The impact of hair covering hearing aid microphones on directional performance

Sara Frances Wagner

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The Impact of Hair Covering Hearing Aid Microphones on Directional Performance

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Abstract

This study examined the effect of hair covering on hearing aid directional microphone performance. Nine adult, experienced hearing aid users (3 males, 6 females; mean age = 64.6 years) with mild to severe, sloping symmetrical sensorineural hearing loss were included in this study. Binaural Oticon Opn 1 receiver-in-the-ear hearing aids with closed domes were used to provide the recommended amplification for each participant. Speech Reception Threshold (dB SNR required for 50% speech understanding) was measured in all combinations of directional microphone (on/off) and hair covering (with/without) resulting in a total of four conditions. Results showed that directional microphones significantly improved speech understanding in noise (F(1,8)=15.51; p=0.004). However, there was no significant effect of hair covering in this small sample size of nine participants (F(1,8)=0.213; p=0.657). A pairwise comparison with Bonferroni corrections (α = 0.025) did not yield any difference between the two hair covering conditions (with and without) when the hearing aid was worn in the directional microphone mode (p=0.77). There was a large intersubject variability noticed in this small sample size.
Chapter I
INTRODUCTION AND LITERATURE REVIEW

It has been well-documented that hearing impaired individuals receive benefit from wearing hearing aids. The most recent and compelling evidence comes from a Cochrane Review by Ferguson et al., 2017. This study reviewed the effects that hearing aids have on everyday life in adults with mild to moderate hearing loss. This review, which included five randomized control trials spanning 30 years and involving 825 participants, concluded that hearing aids were effective at improving the participants’ quality of life and listening abilities. These results supported the use of hearing aids as the intervention of choice for hearing impaired individuals.

It has also been well-documented that a primary shortcoming of current hearing aids is their ability to effectively separate speech from background noise (Gnewikow et al., 2009). The different approaches for accomplishing this task can be separated into three main categories: spatial, spectral and temporal separation. Of these, spatial separation is the preferred method of choice and is the foundation of hearing aid directional microphones (Dillon, 2012). The primary purpose of directional microphones is to enhance the signal of interest (speech) by reducing unwanted background noise. In other words, they aim to improve the listener’s signal-to-noise ratio. This is in contrast to omnidirectional microphones, which pick up and amplify sounds from all degrees azimuth. Directional microphones accomplish their task by taking advantage of the spatial separation between speech and noise (Csermak, 2000).

In today’s hearing aids, the common directional microphone design utilizes two omnidirectional microphones on the body of the device. These two microphones have the same
frequency and phase response. In this system, an electronic time delay is applied to sounds entering the rear microphone, which is then subtracted from the output of the front microphone (see Figure 1). This process reduces sounds originating from a certain direction, which is termed the null point. Where exactly the null point falls is determined by the amount of time delay applied (Csermak, 2000).

Figure 1. Schematic block diagram of a twin microphone directional system used in modern hearing aids. An electronic variable time delay is built into the rear microphone signal path. The sensitivity of the directional microphone system can be changed from different directions by varying the electronic time delay.

For example, sounds originating from the back of a listener will enter the rear microphone first and is delayed by ‘x’ number of microseconds. At the same time, part of that sound wave will enter the front microphone unimpeded. If the delay from the rear microphone
equals the same amount of time it takes the sound to travel to the front microphone (a 1:1 ratio of the internal to external time delay), then the acoustic signal entering from the front and the rear microphone ports nullify each other. This results in a cardioid polar plot, as shown in Figure 2, where the null point is located at 180 degrees azimuth (Csermak, 2000).

**Figure 2.** An example of a cardioid polar plot when beta (the ratio of internal to external time delay) is set to 1. In the cardioid polar plot, the null point is 180 degrees azimuth. Reprinted from Csermak (2000) with permission.

An electronic time delay allows for any amount of internal delay to be applied, which changes the ratio of the internal to external time delay. This changes the resulting polar plot, the location of the null point, and where sound is reduced. This is termed adaptive directionality and is the current standard of hearing aids (Chung, 2004). Further advances in
adaptive directional microphone systems have resulted in “adaptive null-steering” algorithms (Woods et al., 2010). These algorithms automatically classify the acoustic environment into several categories and “steer” the “null” of the microphone’s polar pattern towards the direction of noise.

