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Evaluation of directional microphone drift in digital hearing aids

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EVALUATION OF DIRECTIONAL MICROPHONE DRIFT IN DIGITAL HEARING AIDS

by

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Abstract: The occurrence of directional microphone drift following hearing aid use has been infrequently examined. This study uses the front-to-side ratio to evaluate changes in directional microphone output from new behind-the-ear hearing aids and following approximately three months of hearing aid use. Results indicate no overall significant differences in the front-to-side ratio between initial and follow-up measurements.

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ABBREVIATIONS

ANOVA	Analysis of Variance
BTE	Behind-the-Ear
dB	Decibel
DI	Directivity Index
FBR	Front-to-Back Ratio
FSR	Front-to-Side Ratio
HINT	Hearing in Noise Test
Hz	Hertz
SD	Standard Deviation
SNR	Signal-to-Noise Ratio
SPL	Sound Pressure Level

INTRODUCTION

Hearing impaired listeners have significant difficulty understanding speech in the presence of background noise due to the poor spectral and temporal resolution of the damaged cochlea (Moore, 2008). For these listeners, an increase in the level of speech compared to unwanted noise results in an increase in speech recognition performance (Gelfand, 1998). The signal-to-noise ratio (SNR) is a commonly used measurement in decibels (dB) that describes the level of the target acoustic signal relative to the background noise. Nabelek and Pickett (1974) found that normal hearing listeners could still achieve a 50% word understanding score when the background noise is 9 dB louder than the target signal (-9 dB SNR). However, hearing-impaired listeners needed the signal to be 5 dB louder than the background noise (+5 dB SNR) in order to attain this same word understanding score. When the literature is combed looking for the SNR required for maximum speech intelligibility performance, it appears that while adult normal hearing listeners are able to tolerate a 0 dB SNR before their speech perception abilities are significantly reduced, hearing impaired listeners require a SNR of up to +20 dB for maximum speech intelligibility (Crandall and Smaldino, 2000; Flexer, 2004). Considering that the majority of common environments range from -10 to +5 dB SNR, the speech intelligibility for an individual with hearing loss is often compromised (Ricketts, 2005).

Given the hearing-impaired listeners' decreased ability to separate the desired signal from the background noise, it is important for hearing aid technology to increase the strength of the target signal relative to background noise (increase SNR) prior to entering the auditory system. Based on data from Miller, Heise, and Lichten (1951), speech perception scores in noise increase approximately 3.5% for a 1 dB increase in the SNR. Digital hearing aids employ several processing schemes with the goal of strengthening the SNR. One such technology to enhance the SNR by hearing aids is directional microphones. Directional microphone technology has been found to be extremely useful in increasing the SNR for improved speech intelligibility in noise (Ricketts, 2000; Ricketts and Henry, 2002; Valente et al., 2006; Valente and Mispagel, 2008). Currently, a directional microphone system can increase the SNR by 8 dB to attain 50% word recognition (Hawkins and Yacullo, 1984; Valente et al., 1995).

Current hearing aid directional microphone technology is comprised of two omnidirectional microphones located on a near horizontal plane. When the hearing aid is programmed to be omnidirectional, only one microphone is activated (the front facing microphone) and it collects sound from all locations to be amplified without relative delay. With the directional microphone system, either automatically or manually activated, the second rear-facing microphone is engaged. These two microphones are angled so that sounds coming from behind or the side of the hearing aid user are discriminated from the signal in front by the external delay of sounds reaching one of the microphone ports before the other. The greater the distance between the two microphone ports, the larger the external delay. Sounds that arrive to the rear microphone will be internally delayed in time by the digital processor, then phase inverted before it is combined with the input from the front facing microphone. As a result, the sounds arriving from behind the listener are either not amplified or minimally amplified relative to the input from in front of the listener. The ratio of the external delay (microphone port spacing) to the digitally processed internal delays determines the angles of hearing aid amplification or gain reduction (Ricketts, 2005).

Directionality, or the reduction of amplification at specific angles, can be assessed using various measures. One visual measurement of hearing aid directionality is the polar plot. Polar plots are obtained by plotting the output of the hearing aid in dB SPL in response to input presented at locations from 0 to 360 degrees around the hearing aid. Examination of the nulls or points of greatest attenuation provides an assessment of the hearing aid's directionality. An omnidirectional system as shown in Figure 1a displays equal output or gain at all angles surrounding the hearing aid. Digital hearing aid directivity patterns are described as being bi-directional (Figure 1b), cardioid (Figure 1c), and hypercardioid (Figure 1d). The most common design for directional microphones is the hypercardioid, which has the greatest reduction at 110 and 270 degrees (Valente, 2002).

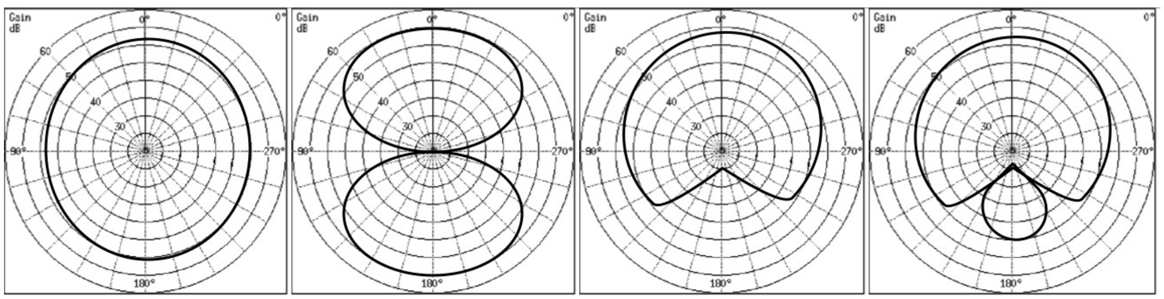

Figure 1: Polar plots of several directional patterns are shown. From left to right: a) omnidirectional b) bi-directional c) cardioid and d) hypercardioid

While polar plots provide information on the pattern of directional hearing aid performance, it does not sum up an entire directional microphone system's degree of attenuation into a single value. The directivity index (DI) calculates the hearing aid output ratio for input stimuli located at 0-degrees azimuth relative to stimuli located at sources other than 0-degrees (Valente, 2002). If the target signal is in front of the hearing aid user, an increase in DI implies that the target signal is louder relative to the sounds coming from angles other than in front of the listener.

