AN ASSESSMENT OF TELECOIL BENEFIT: A PILOT STUDY

by

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As members of the Audiology Doctoral Project Committee, we certify that we have read the Audiology Doctoral Project prepared by: Sarah Beatty

titled: AN ASSESSMENT OF TELECOIL BENEFIT: A PILOT STUDY

and recommend that it be accepted as fulfilling the Audiology Doctoral Project requirement for the Degree of Doctor of Audiology.

Nicole Marrone — Date: Apr 17, 2021

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Final approval and acceptance of this Audiology Doctoral Project is contingent upon the candidate's submission of the final copies of the Audiology Doctoral Project to the Graduate College.

I hereby certify that I have read this Audiology Doctoral Project prepared under my direction and recommend that it be accepted as fulfilling the Audiology Doctoral Project requirement.

Nicole Marrone — Date: Apr 17, 2021
Speech, Language, and Hearing Sciences

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DEDICATION

In memory of my late Nana, Dorothy Davis, and Aunt, Joan Forseth. Your spirits and passion to serve others has been with me every step of the way.

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ABSTRACT

Patients with hearing loss often experience a decreased signal-to-noise ratio (SNR), resulting in an increased difficulty to understand speech in noise, which can negatively impact their quality of life (Dillon, 2012). An induction loop or hearing loop is one type of assistive listening system that improves the signal to noise ratio at the ear level of the user by using an electromagnetic field. Hearing loops are commonly preferred by patients as they do not require the use of any additional device. However, there is currently limited research supporting the benefit of using hearing loops/telecoils in a classroom setting. The purpose of this audiology doctoral project was to measure the benefits of looping in a university classroom under ecological conditions for adults with hearing loss. This project was separated into three phases. The first phase was comprised of verifying a university classroom loop (installed in Speech-Language and Hearing Sciences Building, room 409, summer 2019) to international quality standards (IEC 60118-4). The second phase included facilitating two focus groups with the local hearing loss support group. Using the approach of patient-centered outcomes research, the third phase included subjective and behavioral assessments in a looped classroom. Results revealed that, on average, participants had better speech perception scores as measured by the AZBio sentences in the t-coil conditions than in the non-t-coil conditions. Additionally, participants, on average, reported reduced temporal demand and increased performance when using the t-coil as measured by the NASA Task Load Index.

Keywords: telecoil, induction loop, hearing loop

INTRODUCTION

Background Information and Purpose

Many patients with hearing loss have difficulty understanding speech in noise when signal-to-noise ratios (SNR) are unfavorable, which can negatively impact their quality of life (Dillon, 2012). The SNR refers to the difference between the level of the signal and the level of the noise. For example, in a classroom, a teacher's voice may be 10 dB above the background noise (+10 dB SNR) when they have the full attention of the class. While at other times their voice may be at the same level of the background noise (0 dB SNR) or lower (-10 dB SNR) such as when students are mingling and setting up before class. While hearing aids with directionality have the potential to provide a 2-5 dB HL SNR increase, often, this increase is not enough to overcome the patient's SNR loss, especially in difficult listening environments (Dillon, 2012). Additionally, poor room acoustics can also compromise the SNR. When directionality alone cannot overcome this SNR loss, assistive listening devices such as frequency modulation (FM) systems, infrared (IR) systems, induction loops, and remote microphones are considered. Assistive listening devices usually work with the patient's hearing aids and increase the SNR at the patient's ear, thus making listening in noise and poor room acoustics less problematic.

One common type of assistive listening system that increases the SNR at the ear level of the user is called an induction loop or hearing loop. Figure 1 illustrates the process of converting the audio signal from a sound source to the telecoil (t-coil; a coil of wire within the hearing aid or cochlear implant) A hearing loop converts the audio signal from a sound source, most commonly a personal amplifier (PA) system, into an electrical current that then flows through the wire of the induction loop within that space or room. The wire loop around the room creates a magnetic field that can be sensed by a t-coil. The change in field strength creates an electric voltage in the t-coil of the person's amplification device. Thus, when one is sitting in the middle of the looped room with their t-coil on, the original signal from the PA system is picked up by the hearing aid t-coil and converted back to an acoustic signal (Dillon, 2012). T-coils are also available in cochlear implants or loop receivers, which can be worn as a headset in the room.