**Factors affecting directional microphone performance**

Studies have shown that there are a number of factors that affect the success of directional microphone performance. One of these factors is room and environmental acoustics. Directional benefit has been found to be the greatest with low reverberation and short distances between the speaker and listener (Ricketts & Hornsby, 2003). Although reduced, Ricketts and Hornsby (2003) found that directional benefit was still present even in the condition with moderate reverberation and the farthest distance between speech and the listener.

Hornsby and Ricketts (2007) concluded that directional benefit also depends on microphone mode symmetry – whether one or both hearing aids are utilizing the directional microphone capability – and on the configurations of speech and noise. They found that maximum directional benefit was achieved with symmetric directional microphone fittings when speech was presented in front of the listener and noise was presented to the side or surround of the listener. Benefit was reduced if the noise was located on the side of the listener and directional processing was activated only on the ear nearer to the noise (Hornsby & Ricketts, 2007).
The type of dome coupled to the hearing aid receiver can also have an impact, with open domes allowing low frequencies to enter the ear naturally. The same is true of earmolds with large vents. In these fittings, low-frequency sounds are not subjected to the amplification and processing of the hearing aids, which therefore results in less directional benefit in the low frequencies (Ricketts, 2000a). Directionality is also affected by alterations in the external time delay between the front and rear microphone ports. Although this value is typically fixed by the manufacturer, it can be changed. External time delay can be altered with changes in head angle, as it changes the effective distance between the two microphone ports (Ricketts and Galster, 2008). Ricketts (2000a) concluded that the external time delay also depends on the orientation of the microphone ports in the horizontal plane. He found a significant orientation effect, with reduced directivity in nonoptimal microphone orientations, and concluded that audiologists must use caution when fitting behind-the-ear hearing aids to ensure maximum directional benefit.

Although research has identified many factors that influence directional microphone performance, a study has yet to address the effect of hair or other head coverings that cover the microphones of the hearing aids. When a hearing aid user wears his or her hair down or wears a head scarf that covers the hearing aids, these external objects can act as low-pass filters in addition to interfering with the timing cues that the hearing aid relies on for separating sound from the front versus sounds from the back. This study aims to determine whether hair covering impacts the directional performance of hearing aid microphones, with the assumption that such results will be representative of the effects produced by all forms of external barriers that cover the microphones.
Acoustic Properties of Hair

Absorption: The acoustic absorption properties of hair and skin have been reported in the literature since the 1950s. These early investigations originated primarily from military research studying the effect of loud high frequency sounds on skin and hair absorption. Early literature established that high frequencies sounds are absorbed more by the skin and hair compared to low frequency sounds (Franke, 1951; Farwell, 1955; von Gierke, 1950). Recently, there has been renewed interest in absorption of radio frequencies by human and animal skin to understand the effects of wireless communication on human bodies. There is however a scarcity of literature on the absorptive properties of human hair in the speech frequency range (up to 10,000 Hz). Katz (2000) reported the acoustic absorption properties of human hair and skin in the 1000-6000 Hz frequency range. As shown in Figure 3 below, five different samples of hair (h1, h2, h3a, h3b, and h4) were measured to have different absorption coefficients. Higher frequencies were reported to be absorbed by the human hair more compared to the lower frequencies in all samples. Hair, therefore, acts as a low-pass filter. It should be noted in the figure that sample h4 was deliberately made of thicker hair and greater mass than h1, h2, and h3a. Hair sample h3b was made to represent thin hair.

With hair acting as a low-pass filter and preventing high-frequency sounds from reaching the hearing aid’s microphones, directional benefit is decreased in the high frequencies. Most individuals have high-frequency hearing loss, which necessitates programming more gain at the high frequencies. This results in more directional benefit for these sounds. Therefore, it is problematic when high frequencies are blocked from entering the hearing aid.
**Figure 3.** Absorption coefficient measures of five samples of hair at different frequencies (from Katz, 2000, reprinted with permission). Sound absorption coefficient ($\alpha$) is shown on the y-axis. Larger value of $\alpha$ indicates greater absorption by hair.

**Diffraction**

Diffraction of sound refers to the “bending” of the sound wave when it encounters an obstacle. When the wavelength of a particular sound is longer than the obstructing object, the sound wave can easily diffract around it. Conversely, if the wavelength of the sound is smaller than the object, diffraction does not occur. Low frequency sound waves (longer wavelength) are hence more prone to diffraction around the human head.
Refraction

Refraction of waves refers to a change in the direction of sound waves as they pass from one medium to another. Refraction, or bending of the path of the waves, is accompanied by a change in speed and wavelength of the waves. So, if the media (or its properties) are changed, the speed of the wave is changed. Thus, waves passing from one medium to another will undergo refraction. In the case of a hearing aid that is obstructed (covered) by hair, refraction of the sound wave can occur as the sound travels from the air medium to a relatively denser medium (hair). This interferes with the timing cues the hearing aid microphones rely on to accomplish directionality.