For directional microphones to properly reduce unwanted noise behind the listener, the output of the two omnidirectional microphones needs to be matched. Directional microphone drift occurs when there is a mismatch in output between the front and rear microphones. Drift or mismatch can occur as a result of debris in the microphone ports, shifting of the microphone filters, humidity, and other environmental factors (Thompson, 1999). Directional microphone drift can lead to poorer directional benefit, as reflected by a decrease in DI (Valente, 2002). Furthermore, polar plots display less attenuation at specified angles and shift towards a more omnidirectional pattern when there is a mismatch between the microphones. Although it has not been directly measured, it can be assumed that microphone mismatch can affect speech intelligibility in noise due to the reduction in the directivity of the microphone system. A mismatch in directional microphones results in a lower SNR due to the lack of attenuation of sound behind the listener (predominantly noise) relative to the target signal in front of the listener. Edwards (2000) theorized that a mismatch in directional microphones of 1 dB can degrade word recognition by 10%.

Many studies that have examined the impact of microphone drift on hearing aid directional performance used simulations of these drifts in the laboratory (Edwards, 2000). There are few studies that measure microphone drift of hearing aids that have been dispensed to patients. Matsui and Lemons (2001) measured the DI of 13 non-dispensed hearing aids, and then completed this measurement again 3 months later. They documented an average directional microphone drift of 1 dB after 3 months of non-use. This study did not provide details related to the methods and materials used to reach the conclusions. There is a void in the literature relating to directional microphone drift over time in hearing aids that have been worn consistently by users.

A possible reason for the lack of studies analyzing directional microphone drift is the complexity of calculating DI. Directivity Index is calculated using different formulas depending on the environment that the hearing aid is placed. The most ideal environment to complete this measure is in a free field diffuse sound field where the density is consistent throughout the space and the sound waves are randomly dispersed (Valente, 2002). The measurement calls for an anechoic chamber and for the hearing aid to be placed on a real ear or simulated head with an ear. Due to the cost and rarity of an anechoic room, measurement of DI is generally limited to industry and University research laboratories.

A more appropriate and cost-effective method of verifying the status of hearing aid directional microphone system is the front-to-back ratio (FBR) measurement, which subtracts the output of sounds received at 180 degrees azimuth from the output to sounds at 0 degrees azimuth. This measure differs from the DI in that hearing aid output is only measured at two angles of acoustic inputs rather than at all angles surrounding the aid (Wu and Bentler, 2011). Due to the less complex calculations needed to compute the FBR, clinically available hearing aid analyzers such as the Verifit and Frye can be used to measure the FBR or provide data for the clinician to compute it (Etymonic Design, Inc., 2011; Frye Electronics, Inc., 2012). Although the FBR does not measure directivity like the DI does, a correlation between the measures indicates that FBR can approximate the directional microphone benefit enough to supervise any changes in directionality in a hearing aid (Dittberner and Bentler, 2007).

A recent study by Wu and Bentler (2011) found that, possibly due to the greatest directional microphone attenuation occurring at side angles instead of at 180 degrees, the front-to-side ratio (FSR) has a greater correlation with objective DI measures and functional measures of listeners' performance on the Hearing In Noise Test (HINT) (Nilsson et al, 1994). The FSR compares the output of the hearing aid with inputs presented at 0 degrees and 110 degrees. Also, the study found that significant changes in DI were not reflected in changes of the FBR, while they were more closely documented by the FSR. Conclusively, the FSR is a more reliable and applicable measure for monitoring directional microphone status in the clinic.

Despite the evidence that the FSR is correlated with changes in directivity, the reliability of this measure using clinically available measurement systems is not known. The FSR can be calculated using the directional microphone chamber in the Frye 8000 system designed by Frye Electronics (Frye Electronics, Inc., 2012). The hearing aid analyzer chamber is designed to mimic an anechoic test chamber, and allows for the rotation of hearing aids on an axis so that the output of the aid can be measured in response to inputs from 0 to 360 degrees surrounding the aid. Reliability of the directional microphone chamber has not yet been determined, but sources report practical precision of the measurement (Wu and Bentler, 2011).

As there is a possibility of directional microphone mismatch occurring over time due to wear and tear by the hearing aid user, it is important for the clinician to be able to measure or verify that the directional microphones are working appropriately. Oftentimes patients will report a change in their hearing aid performance in noise, but the clinician is unable to detect any malfunction with traditional hearing aid electroacoustic measures (e.g., output in response to pure tone sweeps, measures of harmonic distortion and levels of circuit noise). The introduction of the Frye 8000 arms the clinician with a new measure of hearing aid performance and may shed light on whether directional microphones of worn hearing aids do in fact drift over time. As a result of the literature suggesting that directional microphone drift could occur in used behind-the-ear hearing aids and the potential of the FSR to document any possible drift, the following objectives of this Capstone Project are posed:

1. The first objective will be to measure the test-retest reliability of the FSR calculated by the directional coupler system by Frye Electronics.

2. Secondly, the author seeks to determine if significant changes in FSR as measured by the Frye Fonix 8000 occur after approximately 3 months of hearing aid use in behind-the-ear hearing aids.