Figure 1: Process of Hearing Loop

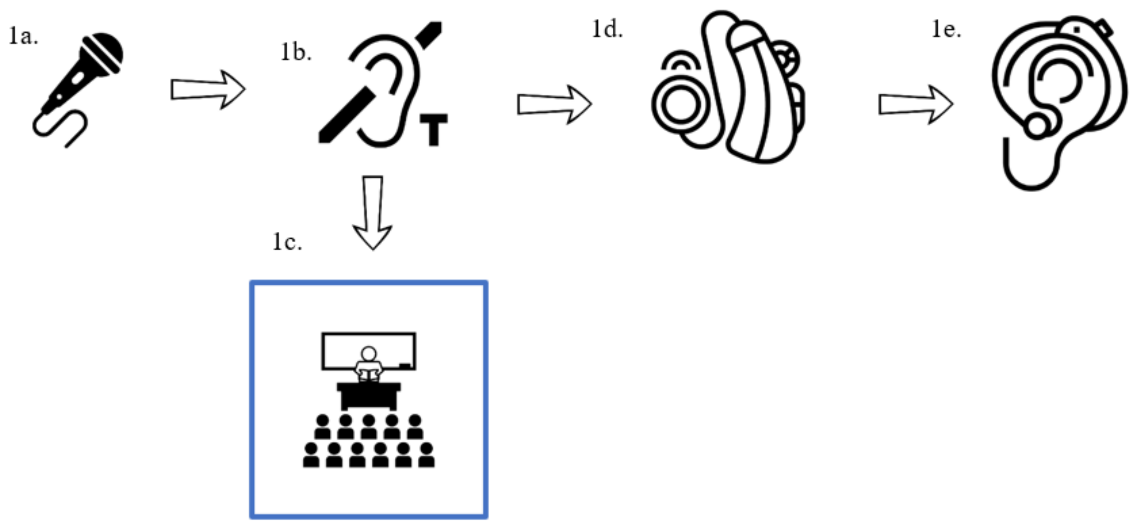


Figure 1: The steps of converting an audio signal from a sound source to a t-coil.
1a. Audio signal from a sound source is converted into an electrical current.
1b. The universal sign for a hearing loop.
1c. The electrical current flows through the hearing loop made from wire in that room. The wire loop or hearing loop is commonly around the parameter of the room which creates a magnetic field.
1d. If the t-coil within the hearing aid/cochlear implant is on it detects the magnetic field, creating an electric voltage within the t-coil.
1e. Therefore, what is said into the PA system is picked up by the t-coil and then converted back to an acoustic signal at the user's ear.

An improved signal-to-noise ratio provided by looping can potentially benefit all who use spoken communication, though their most common application is with adults with hearing loss (Dillon, 2012). There are a number of reasons why hearing loops may be selected. First, hearing loops are commonly seen in churches, lecture halls, and some theaters and are known by a universal sign which is posted in that space or near the entrance of it (see Figure 1b). Second, unlike other types of assistive listening systems, hearing loops/t-coils are discrete and allow for the users to directly access this increased SNR without the use of additional devices (Atcherson, Franklin, & Smith-Olinde, 2015). Also, hearing loops provide an advantage over other assistive listening systems as they are not a one-to-one connection, meaning multiple people can use the loop at the same time (Sterkens, 2017). Finally, a hearing loop does not cause additional battery drain like other assistive listening systems. Specifically, the t-coil is an integrated feature of a hearing aid that uses induction instead of Bluetooth, like many remote microphones which can cause battery drain (Ledda, Valente, Oeding, & Kallogjeri, 2019).

There is currently limited peer-reviewed research supporting the benefit of hearing loops in a classroom setting. A recent study by Alfakir, Holmes, Kricos, Gaeta, & Martin (2015) supported the efficacy of t-coils in hearing aids. In an experiment with a cross-sectional design, Alfakir et al. (2015) assessed the speech perception ability of 12 older adults with hearing loss using the Consonant Nucleus Consonant and Bamford-Kowal-Bench tests when using the t-coil setting in both noisy (+10 dB SNR) and quiet conditions in a standard lecture hall. In addition, participants subjectively assessed listening effort and self-confidence in all conditions tested. Alfakir et al. (2015) found significant improvement in participants' speech perception scores for both noisy and quiet conditions when using the t-coil setting. One limitation of this study is that they did not report participants' audiometric data and had a small sample size: thus, impacting the generalizability of their results.

Additionally, there is one non-peer-reviewed study by Faivre, Ismail, Sterkens, Thunder and Chung (2016) that assessed speech perception and subjective sound and music quality of using a hearing loop in a traditional lecture hall. Participants included listeners with normal hearing and hearing aids users. Speech perception was measured using the Hearing in Noise Test (HINT) at two different SNR levels of +3 and -3 dB. Faivre et al. (2016) found improved speech understanding in noise when using the hearing loop and better speech understanding scores with the higher SNR. Sound quality ratings revealed that listeners with normal hearing and hearing aid users reported reduced listening effort, improved understanding of music, and more natural sound quality when using the hearing loop in comparison to when not using the loop. However, beyond Alfakir et al., (2015) and Faivre et al., (2016), most research on loops only discusses what hearing loops do and how they can be beneficial in theory.

Other previous studies on benefit from hearing assistive technology have focused on other types of assistive listening systems in classrooms such as Frequency Modulated systems (FM). A study done by Norrix, Camarota, Harris, and Dean (2016) investigated the SNR in noise at the tympanic membrane of adults and children under three FM conditions. These conditions included FM on-only, FM and hearing aids on, and hearing aids on-only. This study concluded that under some circumstances (e.g., when background noise levels are high) the SNR at the user's ear may not be optimal when the hearing aids and FM are on together. Similarly, Thibodeau (2010) conducted a study comparing fixed processing FM systems to adaptive processing FM systems in five (+30, +21, +16, +11, +4 dB SNR) SNR conditions. It was found that adaptive FM processing resulted in better speech recognition in noise as measured by the

HINT and Speech Perception in Noise (SPIN) sentences when compared to fixed FM processing (Thibodeau, 2010). While this data is useful in terms of the benefits that an increased SNR can have, it does not address the benefit of hearing loop assistive listening systems.