Owing to the absorption, diffraction and refraction properties of a hair covering, it is hypothesized that this external object will reduce the amount of directional benefit users experience from the hearing aid directional microphones.

Laboratory vs. real-world benefits from directional microphones

This study also takes into account that research has shown a discrepancy between laboratory and real-world performance of directional microphones. Many laboratory studies have shown an objective benefit of directional microphones (Bentler, 2005). However, there are fewer studies relating this objective benefit to subjective benefit in the real world (Bentler, 2005).

Cord et al. (2004) examined whether participants who were successful users of directional microphones in everyday life had larger directional benefit in the laboratory than
those who were unsuccessful users. Successful users were defined as those who reported using the directional mode at least 10% of the time, while unsuccessful users left their hearing aids in the omnidirectional mode. Using the Hearing in Noise Test (HINT), they found no objective difference between these two groups. The authors concluded that success with directional microphones in daily life cannot be accurately predicted by the amount of directional advantage obtained under laboratory conditions.

In another study, Walden et al. (2000) assessed the objective and subjective performance of participants who were fit with switchable omnidirectional microphone/directional microphone hearing aids. They measured performance using both the Connected Sentences Test (CST) and the Profile of Hearing Aid Benefit (PHAB). They found that there was a substantial advantage for the directional microphones over the omnidirectional microphones when measured by the CST, but participants did not perceive these large advantages in everyday listening.

Cord et al. (2002) contacted clinic patients via a telephone interview and mailed to those who reported at least occasional use of both omnidirectional and directional microphones two questionnaires designed to compare subjective report of the performance of the two types of microphones. They concluded that only when the real-world listening environment of the participant matched the ideal, contrived laboratory setting, did a preference for the directional microphone emerge.

The conditions under which directional hearing aids is important to consider when evaluating this discrepancy. Unfortunately, many studies of directional microphones control for the very factors that have been shown to affect directional benefit. Most laboratory
configurations include parameters that are not representative of real-world environments, such as speech at 0° azimuth and noise only at 180° azimuth; the use of correlated noise sources; or carrying out testing in a sound-attenuated room with low reverberation (Gnewikow et al., 2009). Compton-Conley et al. (2004) evaluated directional microphone performance in three simulated conditions (multimicrophone/multiloudspeaker, single noise source behind the listener, and a single noise source above the listener) and in a live restaurant situation. They found that neither of the single-noise-source simulations accurately predicted the performance in the live restaurant setting. Only the simulation with multiple noise sources most adequately reproduced the real-world results. They also concluded that correlated noise sources, which is when identical noise is presented simultaneously from multiple sources, is not representative of everyday listening situations. Ricketts (2000b) concluded that data obtained when using a single noise source at 180° azimuth cannot be used to predict directional benefit in real-world environments because they found less directional benefit when multiple noise sources were used. Likewise, as can be inferred from the results of the aforementioned Ricketts and Hornsby (2003) study, carrying out testing in a non-reverberant room can have similar effects.

The present study addresses this discord by testing a feature - hair covering - that represents a realistic aspect of the nature in which many individuals utilize the directional setting on their hearing aids and testing subjects in an environment that stimulates realistic settings. This includes: noise emanating from the back and to the sides of the listener; the use of uncorrelated speech-shaped noise; and testing participants in a room that simulates an individual’s living room or household space instead of in a sound-treated booth. Utilizing this set-up will allow for greater confidence in generalization of the results.
Chapter II
MATERIALS AND METHODS

Participants

Nine adults with previously diagnosed mild sloping to severe symmetrical sensorineural hearing loss served as participants in the present study. Mean hearing thresholds with standard deviations of the ten participants are shown in Figure 4. Data for the left and right ears at octave frequencies between 250 to 8000 Hz are depicted using “X” and “O” symbols, respectively. Symmetry between the two ears was defined as a difference between hearing thresholds of no more than 20 dB at any octave frequency between 500 Hz to 4000 Hz. Air conduction hearing thresholds were tested as a part of the research protocol, and normal middle ear functioning was assessed by verifying the presence of a type ‘A’ tympanogram. Participants ranged in age from 25 to 81 years (mean age = 64.6 years) and included three males and six females.
Figure 4. Mean and standard deviation of hearing thresholds measured at octave frequencies of the ten participants. Data for the left and right ears are displayed using “X” and “O” symbols, respectively.