METHODS

Pre-Experiment: Test-Retest Measures of the FSR using Fonix 8000

The Fonix 8000 system has a new feature to Frye Electronics hearing aid analyzers that creates polar plots for directional microphone assessment. This system measures the output of the hearing aid in dB SPL as it rotates 360 degrees on an axis in front of a speaker presenting a specified signal. This system is capable of calculating polar plots for inputs of differing frequencies and intensity. The Fonix 8000 system is designed to approximate measurements obtained in an anechoic chamber due to the chamber's low reverberation (Frye Electronics, Inc., 2012). However, the reliability of its directional output measurement has not yet been determined. A pre-experiment to this Capstone Project was conducted to determine test-retest reliability of the Fonix 8000's polar plot generator.

Hearing aids and hearing aid settings

Fifteen stock BTE hearing aids were used for the pre-experiment. BTE hearing aids were approximately 18 months old and used intermittently as loaner aids and for student practice at the Spencer T. Olin Clinic at Washington University School of Medicine. Hearing aids included Starkey Series 11, Phonak Versata, and Phonak Audeo Yes.

The hearing aids were programmed to provide appropriate gain for a flat 50 dB loss from 250 to 8000 Hz using the National Acoustics Laboratory Non-linear (NAL-NL1) prescriptive formula. (Johnson and Dillon, 2011). As described by Keidser et al (2006), wide dynamic range compression does not negatively affect directional microphone performance compared to linear settings. Other automatic features of the hearing aids such as feedback reduction, noise reduction, wind noise reduction, and low-frequency echo-block were deactivated. Finally, the microphone settings were set to fixed directional. For Phonak hearing aids, the programming software allows the Audiologist to determine the aggressiveness of the directional microphone settings. For these aids the fixed directional settings were set to the maximum position in the programming software's fixed directional range.

Set up of the Fonix 8000

The directional microphone measurement parameters in the Fonix 8000 hearing aid analyzer were specified as follows. The output of the hearing aid was measured in response to 500, 1000, 2000, 3000, and 4000 Hz pure tone stimuli presented at 60 dB sound pressure level (SPL). Stimulus presentation was set to fully automatic mode so that each frequency was measured individually. The noise reduction features on the Frye system were disabled. In order to capture output at appropriate frequency to complete an FSR at 0 degrees and 110 degrees, the Fonix 8000 was set up to capture output for each frequency at every 10 degrees from 0 to 360 degrees.

Hearing aids were coupled according to the type of BTE hearing aid being measured. BTE hearing aids with earhooks were measured using the HA-2 coupler. Receiver in the canal hearing aids (RIC) were coupled to the HA-1 coupler by inserting the receiver into the coupler opening and sealing with putty. The same type of coupler was used for each hearing aid for both measurements. The coupler was connected to the coupler microphone inside the chamber and the body of the hearing aid was inserted into the Positioning Saddle with the microphones positioned in a horizontal plane. The Positioning Saddle was connected to the Rotating Shaft that allowed for rotation of the aid at the axis. Figure 2a displays the Fonix 8000 set up for a behind the ear hearing aid while figure 2b shows the apparatus with a RIC hearing aid.