As discussed, the limited previous research has evaluated the benefit of hearing loops, but no previous study has taken the approach of patient-centered outcomes research (PCOR). PCOR refers to evaluating a question and outcomes that are considered meaningful and important to patients (Frank et al., 2014). Past research has subjectively assessed hearing loops using, listening to effort, self-confidence, and perceived sound quality of speech and music. However, these subjective measures may negate the experience of patients who use hearing loops as they do not report using patient input in the selection of these measures (Frank et al., 2014). By using the PCOR approach it can increase the relevance of study results and improve content and construct validity (Frank et al., 2014). Given the fact that previous research on the benefits of hearing loops in a classroom are limited and have not reported the use a patient-centered approach, the question remains: What do patients perceive to be the benefit of using a hearing loop?

The purpose of this audiology doctoral project was to measure the benefits of looping in a university classroom under ecological conditions for adults with hearing loss. This project was separated into three phases. The first phase was comprised of verifying a university classroom loop (installed in Speech Language and Hearing Sciences Building, room 409, summer 2019) to international quality standards (IEC 60118-4). The second phase included facilitating two focus groups with a local hearing loss support group. The purpose of these focus groups was to learn more from hearing loop users on their experiences with hearing loops and their perceived benefits and challenges. Subjective outcome measures for the third phase of this study were selected based on the qualitative data from these focus groups. The organization of the following text will follow the sequence of each phase, with methods and results, as each phase built upon the prior phase.

METHODS & RESULTS

Ethics

This study was approved by the Institutional Review Board (IRB) of the University of Arizona. A site authorization was obtained to conduct research off campus (phase two) and an amendment to an existing protocol was made for phase three of the study.

Phase One: Loop Verification

Methods

The hearing loop in room 409 of the Speech-Language and Hearing Sciences (SLHS) building at the University of Arizona was installed in the summer of 2019. This classroom represents a collaborative learning space in that the seating is mobile and arranged in small groups. The acoustical make-up of the classroom includes carpet, three walls with whiteboards, and one wall with windows. This classroom was selected for a combination of reasons including it had a newly installed loop and it is one of the most commonly used classrooms for teaching in the SLHS department.

Using the Oval Window Audio FSM Loop Test Set, the classroom hearing loop was verified to the International Quality Standards (IEC 60118-4) in January of 2020. These IEC standards assess magnetic background noise, field strength, peak field strength, and frequency response of the induction loop. Additionally, the IEC standards include a listening check for clear and audible sounds and verification that proper signage is in place. Peak field strength as measured from where the participant would sit in phase three of this study was measured to be between -3 and +3 dBA in reference to 400 mA/m meaning the acoustical output of the loop is equivalent to 70 dB SPL on average.

Results

Figure 2 shows the measured field strength for each seat in the classroom. The field strength in this classroom was considered uniform as the difference between the highest and lowest field strength reading did not exceed 6 dBA (International Electrotechnical Commission, 2017).

Figure 2: Map of the Measured Field Strength in SLHS 409

Figure 2: This map shows the classrooms measured magnetic field strength for each seat in the classroom. The blue line around the parameter and in the center represent the induction loop which was installed underneath the carpet in the floor. The legend on the right shows the dBA level per color in reference to 400 mA/m. The red star represents were the participant sat during behavioral testing in phase three.

Phase Two: Focus Groups

Methods

Community Partners. The second phase of this study used a patient-centered outcomes research approach to better understand patients' experiences with hearing loops. Two focus groups were conducted at a local hearing loss support organization. The particular hearing loss support organization was selected to host this study's focus groups due to their members' invested interest in looping and close relationship with the University of Arizona. Additionally, this hearing loss support organization has members who volunteer to verify hearing loops within the southern Arizona community and have a list of 136 looped venues in the community.

Participants. Participants were recruited through IRB-approved flyers that local hearing loss support groups sent out to their members and posted in their facility. A total of 10 adults with hearing loss and experience using induction loops were recruited. However, from those recruited eight participated in one of two focus groups. A majority of the participants were male (n = 5), ages ranged from 60 to 84 years, and all participants were native English speakers. Table 1 details the focus group participants' demographics.

Table 1: Focus Group Demographics

Factor	Total Sample
Gender	
n	8
% Male	62.50
% Female	37.50
Age	
n	8
% 60 -69 years old	25
% 70-79 years old	37.5
% 80-89 years old	37.5
Race	
n	8
% Caucasian	100
Highest Education Level	
n	8
% Associates Degree	25
% Bachelor’s Degree	25
% Master’s Degree	37.50
% Doctorate Degree	12.50
Native Language	
n	8
English	100

Procedure. Following signed informed consent, participants were asked to complete a listener questionnaire and the Abbreviated Profile of Hearing Aid Benefit (APHAB). The listener questionnaire asks questions regarding demographics, hearing health history, use of amplification history and satisfaction. The APHAB is a 24-item questionnaire that asks the participant to rate communication scenarios from the perspective of listening without their amplification and with their amplification (Cox & Alexander, 1995).