Participants needed to be experienced hearing aid users, which was defined as hearing aid use for at least 4 weeks. A total of 17 potential subjects were tested for candidacy for this study. Only nine participants were found to match all the inclusion and exclusion criteria. All the participants were experienced hearing aid users ranging from 4 months to 30 years. The study was conducted with approval from the James Madison University’s Institutional Review Board (IRB approval # 18-0281). Participants were compensated $20 for their time, and if needed were offered free cleaning and check of their own hearing aids.
**Hearing Aid Fitting Procedures**

All participants were fit with bilateral Oticon Opn 1, receiver-in-the-ear style hearing aids for this study. The hearing aids were coupled with Oticon’s closed dome ear tips for all participants to allow maximum directional benefit at low frequencies. Closed domes were also used to prevent unamplified sound reaching the ear canal through any opening in the ear tips. In order to assess directional benefit provided by the hearing aids, the hearing aids were programmed with two programs - the “Omni Pinna” mode (omnidirectional), and the “Fixed Directionality” mode with directionality activated. The present study measures the effect of directionality with hair covering; therefore, “Fixed Directionality” was chosen over adaptive directionality, which has been shown to default to omnidirectional mode in noisy environments (Ricketts et al., 2017). All other adjustable signal processing features such as the digital noise reduction were turned off or minimized as permitted by the Oticon Genie 2 fitting software. The adaptation manager was set to level 2.

Prior to data collection, directional sensitivity patterns for both the omnidirectional and directional modes were measured in order to verify that activating the directional microphones resulted in a directional advantage. These patterns were measured on a Knowles Electronics Manikin for Acoustic Research (KEMAR) in a double walled IAC sound-treated room at 500 Hz and 2000 Hz. Because the hypotheses of this study were built around the concept of directionality, initial verification of directional advantage was a necessary step to provide credibility to the results.

The hearing aids were programmed separately for each participant’s degree of hearing loss using the manufacturer’s proprietary fitting formula. Hearing aid programming was verified
using real ear aided response (REAR) to a 65 dB SPL input on the Audioscan Verifit for the first two participants. The Frye Electronics Fonix 8000 real ear analyzer was used with the subsequent participants.

Hair Covering

In order to assess whether hair covering had an effect on hearing aid directional benefit, participants wore a nylon wig during two of the test conditions. The wig was approximately 12 inches in length all around the head. Each participant wore the same wig to maintain consistency across individual test sessions. It was sanitized in between participants using a UV sterilizer light. Special care was taken to maintain similar hair covering over the ears across all participants. Two female participants had natural long hair. They were provided hairpins to wear their natural hair away from the pinna before placing the wig.

Test Conditions

This was a 2x2 repeated measures study design to evaluate directional benefit with and without hair covering. As a within-subjects study, participants were tested in four different test conditions - (1) directionality off, wig off; (2) directionality off, wig on; (3) directionality on, wig off; (4) directionality on, wig on. Aided speech understanding in noise was measured in each of these conditions using the Hearing in Noise Test (HINT).
The Hearing in Noise Test

The HINT is an adaptive SNR test used to estimate an individual’s signal to noise ratio (SNR) required to achieve 50% correct sentence recognition. During the HINT testing, the background noise was held constant at 65 dBA while the level of the speech was varied up or down in an adaptive method depending on whether the previous sentence was repeated correctly. A Quest Pro type 1 sound level meter was used to perform calibration of the noise and speech signals prior to data collection for every participant.

In each of the conditions described above, participants received two consecutive lists of 10 sentences each for a total of 20 sentences. The first four sentences are practice sentences. The SNR of each condition was calculated by subtracting the noise level from the average presentation level across sentences #5-20 as per the original HINT test manual instructions (Nilsson et al., 1994).

