclusion

Given the advancement of HAs using digital signal processing, new testing protocols need to be established to account for varied results found using the ASHA protocol (2002). Results of this study show that the desired +10 dB FM advantage was not achieved in many HAs, and large differences were found across different manufacturers. Attempts to obtain a +10 dB FM advantage through adjustments of the FM receiver setting were successful, but often resulted in an increase in the internal noise and distortion. Modern HAs typically possess nonlinear signal processing, and as a result, the FM advantage obtained in a sequential assessment approach using different levels may underestimate the FM advantage obtained during use in most realistic situations. Therefore, these authors believe that clinicians should exercise caution in using the ASHA 2002 procedure for all WDRC hearing aids. Although, several researchers have described alternative approaches to evaluating the FM advantage with contemporary HAs, audiologists and manufacturers must continue to develop and implement clinically practical electroacoustic verification protocols for the assessment of FM performance with modern HAs and personal FM systems.

Figure 7. Long-term average speech spectrum (LTASS) for the average conversational level (65 dB SPL) and FM Chest-level Speech-shaped (85 dB SPL) signal of the Audioscan Verifit.



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Appendix
Hearing Aid/FM Technology Conditions

Hearing Aid Manufacturer	Hearing Aid Type	FM System	Hearing Loss
A	High-end Digital	FMTx1	Mild
A	Low-end Digital	FMTx1	Mild
A	Power Digital	FMTx1	Mild
A	High-end Digital	FMTx2	Mild
A	Low-end Digital	FMTx2	Mild
A	Power Digital	FMTx2	Mild
B	High-end Digital	FMTx1	Mild
B	Low-end Digital	FMTx1	Mild
B	Power Digital	FMTx1	Mild
B	High-end Digital	FMTx2	Mild
B	Low-end Digital	FMTx2	Mild
B	Power Digital	FMTx2	Mild
C	High-end Digital	FMTx1	Mild
C	Low-end Digital	FMTx1	Mild
C	Power Digital	FMTx1	Mild
C	High-end Digital	FMTx2	Mild
C	Low-end Digital	FMTx2	Mild
C	Power Digital	FMTx2	Mild
D	High-end Digital	FMTx1	Mild
D	Low-end Digital	FMTx1	Mild
D	Power Digital	FMTx1	Mild
D	High-end Digital	FMTx2	Mild
D	Low-end Digital	FMTx2	Mild
D	Power Digital	FMTx2	Mild
A	High-end Digital	FMTx1	Severe
A	Low-end Digital	FMTx1	Severe
A	Power Digital	FMTx1	Severe
A	High-end Digital	FMTx2	Severe
A	Low-end Digital	FMTx2	Severe
A	Power Digital	FMTx2	Severe
B	High-end Digital	FMTx1	Severe
B	Low-end Digital	FMTx1	Severe
B	Power Digital	FMTx1	Severe
B	High-end Digital	FMTx2	Severe
B	Low-end Digital	FMTx2	Severe
B	Power Digital	FMTx2	Severe
C	High-end Digital	FMTx1	Severe
C	Low-end Digital	FMTx1	Severe
C	Power Digital	FMTx1	Severe
C	High-end Digital	FMTx2	Severe
C	Low-end Digital	FMTx2	Severe
C	Power Digital	FMTx2	Severe
D	High-end Digital	FMTx1	Severe
D	Low-end Digital	FMTx1	Severe
D	Power Digital	FMTx1	Severe
D	High-end Digital	FMTx2	Severe
D	Low-end Digital	FMTx2	Severe
D	Power Digital	FMTx2	Severe