The focus groups were facilitated by S. Beatty and N. Marrone. The hearing loop installed at the local hearing loss support organization was used during the focus groups by facilitators and participants. Questions asked during the focus groups facilitated discussion about participants' experience using hearing loops, learning about hearing loops, perceived benefits of hearing loops, and struggles with hearing loops. Each focus group discussion lasted for one hour.

Results

Results from the APHAB demonstrated that participants had varying perceived amplification benefits in terms of speech understanding in everyday environments and adverse reactions to environmental sounds. Figure 3 illustrates each participant's APHAB benefit score in terms of the four subscales: ease of communication, background noise, reverberation, and aversiveness to sound.

Figure 3: Focus Groups APHAB Scores

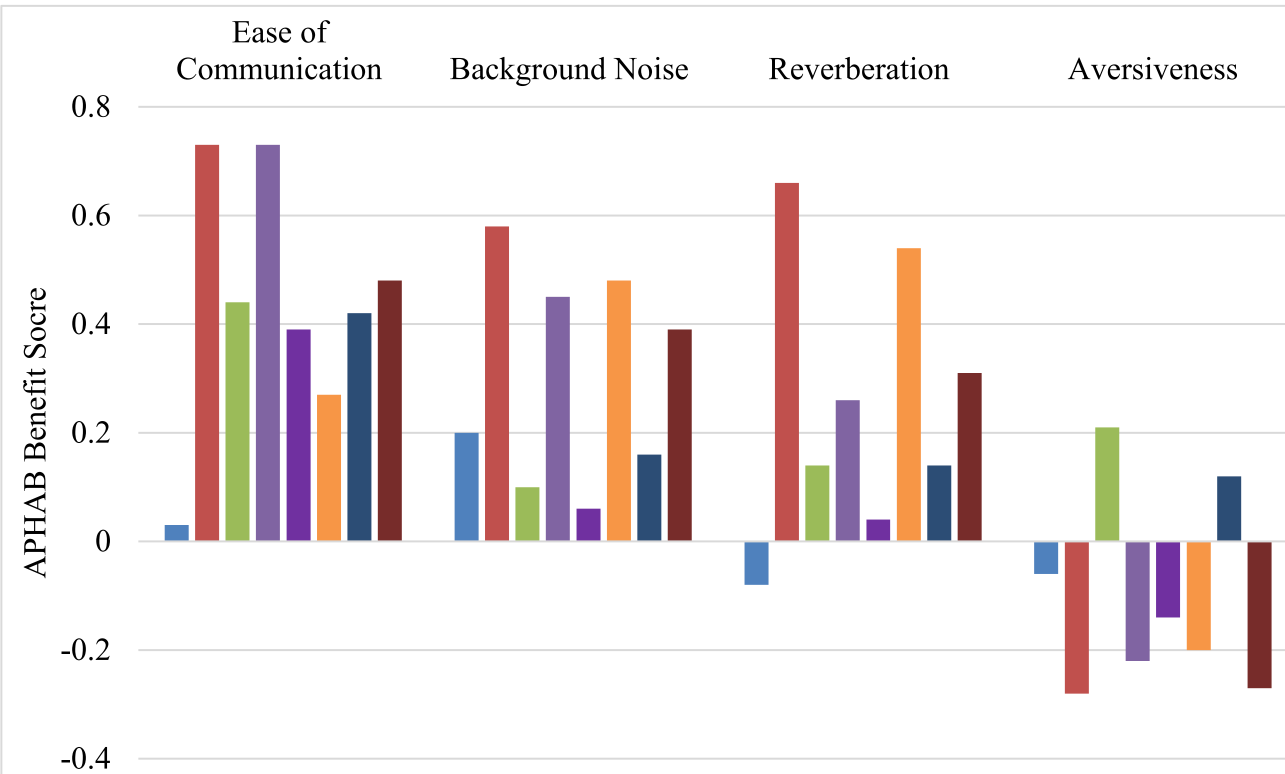


Figure 3: Each color represents one of the eight focus group participant's APHAB benefit score for each subscale. The higher the score, the more the participant benefited with their hearing devices than without it.

Participants in the focus groups engaged in an active discussion surrounding hearing loops and their experiences. Full qualitative analysis of the results is ongoing. For the purpose of this audiology doctoral project, I will report on two major themes with representative quotes from content analysis.

One major theme was participants' perceived benefit of hearing loops. When the discussion was facilitated about their perceived benefit of hearing loops, many commented that they felt hearing loops made sounds less distorted and cut out background noise resulting in them feeling less stressed. One participant stated, "I feel like I have a sense of command with the loop – I am not stressed, or worried, I am in command." Another participant reported, "It lets me feel like a participant in life – it's major!"

The second major theme was participants reported experiences and use of hearing loops. Regarding hearing loop use, participants reported using hearing loops at churches, local hearing loss support organizations, movie theaters, and home. Additionally, when asked to discuss their difficulties with hearing loops, participants shared that one of the most significant issues is that many places do not know what assistive listening systems they have to offer or how to turn it on or use it.