As Figure 5 shows, the background noise (uncorrelated speech babble) was presented in the soundfield through Polk Audio fxi5 bipole/dipole loudspeakers located at 90°, 180° and 270° azimuths and speech was presented in the soundfield at 0° azimuth from a Tanoy System 600 loudspeaker. Uncorrelated speech noise was streamed from the hard drive of a personal computer routed through a multichannel Russsound 1200 amplifier. Signal presentation was manipulated using commercially available sound editing software (Sound Forge 9, Sony Corporation). Since the speech was adjusted adaptively while the noise level was kept constant, the speech (HINT sentences) were streamed from a separate computer routed through a GSI Astera audiometer and delivered through the Tanoy loudspeaker.
Procedure

After providing informed consent, participants had their pure tone air conduction thresholds measured from .25-8 kHz to record their current hearing loss. Testing was performed in an IAC double walled sound treated audiometric booth. Tympanometry was also performed to confirm Type A tympanograms. Using this audiogram, the Oticon Opn 1 hearing aids were then programmed and verified using real ear aided response (REAR) to a 65 dB SPL input. Following the hearing aid fitting, data collection began. Aided speech recognition in noise was measured using the HINT in four different test conditions following the protocol outlined above. The conditions were counterbalanced across participants. The researcher switched the program for the participant between conditions to ensure the participants remained blinded to the hearing aid program. All data was collected during a single test session. HINT testing was performed in the Hearing Aid Research laboratory work area (Figure 5) in order to simulate acoustic conditions encountered in a real world living room. The floor was covered with carpet and the room included several padded chairs, tables and bookshelves.
Figure 5. The loud speaker set-up showing location of the speakers in relation to the participant’s position (chair). The speakers were located at a distance of 1 meter from the participant’s head in the horizontal plane.

Following data collection, the SNR values from the HINT were compared between conditions to determine (a) if there was a directional benefit when the hearing aids were put into directional mode and (b) whether or not the presence of the hair covering affected directional benefit. An increase in SNR between conditions represented a decrease in directional benefit, while a decrease in SNR between conditions represented an increase in directional benefit.
Chapter III

RESULTS

Polar Directivity Pattern (Polar Plot)

Frequency-specific polar directivity patterns at 2000 Hz and 500 Hz revealed that fixed directionality showed lower sensitivity from the rear azimuths of 150° to 300°. Average sensitivity in these azimuths was 5 dB lower in the directional mode compared to the omnidirectional mode (range: 0.2 – 11.2 dB). The largest difference between the directional and omnidirectional mode was observed at 210° azimuth. The polar directivity patterns for 2000 Hz and 500 Hz are shown in Figures 6 and 7, respectively. Larger directional benefit was observed at 2000 Hz, which was not unexpected, as more gain was programmed at this frequency to compensate for the sloping hearing loss configuration.

Polar plots with hair covering

Polar directivity patterns to a 2000 Hz tone were also measured with the hair covering. These were measured with KEMAR wearing the Oticon Opn 1 hearing aid in directional mode with the wig off and the wig on (see Figure 8). The hearing aid was programmed using the average of the participants’ audiometric data.
Figure 6. Polar directivity patterns of the Oticon Opn 1 receiver-in-the-ear hearing aids at 2000 Hz obtained in the sound field. Solid lines depict omnidirectional and dashed lines represent directional sensitivity at different angles in the horizontal plane.

Figure 7. Polar directivity patterns at 500 Hz of the Oticon Opn 1 receiver-in-the-ear hearing aids obtained in the sound field. Solid lines depict omnidirectional and dashed lines represent directional sensitivity at different angles in the horizontal plane.
Figure 8. Polar directivity pattern with and without the wig at 2000 Hz from the Oticon Opn1 hearing aid used in the current study. The polar plot was obtained in the sound field when the hearing aid was worn by KEMAR. The sensitivity of the directional microphone is represented by the dashed line and the solid line shows the reduced directionality (i.e. more omnidirectional) when the hearing aid was covered by a wig. The y-axis labels are arbitrary units in decibels with reference to the maximum output of the computer sound card.
HINT Scores

Average HINT scores across all four conditions are shown in Figure 9. To assess the effect of hair covering on directional benefit, a two-factor repeated measures analysis of variance (ANOVA) was performed with directionality and hair covering as the within-subjects (independent) variables. The dependent variable was the HINT score in dB SNR required to achieve 50% correct speech understanding in the presence of noise.

Figure 9. The average sentence reception threshold performance (HINT scores) across all test conditions. The solid bars represent HINT scores in the hair covering condition and the cross hatches depict the regular condition. Because these scores reflect a signal to noise ratio needed for understanding 50% of the speech, lower scores indicate better performance. Hence a smaller positive score and a larger negative score indicate better speech understanding performance. The error bars indicate ±1 standard error of mean.
Results of the ANOVA revealed a main effect of directionality, with a significant difference in HINT scores between the omnidirectional and directional HINT scores $(F(1, 8) = 15.51; p = 0.004)$. This result was expected and was the foundation for testing the main hypothesis regarding directionality and hair covering. However, there was no significant effect of hair covering in this small sample size of nine participants $(F(1, 8) = 0.213; p = 0.657)$. In order to assess the interaction between hair covering and directional benefit, a pairwise comparison with Bonferroni corrections ($\alpha = 0.025$) was performed. This compared only the directional + hair covering and the directional + no hair covering conditions. The comparison indicated that there was no significant difference in directional performance between hair covering and no hair covering $(p = 0.77)$. Due to the limited sample size ($n = 9$) and the large variability in the HINT scores across the listeners (see Figure 10), the observed power was low for the conditions evaluating the effect of hair covering.