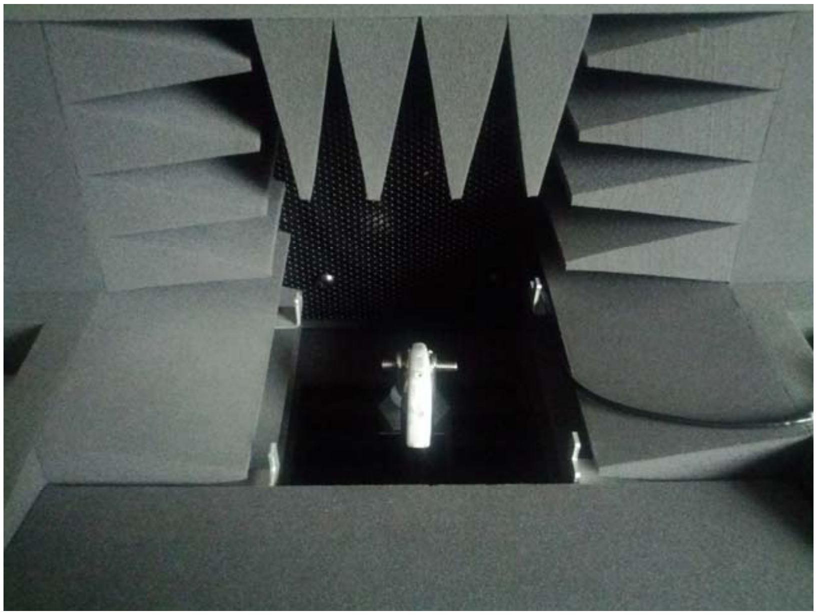

Figure 2a: Traditional BTE hearing aid connected to an HA-2 coupler

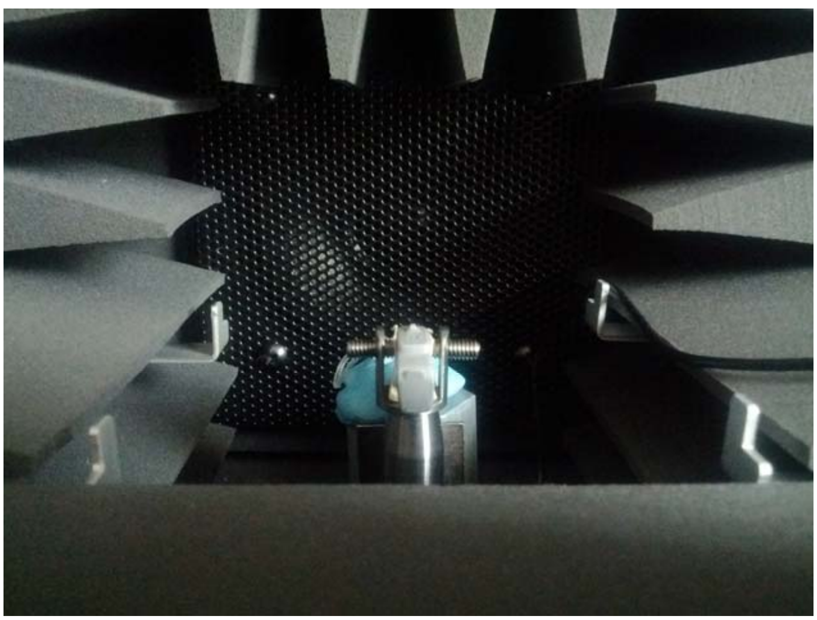

Figure 2b: RIC BTE hearing aid connected to an HA-1 coupler

Data Collection and Calculation of FSR

Once the hearing aids were coupled to the microphone for measurement, the testing was performed and all data were saved to a separate computer using fCapture software. The data contained screen shots of both the polar plots displaying the dB SPL output of the aid in response to stimuli presented from 0 to 360 degrees, as well as the numerical output data in dB SPL for each frequency at every 10th degree. FSR was calculated by subtracting the dB SPL value at 110 degrees from the output at 0 degrees, as suggested by Wu and Bentler (2011). For the retest condition, hearing aids were uncoupled from the Fonix 8000 chamber. Hearing aids were turned off and turned back on to imitate standard procedures between testing hearing aids at different times. After restarting the hearing aid, it was recoupled using the same method. This process was to account for possible changes in repositioning with the coupler and microphone placement in front of the speaker. After recoupling the hearing aids, measurements were collected and saved.

Data Analysis

The FSR data from the first and second measurement were analyzed with a paired t-test to test for significant differences between the first and second measurement and to obtain the correlation values between these measures for purposes of performing a power analysis to determine the number of aids needed for the main experiment.

Main Experiment: Measurement of Hearing Aid Directional Microphone performance after approximately 3 months of use

The FSR of newly dispensed hearing aids was measured either before the aid(s) were dispensed or before the end of a 30-day trial period once the user decided to keep the hearing aid(s) and then again at a routine clinical follow up appointment after approximately three months of use. The FSR of 63 new BTE hearing aids were measured at Washington University

School of Medicine's Adult Audiology Clinic at the Center for Advanced Medicine and the Spencer T. Olin Clinic. The majority of initial measurements were taken before users wore the hearing aids out of the office. Six hearing aids were measured within two weeks of wear due to scheduling conflicts of new aid arrival times. Twenty-four hearing aids were measured at and average of 3.5 months follow up. Table 1 gives the description data of all of the hearing aids collected at follow up.

Make	Model	Time Between Measures (Months)
Widex	Mind 440-9	6
Widex	Mind 440-9	6
Widex	Clear 440 Fusion	5
Widex	Clear 440 Fusion	5
Widex	Clear 440 Fusion	4.5
Widex	Clear 330-9	4
Widex	Clear 330-9	4
Phonak	Ambra M H20	4
Phonak	Audeo Smart III	3.5
Widex	Mind 440-9	3.5
Widex	Clear 440 Fusion	3
Widex	Clear 220 Fusion	3
Widex	Clear 220 Fusion	3
Widex	Clear 220 Fusion	3
Widex	Clear 220 Fusion	3
Widex	Clear 220 Fusion	3
Widex	Clear 220 Fusion	3
Phonak	Solana M H20	3
Phonak	Solana M H20	3
Phonak	Audeo Smart III	3
Widex	Clear 330 Fusion	2
Widex	Clear 330 Fusion	2
Phonak	Naida CRT V	2
Phonak	Naida CRT V	2
	Average	**3.5**

Table 1: Make, model, and time between initial and follow up measurements in months. Average time between measurements was 3.5 months.

Inititial- and three-month measurements were completed using the same hearing aid programming strategies and Fonix 8000 set up described in the pre-experiment section. Data collection and the calculation of the FSR for the initial- and three-month measurements also were conducted according to the same procedures described in the methods section of the pre-experiment.

Data Analysis

The FSR data from the initial- and three-month measurement were analyzed using a repeated measures analysis of variance in order to test for significant differences between the two measurements. The data was analyzed to see if there was an interaction between the frequency tested (500, 1000, 2000, and 4000 Hz) and measurement time point (initial vs three-month). Pairwise comparisons with a Bonferroni correction factor were executed to provide more information about any potential interaction between frequency and time.

RESULTS

Pre-Experiment

The FSR data from the first and second measurement of each of the 15 hearing aids were compared using a paired t-test and the descriptive data is shown in Table 2. There were no significant differences between the resultant average FSR from the first measurement and the second measurement. Table 3 displays the results of the paired samples t-test as well as the correlation between measurement time points of the 15 aids. The FSR calculation as measured by the Fonix 8000 hearing aid analyzer demonstrated good reliability in that that the two measurements demonstrated moderate to strong correlation with one another and the measurement outcomes did not significantly different from one another. Individual FSR measurement data for each hearing aid per stimulus frequency is listed in Appendix A.

Frequency	Measurement	Mean FSR (dB SPL)	Standard Deviation
500 Hz	First	14.84	5.64
	Second	15.18	6.48
1000 Hz	First	17.57	5.92
	Second	18.12	5.11
2000 Hz	First	25.67	8.55
	Second	26.17	8.3
3000 Hz	First	20.89	5.37
	Second	20.38	5.65
4000 Hz	First	23.88	3.38
	Second	24.68	3.36

Table 2: FSR results for pre-experiment hearing aids. No significant differences are found between first and second measurements at any frequencies tested.