Phase Three: Subjective and Behavioral Measures

Methods

From the information shared and discussed at the focus groups, the research question for phase three was developed. This phase of the project sought to explore how t-coils benefit adults with hearing loss in a classroom regarding speech perception performance and perceived workload. Continuing to use the patient-centered research outcomes approach, the behavioral and subjective outcome measures for phase three were developed from the focus group discussions in phase two. It was hypothesized that adults with hearing loss would benefit both in terms of speech perception and workload when using a hearing loop.

Classroom Setting. A classroom (SLHS, Room 409) was selected to administer the subjective and behavioral measures for phase three. While classrooms are traditionally used for teaching students, they can also be used for engaging with community members. For example, the University of Arizona annually host an annual community event called the Tucson Festival of Books in which author lectures are held in various classrooms on campus. At events like this, many community members with hearing loss, may request assistive listening systems.

Participants. Participants were recruited from the University of Arizona Adult Hearing Clinic and local hearing loss support organizations. Emails and phone calls using IRB-approved scripts were made to recruit participants. Inclusion criteria included having bilateral sensorineural hearing loss ranging from mild to profound and currently wearing a hearing device with a telecoil (hearing aid or cochlear implant). Initially, eleven participants were recruited. Data was only obtained on six participants as the pandemic of COVID-19 forced research in-person efforts to be halted. However, this phase only reports on five participants as one of the participant's data was inaccurately obtained due to technical issues.

Table 2 and 3 describes phase three participants' demographics and hearing technology characteristics. Of the five participants, four were male, all were native English speakers, and their ages ranged from 67 to 82 years. Of the five participants, three wore bilateral open-fit hearing aids, one wore a bimodal fitting (cochlear implant and hearing aid, both had t-coils), and one wore bilateral cochlear implants. The three participants who wore hearing aids all had a t-coil only setting (output is from the input of the loop). In contrast, the two cochlear implant users used a t-coil+mic setting (output in this setting included input from cochlear implant microphones and the loop).

Table 2: Phase Three Participants' Demographics

Factor	Total Sample
Gender	
n	5
% Male	80
% Female	20
Age	
n	5
% 60 -69 years old	20
% 70-79 years old	60
% 80-89 years old	20
Race	
n	5
% Caucasian	100
Highest Education Level	
n	5
% Bachelor's Degree	40
% Master's Degree	60
Native Language	
n	5
% English	100

Table 3: Phase Three Participant Hearing Technology Characteristic's

Participant	Type of Amplification	Brand of Technology
2	Bimodal (Cochlear Implant + Hearing Aid)	Advanced Bionics
3	Open Fit Hearing Aids	Phonak
4	Open Fit Hearing Aids	Starkey
5	Bilateral Cochlear Implants	Cochlear
6	Bilateral Hearing Aids	Widex

Audiologic Measures. Prior to data collection in the classroom, participants had an audiologic evaluation completed (including unaided pure-tone air and bone conduction measures to establish type, degree, and configuration of hearing loss). Also, aided warble-tone testing, the QuickSIN speech-in-noise test (Killion, Niquette, Gudmundsen, Revit, & Banerjee, 2004), and the aided Word Auditory Recognition and Recall Measure (WARRM; Miller et al., 2017) were obtained from the participants in the sound booth from a single loudspeaker at 0 degrees azimuth. Refer to Appendix A for individual participant QuickSIN and WARRM scores. Figures 4 and 5 display the unaided and aided audiograms for each participant. All participants had sensorineural hearing loss. Hearing aid users unaided audiograms ranged from moderate to severe, and their aided audiograms ranged from normal to moderately-severe. Cochlear implant users' unaided thresholds were profound, and their aided thresholds ranged from normal to mild.