**Individual Participant Data**

Individual analysis of data revealed that 4 out of the 9 participants’ directional benefit decreased when the hearing aid was covered with hair, as predicted in the hypothesis. Additionally, for two of these subjects (S14 and S003), there is the possibility of a programming issue. However, their data were not excluded due to the lack of concrete evidence that their results were erroneous. Additionally, three other subjects’ performance was comparable in both conditions.
Figure 10. Individual sentence reception threshold performance (HINT scores) across all test conditions. Since these scores reflect a signal to noise ratio needed for understanding 50% of the speech, lower scores indicate better performance. Omnidirectional and directional performances are shown on the left and right sides, respectively.
Chapter IV

DISCUSSION AND CONCLUSION

The purpose of this study was to investigate the effect of hair covering on hearing aid directional microphone performance. It was hypothesized that hair covering would decrease directional benefit due to the hair acting as a barrier to sound transmission reaching the microphone ports, and the possible diffraction and refraction of the sound waves while passing through different media. The HINT was used to quantify directional benefit and each participant was tested in four conditions: (1) omnidirectional, wig off; (2) omnidirectional, wig on; (3) directional, wig off; (4) directional, wig on. The HINT scores were then compared across conditions.

The results of this study confirmed that in a laboratory setting, activating directional microphones resulted in a directional benefit for individuals with mild sloping to moderately-severe hearing loss. This is in agreement with other laboratory studies of hearing aid directional microphones (2), and a meta-analysis by Amlani (2001). The mean directional benefit of 2.9 dB between the regular omnidirectional and directional modes is in agreement with previous studies examining the effect of directionality using HINT sentences (Amlani, 2001; Ricketts and Hornsby, 2003). Interestingly, there was a slight improvement in speech understanding ability (lower HINT score) in the omnidirectional hair covering condition. There are no studies reported in the literature about the effect of hair covering on directional microphones. In the absence of any previous literature, it is possible that the slight improvement could be due to the hair covering creating an obstruction for the noise from the side speakers (90° and 270°). In the
present study speech was always presented from the front speaker while noise was presented from the sides and behind the listener. The HINT test has been shown to be extremely sensitive to variations in background noise (Nilsson et al., 1994). The normative data from Nilsson et al. (1994) indicates a 10% improvement in speech recognition score for each dB improvement in the HINT score.

Contrary to this study’s hypothesis, there was no interaction effect between directionality and wig covering. Participants’ HINT scores did not significantly decrease between the directional, wig off and directional, wig on conditions and there was substantial variability between the conditions for each participant. There are several factors to consider when interpreting this result. Only one type of wig was used throughout testing, and it is possible that a different wig thickness and/or length would result in a more pronounced decrement in directional benefit with the wig added.

Although a different sentence list was used for each condition, a learning effect could have taken place during the HINT testing, where participants improved in subsequent conditions simply due to increased familiarity with the test. If this were true, then the scores for the participants who were tested in the directional, wig on condition last may be artificially enhanced and could explain why some subjects performed better when the wig was added. Finally, there is the possibility that there is simply no effect of hair covering directional microphones. Although no effect was reported here, more studies are needed in order to confirm this result. The small sample size of this study resulted in a low power and makes it impossible to draw a definite conclusion from the statistics presented here.
Although the test environment in the current study was designed to replicate a real-world setting (living room) as much as possible, participants were still tested in an environment that is conducive to the function of directional microphones. That is, with speech in front of the listener and noise to the side and surround. This implies that when individuals are in a real-world setting with a similar speech and noise configuration, hearing aid directional microphones are likely to improve their signal-to-noise ratio. Therefore, we suggest that clinicians can continue to recommend the use of directional microphones in settings with background noise. However, the amount of directional advantage for varying speech- and noise-source configurations were not evaluated and this study, and a statement regarding directional microphone performance in situations other than what was tested in this study cannot be made. It is important that clinicians counsel patients regarding what situations are most conducive to directional benefit, a suggestion that has been supported by previous studies (Gnewikow et al., 2009; Bentler, 2005; Walden et al., 2000).