Frequency Pair	Mean difference (dB SPL)	Standard Deviation of difference	P-Value	Correlation
500 Hz	-0.34	4.65	0.78	0.71
T1 v T2				
1000 Hz	-0.54	4.79	0.67	0.63
T1 v T2				
2000 Hz	-0.5	3.73	0.61	0.9
T1 v T2				
3000 Hz	0.5	4.42	0.67	0.68
T1 v T2				
4000 Hz	-0.8	3.16	0.35	0.56
T1 v T2				

Table 3: Correlation for first and second measurements of pre-experiment hearing aids. High correlation and lack of significant difference seen for all frequencies implies high reliability of directionality measure.

Power Analysis for Main experiment

Using the results from the pre-experiment that shows moderate-strong correlation within the measurement, a power analysis was performed to determine the number of hearing aids needed to achieve a power of 0.8. As the design of the main experiment is a repeated measures ANOVA, the degree of correlation between measures has a significant impact on power. Based on a moderate effect size, alpha set to 0.05, and the correlation fixed to 0.6 (a conservative estimate based on the average correlation of measures in the pre-experiment) it was calculated that 20 hearing aids were necessary to achieve a power level of 0.8. However, more hearing aids were recruited and used in this study in order to account for attrition due to scheduling conflicts and to get a variety of hearing aid users and environmental conditions.

Main Experiment

A repeated measure ANOVA was performed to test for the main effects of time (initial- and three-month measurement), and the interaction between stimulus (500, 1000, 2000, 3000, and 4000 Hz) and time on the FSR of directional microphone hearing aids worn by patients. Figure 3 displays the FSR in dB SPL relative to frequencies at the two different time points. A main effect for frequency was found ($F(4, 92) = 7.793$, $p < 0.05$), which is to be expected as the programmed settings (based on NAL-NL1) in the hearing aid does not provided the same output for every frequency. There was no main effect for time ($F(1, 23) = 0.827$, $p = 0.373$), or the time by frequency interaction ($F(4,92) = 0.676$, $p = 0.610$).

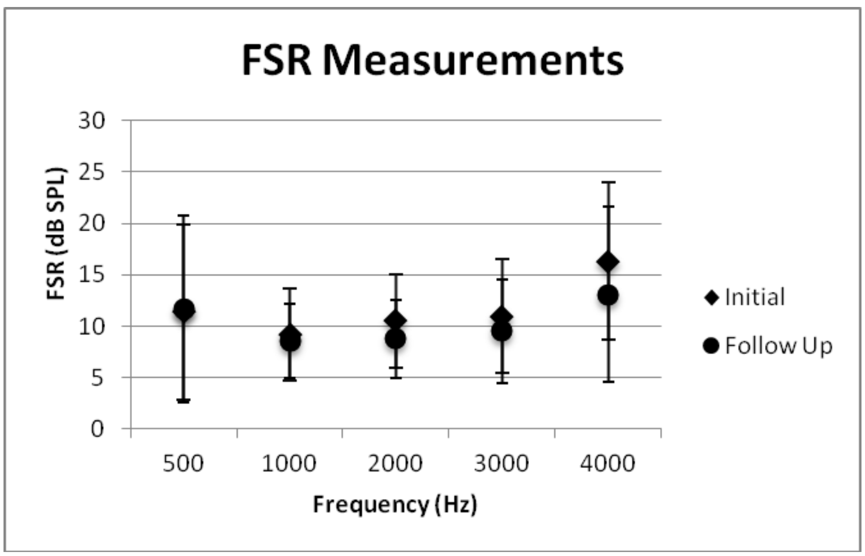

Figure 3: FSR measurements with standard deviations at initial and follow up data collection times.

Individual data of the FSR measurement for each hearing aid per stimulus frequency is listed in Appendix B. Hearing aid case 4 is an outlier in that the directionality measurements are reversed between the initial and follow up measurements, which indicates a possible error in measurement at the initial trial. Therefore, statistical measures were performed again excluding case 4 and are listed in Appendix C. Excluding the data from the hearing aid did not alter the statistical outcome.

DISCUSSION

Results from this study revealed no significant difference in the average FSR output (dB SPL) of the directional microphone of digital BTE hearing aids measured before use and at approximately three months of hearing aid use. This finding indicates that on average significant directional microphone drift does not occur within the first three months of digital BTE hearing aid use. Minimal overall directional microphone drift within the first three months of hearing aid use is a desirable result for both audiologists and hearing aid users, as it indicates that the directional microphone system is functioning properly. An example of a hearing aid that did not show significant changes in both the FSR and polar plot is demonstrated in Figures 4a and 4b. For this particular hearing aid the FSR at the initial and 3-month post-fit measurement were 24.58 and 22.51 dB respectively for 500 Hz, 12.26 and 12.46 dB for 1000 Hz, 12.03 and 12.46 dB for 2000 Hz, 13.1 and 15.12 dB for 3000 Hz, and 19.61 and 19.64 dB SPL for 4000 Hz.