Figure 4a: Unaided Audiograms for Hearing Aid Users

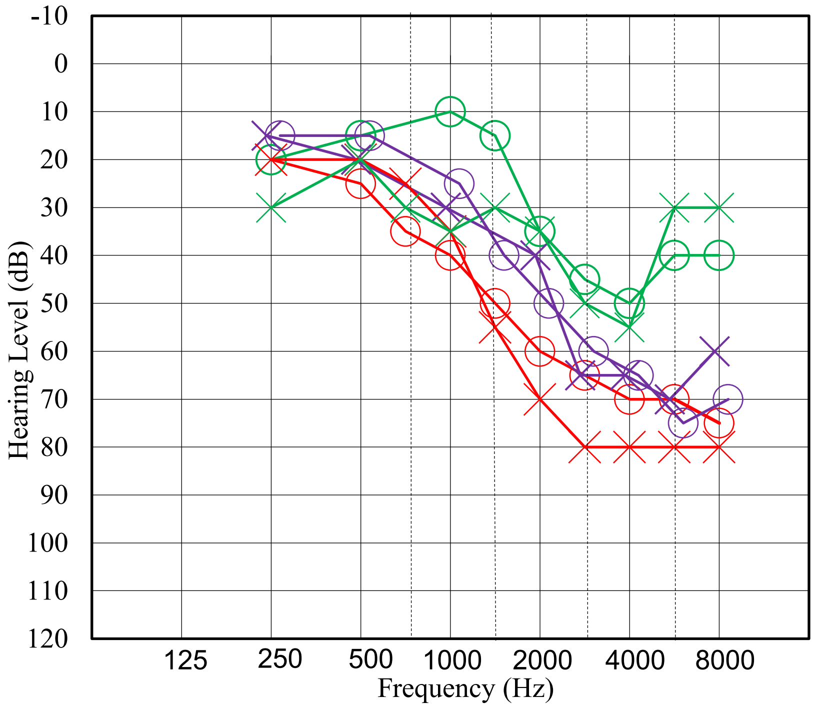
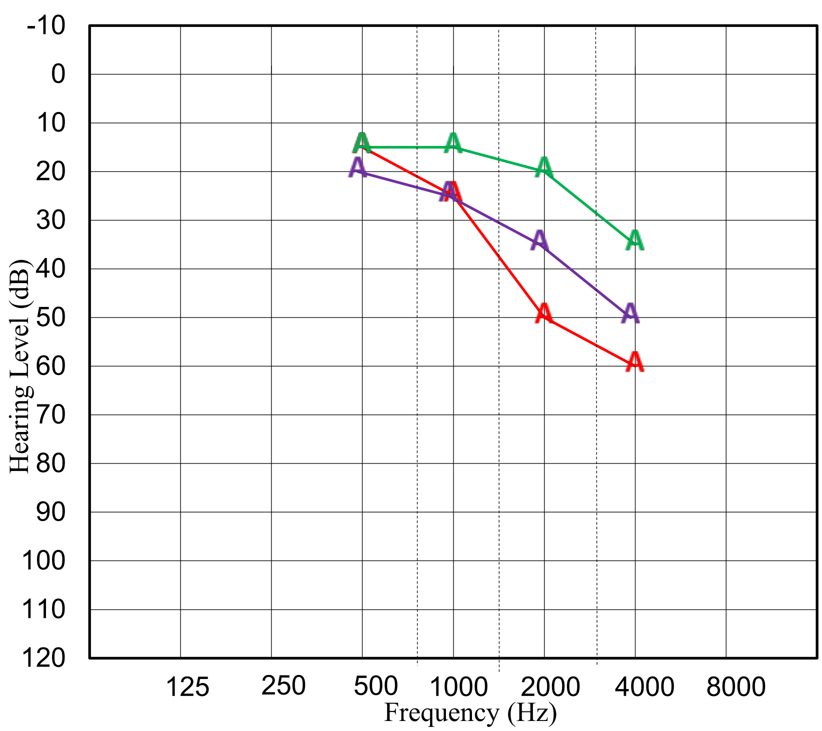
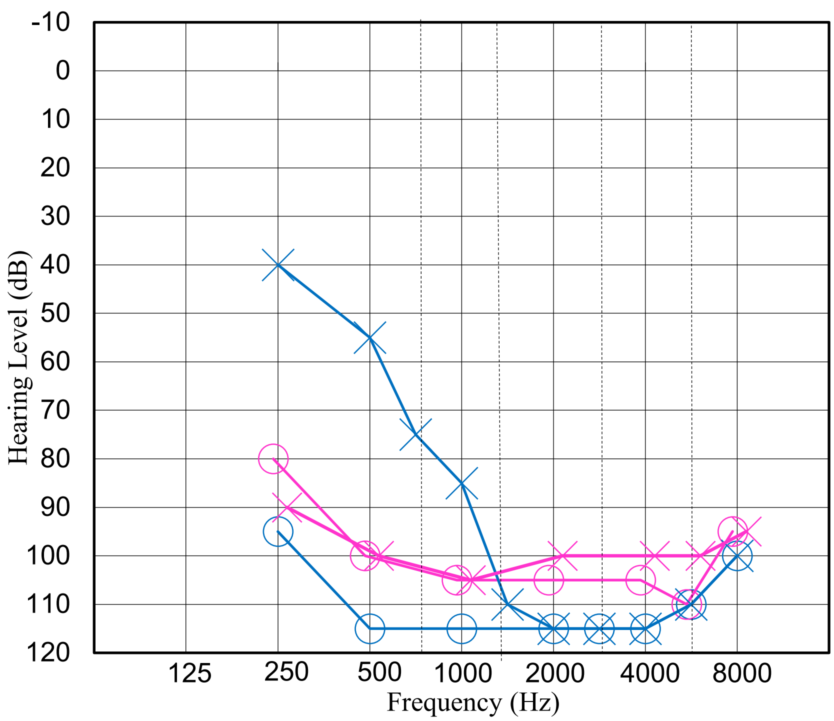