The current study was conducted as a pilot study to examine the effects of hair covering on directional benefit. It is strongly suggested that additional studies of hair or other head coverings and hearing aid directional microphones include a larger sample size. A power analysis was conducted based on the effect size from the 9 subjects in the current study using G-Power software (Faul et al., 2007). As shown in Figure 11, this resulted in a required sample size of 24 subjects. This would increase the power and the confidence in the results. It is recommended that future studies use a head covering, like a scarf, instead of a wig to simulate an obstruction. Since it is easier to maintain a similar thickness of covering for each participant with a scarf, this would not be a confound to the results. Future studies could consider using a
nonsense syllable test as the objective measure instead of the HINT or similar speech-in-noise tests, which would reduce any learning effect.

![Figure 11](image_url)

**Figure 11.** A priori power analysis for the required sample size based on a small effect size (0.25), alpha level of 0.05 and 0.8 power. Results indicated a minimum 24 required subjects to achieve the required statistical power.
The results presented here should be interpreted with caution due to the small sample size and low power. This preliminary study established a framework upon which subsequent studies should be built. No final statement can be made regarding the effect of hair covering on hearing aid directional microphone performance until additional studies are completed. Once the effect of hair covering has been determined, whether it be no effect at all, it will provide clinicians with valuable information to include when counseling patients regarding their hearing aids and directional microphones.

Conclusions

(1) Activating the fixed directional mode resulted in a directional benefit of 2.9 dB, which is consistent with other studies of directionality. Clinicians should continue encouraging the use of directional microphones, taking care to emphasize the types of listening environments where patients are most likely to experience directional benefit.

(2) This study found no significant interaction found between directionality and hair covering. Possible explanations include wig thickness, inconsistency of the thickness between participants and a learning effect. However, a definitive conclusion cannot be drawn due to the low power of this study.

(3) Future studies should include a larger sample size and consider using a scarf to mimic an external barrier as well as the use of a nonsense syllable test to quantify directional benefit.
REFERENCES


APPENDIX A

IRB APPROVALS

From: Morgan, Cindy - morgancs
Sent: Friday, April 19, 2019 11:46 AM
To: Wagner, Sara Frances - wagnersf (Dukes)
Cc: Rout, Ayasakanta - routax; ils.finance
Subject: IRB Extension and Addendum Approval
Importance: High

Dear Sara,

I want to let you know that the extension and addendum request for your IRB protocol # 18-0281 entitled, "The Impact of Hair Covering Hearing Aid Microphones on Directional Performance" has been approved for you to continue your study from 5/2/2019 to 4/17/2020. The signed action of the board form, approval memo, and close-out form will be sent to your advisor via campus mail.

This Addendum Request approval is for the following protocol changes:

- Extending the age range of participants to 18 – 85 years of age.

Your Close-Out Form must be submitted within 30 days of the project end date. If you wish to continue your study past the approved project end date, you must submit an Extension Request Form indicating a renewal, along with supporting information. Although the IRB office sends reminders, it is ultimately your responsibility to submit the continuing review report in a timely fashion to ensure there is no lapse in IRB approval.

Thank you again for working with us to get your protocol extension and addendum approved. We look forward to receiving your project close-out form upon completion of your study.

Best Wishes,
Cindy

Cindy Morgan
IRB Coordinator
Office of Research Integrity - James Madison University
Engineering/Geosciences Bldg., Room 3152
MSC 5738
Harrisonburg, VA 22807
morgancs@jmu.edu
(540) 568-7125
Dear Sara,

I wanted to let you know that your IRB Protocol entitled, "The Impact of Hair Covering Hearing Aid Microphones on Directional Performance," has been approved effective from 1/24/2018 through 1/23/2019. The signed action of the board form, approval memo, and close-out form will be sent to you via campus mail. Your protocol has been assigned No. 18-0281. Thank you again for working with us to get your protocol approved.

All research must be conducted in accordance with this approved submission, meaning that you will follow the research plan you have outlined in your protocol, use approved materials, and follow university policies.

Please take special note of the following important aspects of your approval:

- Participants in the study will be offered monetary compensation for their time.

- Any changes made to your study require approval before they can be implemented as part of your study.
  Contact the Office of Research Integrity at researchintegrity@jmu.edu with your questions and/or proposed modifications. An addendum request form can be located at the following URL: http://www.jmu.edu/researchintegrity/irb/forms/irbaddendum.doc.