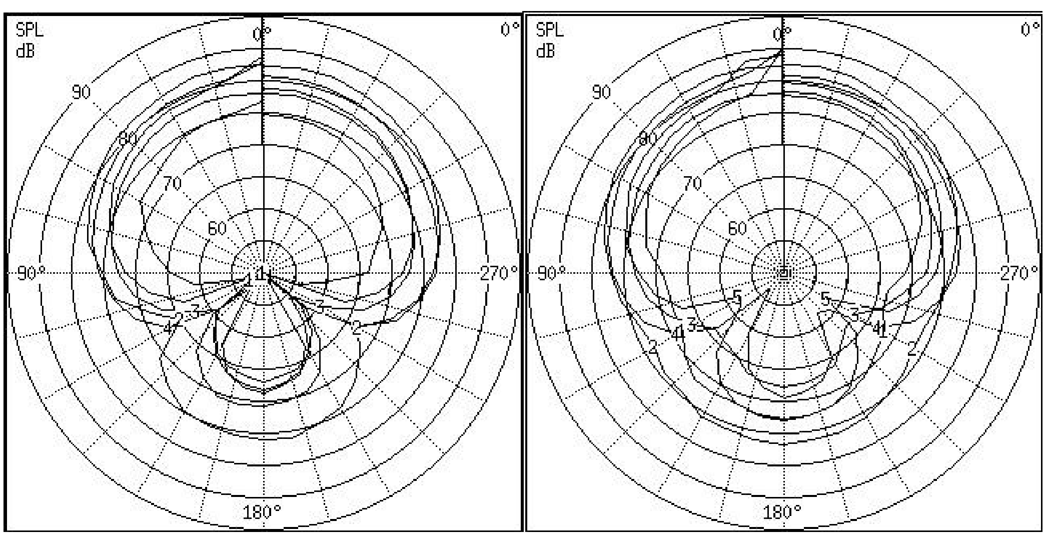

Figure 4: An example of a hearing aid that shows minimal change in both the FSR calculation and graphic representation of polar plots between the initial measurement (a) and the follow up measurement 3 months later (b) .

Noticeable differences in polar patterns were observed in hearing aids when individual data were examined. Figure 5 displays the initial and 3-month post-fit polar plot of a hearing aid that demonstrated a visible change in pattern at three of the five measured frequencies. The FSR at the initial measurement were 7.07, 7.58, 9.69, 6.87, and 10.38 dB at 500, 1000, 2000, 3000, and 4000 Hz respectively (Figure 5a), while the FSR at the 3-month measurement were 13.16, 3.91, 2.32, 1.95, and 4.1 dB at the corresponding frequencies. The FSR difference in this aid exceeded the variance of the FSR measurement itself indicating that the directional microphones may have drifted within the 3-month time period at 500 Hz, 2000 Hz, and 4000 Hz.

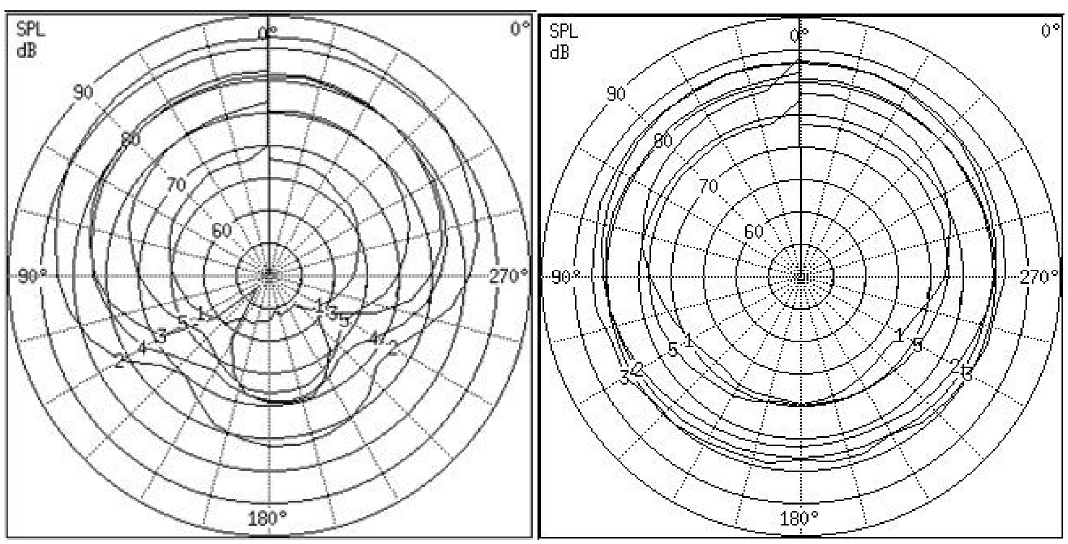

Figure 5: An example of a hearing aid that shows remarkable change in both the FSR calculation and graphic representation of polar plots between the initial measurement (a) and the follow up measurement 3 months later (b) .

Moreover, differences were found between frequencies for amounts of drift that occurred in some hearing aids. The results of this study found that standard deviations for 500 Hz and 4000 Hz indicated greater variability in the FSR measurement. Further analysis of the data shows that possible measurement artifact by the Frye 8000 within the first 45 degrees of the 500 Hz signal. Due to the variability of the measure at 500 and 4000 Hz, audiologists may be more concerned with 1000, 2000, and 3000 Hz when considering appropriate frequencies to base sending hearing aids for repair.

Despite an overall lack of change in microphone performance over the first 3.5 months, two hearing aids demonstrated noticeable changes in directional microphone performance at all five measured frequencies. Sixteen of the twenty-four hearing aids had at least one frequency in which the difference between the initial and follow up FSR fell outside of the standard deviation. Table 4 contains the difference between these measurements (FSR initial – FSR 3-month) for each frequency as compared to the difference and standard deviation of the test-retest data from the pre-experiment. The presence of changes in individual hearing aids demonstrates that the clinician must consider patient differences when deciding on an appropriate plan of care.

Frequency Pair	Mean Difference for Pre-Experiment (dB SPL)	SD of Difference for Pre-Experiment (dB SPL)	Mean Difference for Main Experiment (dB SPL)	SD of Difference for Main Experiment (dB SPL)
500 Hz	-0.34	4.65	-0.52	8.53
T1 - T2				
1000 Hz	-0.54	4.79	0.86	4.94
T1 - T2				
2000 Hz	-0.5	3.73	1.38	4.08
T1 - T2				
3000 Hz	0.5	4.42	0.82	4.70
T1 - T2				
4000 Hz	-0.8	3.16	1.73	8.62
T1 - T2				

Table 4: Mean difference in dB SPL between initial and follow up FSR measurements for both pre-experiment and main experiment hearing aids. Mean difference for main experiment hearing aids falls within the standard deviations for pre-experiment data for all five tested frequencies.