Figure 4b: Aided Audiograms for Hearing Aid Users



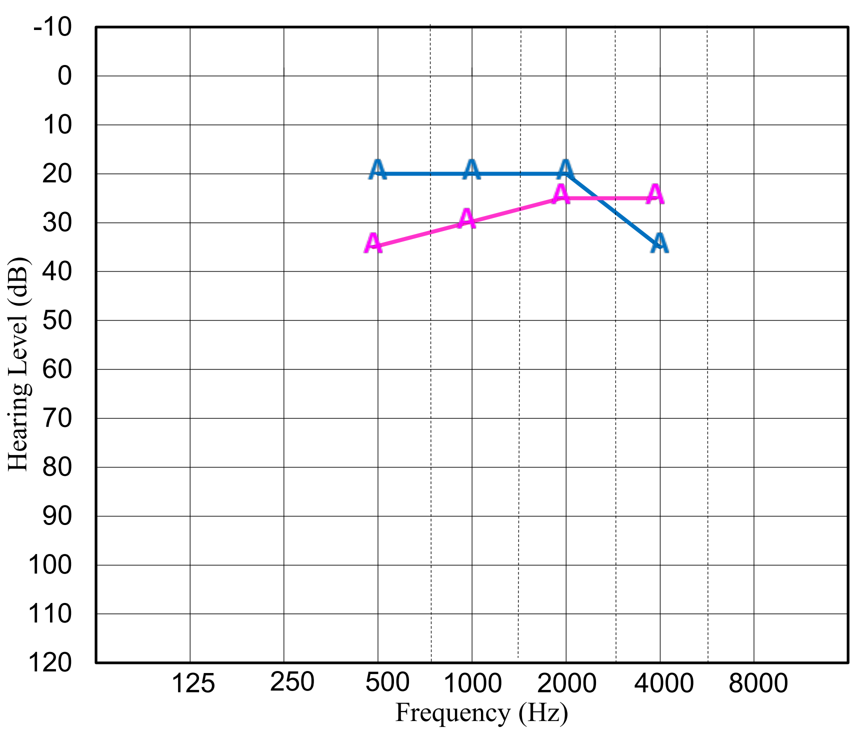
	Participant 4	Open Fit Hearing Aids
	Participant 6	Open Fit Hearing Aids
	Participant 3	Open Fit Hearing Aids

Figure 5a: Unaided Audiograms for Cochlear Implant Users



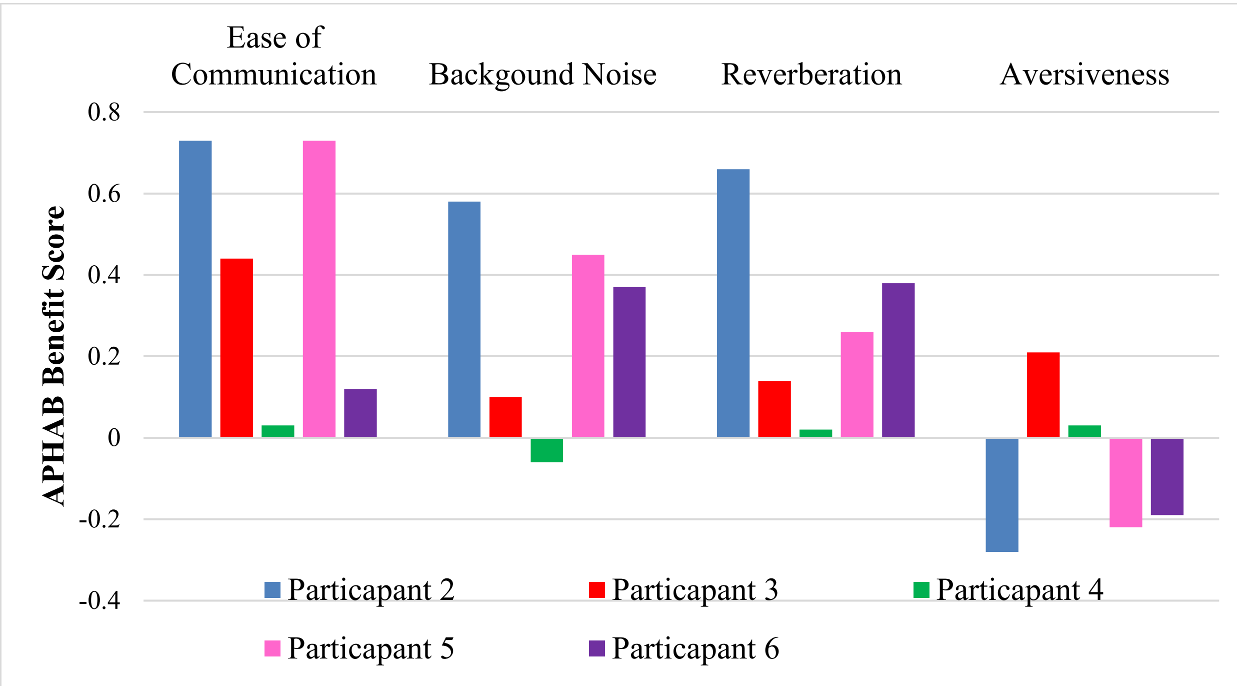
	Participant 2	Bimodal Fitting (Right: CI, Left: HA)
	Participant 5	Bilateral Cochlear Implanted