- As a condition of the IRB approval, your protocol is subject to annual review. Therefore, you are required to complete a Close-Out form before your project end date. You must complete the close-out form unless you intend to continue the project for another year. An electronic copy of the close-out form can be found at the following URL: http://www.jmu.edu/researchintegrity/irb/forms/irbcloseout.doc.

- If you wish to continue your study past the approved project end date, you must submit an Extension Request Form indicating a renewal, along with supporting information. An electronic copy of the close-out form can be found at the following URL: http://www.jmu.edu/researchintegrity/irb/forms/irbextensionrequest.doc.

- If there are in an adverse event and/or any unanticipated problems during your study, you must notify the Office of Research Integrity within 24 hours of the event or problem. You must also complete adverse event form, which can be located at the following URL: http://www.jmu.edu/researchintegrity/irb/forms/irbadverseevent.doc.

Although the IRB office sends reminders, it is ultimately your responsibility to submit the continuing review report in a timely fashion to ensure there is no lapse in IRB approval.

Thank you again for working with us to get your protocol approved. If you have any questions, please do not hesitate to contact me.

Best Wishes,
Cindy
Appendix B

IRB CONSENT FORM

Consent to Participate in Research

Identification of Investigators & Purpose of Study
You are being asked to participate in a research study conducted by Sara Wagner from James Madison University. The purpose of this study is to assess the performance of hearing aid directional microphones when the hearing aid is covered by hair. This study will contribute to the researcher’s completion of her Doctor of Audiology dissertation research.

Research Procedures
Should you decide to participate in this research study, you will be asked to sign this consent form once all your questions have been answered to your satisfaction. This study consists of several tests of speech understanding in noise, which be administered to individual participants in HBS 5008. In these tests, you will be asked to listen to and repeat sentences that are presented in various conditions.

Time Required
Participation in this study will require approximately 2 hours of your time. The testing is broken up into two one-hour long sessions: in the first, your hearing status will be evaluated using standard clinical protocol. A pair of hearing aids will be programmed to fit your exact degree of hearing loss. The second session is comprised of a speech understanding test in four different conditions. You have the option of completing both session in the same day, or returning a different day for the second session.

Risks
The investigator does not perceive more than minimal risks from your involvement in this study (that is, no risks beyond the risks associated with everyday life). A potential risk may include fatigue from the effortful listening required during the speech recognition tasks, however this risk will be minimized by allowing you to take both restroom and water breaks between each of the four listening conditions.

Benefits
Potential benefits from participation in this study include a free hearing test and a participation fee of $10 per hour. With each session requiring approximately one hour your time, you will
therefore be compensated $10 per session, leading to a maximum of $20 in participation fees. The results of this study could potentially be beneficial to the field of clinical audiology by informing us how directional microphones perform in real world situations.

**Incentives**
The participant will receive $10 per hour in financial compensation for participation in this study.

**Confidentiality**
The results of this research will be presented at a conference and at the researcher’s doctoral dissertation defense. The results of this project will be coded in such a way that the respondent’s identity will not be attached to the final form of this study. The researcher retains the right to use and publish non-identifiable data. While individual responses are confidential, aggregate data will be presented representing averages or generalizations about the responses as a whole. All data will be stored in a secure location in the Hearing Aid Research Laboratory accessible only to the researcher and her research advisor.

Upon completion of the study, all information that matches up individual participants with their answers, including the transcription of the repeated sentences, will be shredded.

**Participation & Withdrawal**
Your participation is entirely voluntary. You are free to choose not to participate. Should you choose to participate, you can withdraw at any time without consequences of any kind.

**Questions about the Study**
If you have questions or concerns during the time of your participation in this study, or after its completion or you would like to receive a copy of the final aggregate results of this study, please contact:

Sara Wagner  
Communications Sciences and Disorders  
James Madison University  
wagnersf@dukes.jmu.edu

Ayasakanta Rout  
Communications Sciences and Disorders  
James Madison University  
routax@jmu.edu

**Questions about Your Rights as a Research Subject**
Dr. David Cockley  
Chair, Institutional Review Board
Giving of Consent

I have read this consent form and I understand what is being requested of me as a participant in this study. I freely consent to participate. I have been given satisfactory answers to my questions. The investigator provided me with a copy of this form. I certify that I am at least 18 years of age.

____________________________________
Name of Participant (Printed)

____________________________________    ______________
Name of Participant (Signed)    Date

____________________________________    ______________
Name of Researcher (Signed)    Date