Several factors may have attributed to the potential microphone mismatch noticed in some hearing aids and not others. Hearing aid user lifestyle may be a large factor in what causes drift. Some users may lead a more active lifestyle that may lead to microphone mismatch due to exposure to harsher environmental conditions including humidity and dirt. Also, the dexterity of the hearing aid users may be a factor in that a person with poorer dexterity could either mishandle (e.g., drop the aid on a hard surface) the device or not be able to properly clean the device. However, no data was collected regarding the lifestyle of the hearing aid users of these hearing aids. Future studies looking at potential changes in directional microphone performance over time should include a questionnaire that collects data about the hearing aid user's workplace environment, hobbies inducing high amounts of dust/debris, and frequency of hearing aid use and maintenance. Patient reliability in reporting frequency of maintenance and hours of hearing aid use may be unreliable if patients feel that they are not doing either of these measures enough. Therefore, datalogging of hearing aid use time can be activated in the programming software to support the survey.

The lack of drift noticed within the first three months also implies that audiologists may not need to measure directional microphone integrity again at follow ups immediately following hearing aid purchase. Although it is recommended to verify that the directional microphones are working before the patient begins use, frequent measurements afterward will not show changes for the majority of patients. Moreover, the differences seen in several hearing aids despite the lack of overall change imply that the clinician should address patient concerns of changes in performance in background noise.

For a case that demonstrated directional microphone drift, the majority of hearing aid programming software provides audiologists with very limited options to adjust the directivity setting of the aid if any. A hearing aid with drift would need to be sent into the manufacturer to correct for the mismatch of microphone output. This procedure is a cost to the hearing aid user, who may also experience a detriment in speech understanding in noise if the mismatch is not corrected.

Although drift does not happen within the first 3.5 months, future studies may find out when change in directional microphone performance does occur. Directional microphone performance can be measured at three-month intervals, such as six months, nine months, and twelve months following the initial measurement. Although clinicians follow varied protocols on how often hearing aid patients return for follow up, measurements taken at every three months for the first year should provide enough data for the average clinician to incorporate into their own follow up schedules.

Even if the results of this study indicated that drift occurred within the first three months of hearing aid use, more research would need to be completed in order to determine the real world significance of directional microphone drift using the FSR. Wu and Bentler (2011) determined that FSR provided highest correlation to DI and HINT results, but no exact changes in FSR to demonstrate detriment in HINT scores were provided. As this study intended to use the FSR to determine if drift occurred in early hearing aid use, it did not assess the functional aspect of FSR changes between measurements. Therefore, more research needs to be completed to assess when the patient should actually send the hearing aid to the manufacturer for repair. If there is a cost to the user, the audiologist may consider recommending this only if speech understanding in noise becomes impaired.

CONCLUSIONS

On average, directional microphone drift does not occur within the first 3.5 months of hearing aid use. However, individual differences were observed indicating that for some hearing aid users, directional microphone drift may occur. More research needs to be completed to determine the degree of change in the FSR that will cause a reduction in significant percentage points of speech understanding and whether the change in FSR is correlated with more active lifestyles of hearing aid users.

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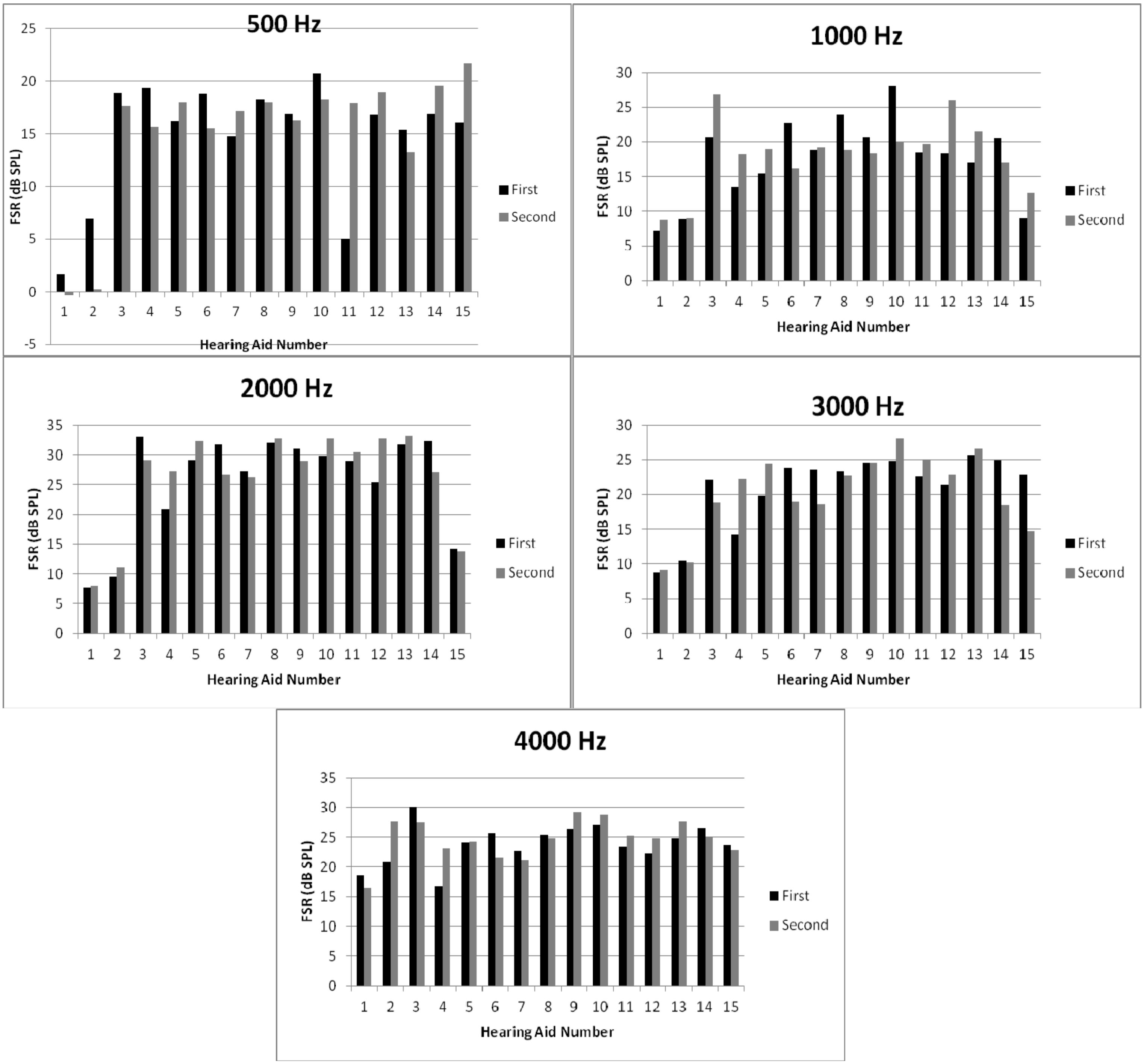
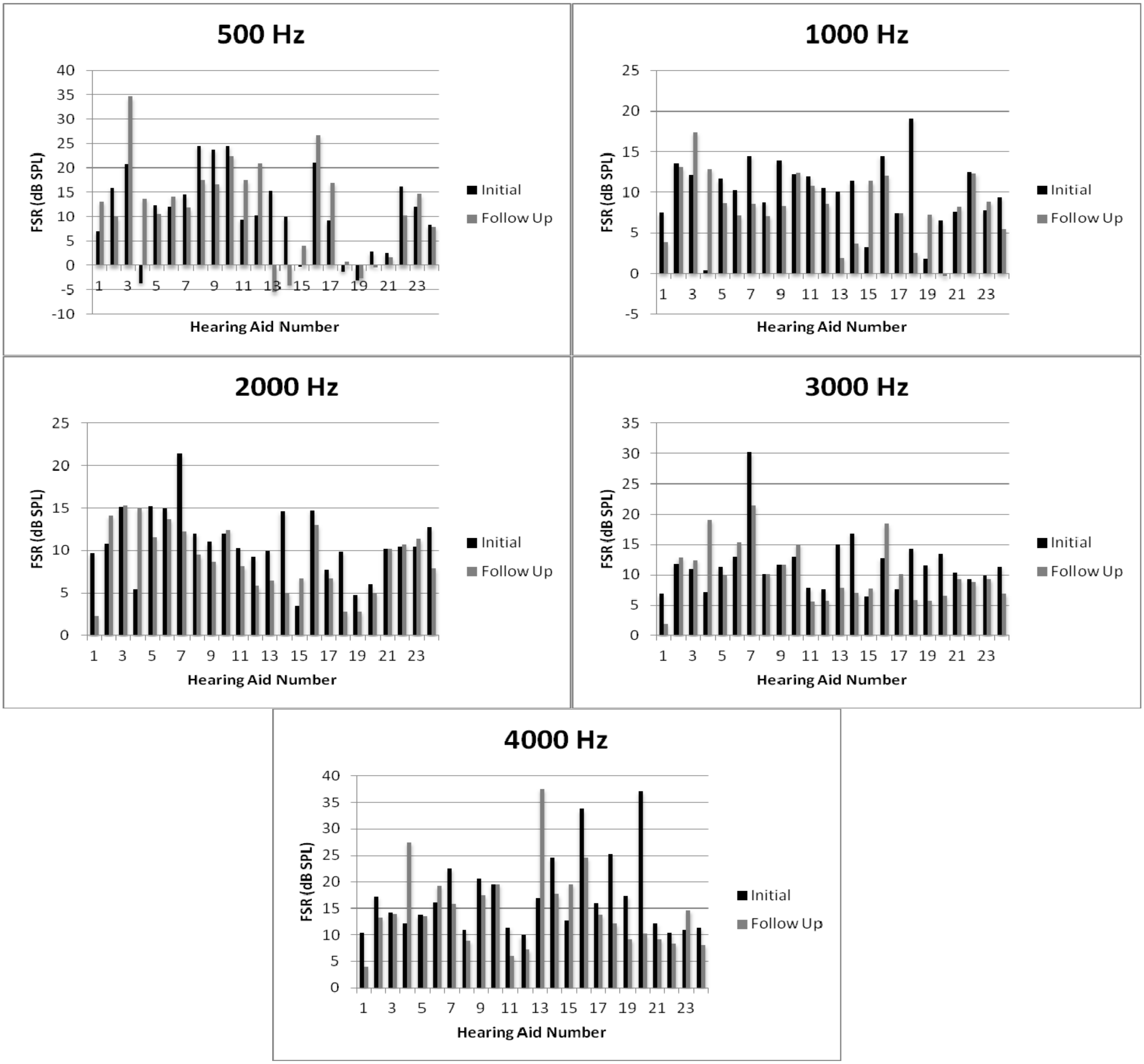
APPENDIX A

Pre-experiment FSR measurements for 15 hearing aids by frequency stimulus



APPENDIX B

Main experiment FSR measurements for 24 hearing aids by frequency stimulus



APPENDIX C

Main experiment statistical analysis without hearing aid case 4 (outlier)

Results of ANOVA

	F-Test	Statistical Significance
Frequency	F(4, 88) = 7.07	$p < 0.05$
Time	F(1, 22) = 3.92	$p = 0.06$
Frequency by Time Interaction	F(4, 88) = 7.92	$p = 0.67$

Table of Difference

Frequency Pair	Mean Difference (dB SPL)	Standard Deviation of Difference (dB SPL)
500 Hz	0.21	7.92
T1 - T2		
1000 Hz	1.44	4.14
T1 - T2		
2000 Hz	1.85	3.44
T1 - T2		
3000 Hz	1.37	3.92
T1 - T2		
4000 Hz	2.47	8.00
T1 - T2		