Figure 5b: Aided Audiograms for Cochlear Implant Users



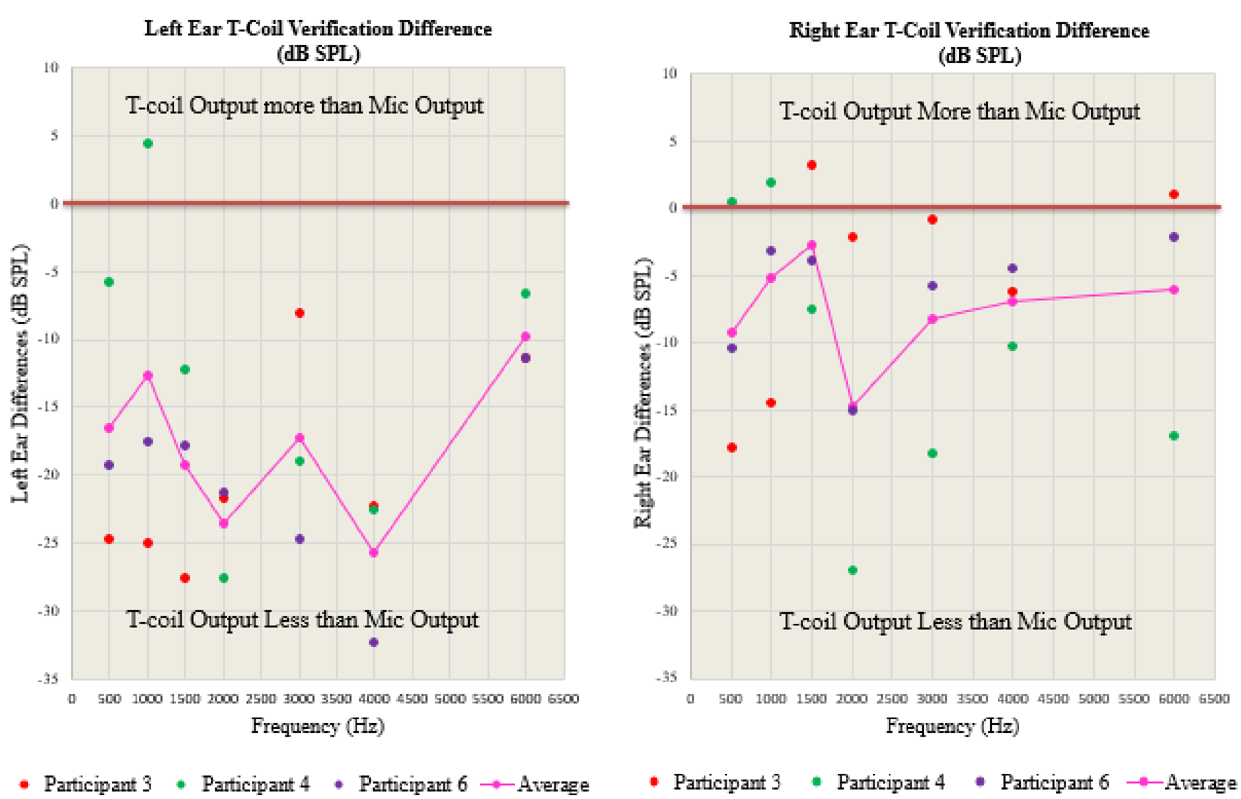
Additionally, participants completed the APHAB and listener questionnaire. The APHAB results indicated that despite participants' similar demographics, they had reported differences in amplification benefit. Figure 6 illustrates each participant's APHAB benefit score in terms of the four subscales: ease of communication, background noise, reverberation, and aversiveness to sound.

Figure 6: Phase Three APHAB Scores



Hearing aid T-coil Verification. Hearing aid t-coils were verified to the American National Standards Institute (ANSI; S3.22-2003) standard using test-box measures. The hearing aid in user settings was placed in the Frye 7000 test box connected to a 2cc coupler. Using a pure-tone input of 60 dB SPL stimulus, a microphone frequency response (dB SPL) was measured for the hearing aid in user settings (the setting that participant reported using daily). Following, the sound pressure level in a vertical magnetic field (SPLIV) was obtained. The SPLIV was obtained by switching the hearing aid into the t-coil mode and measuring the t-coil frequency response using the Frye 7000 Telewand and 2-cc coupler with the equivalent pure-tone input delivered via an electromagnetic signal (31.6 mA/m). According to the ANSI standard (S3.22-2003), the difference between the t-coil frequency response and microphone frequency response should be as close to zero as possible. Figure 7 shows the t-coil verification results for the three hearing aid participants. On average, the output levels from the hearing aid t-coils were significantly less than the hearing aid microphone output levels by frequency.

Figure 7: Hearing Aid T-coil Verification



Cochlear Implant T-coil Validation. Given that there is not a test-box measure for cochlear implant t-coils verification, cochlear implant participants t-coils were validated using a recorded presentation of the Ling Six Sounds as they represent speech sounds across varying frequencies (Scollie et al., 2012). Participants were instructed to repeat aloud each of the sounds they heard. The signal of the Ling Six Sounds recording was presented directly through the loop in the classroom to the participant's t-coil. The two cochlear implant users were able to repeat aloud each sound correctly.

Hearing Aid Verification. Additionally, hearing aids were verified to NAL-NL2 prescriptive targets using a Natus Aurical Freefit and probe-tube real-ear measurements. Real ear measurements should ideally be within +/- 10 dB (SPL) of the prescriptive target (Aazh, Moore, & Prasher, 2012). As shown in Figure 8, on average, the mid and high frequencies were under-target for the hearing aid users.

Figure 8: Hearing Aid Verification – Real Ear Measurements

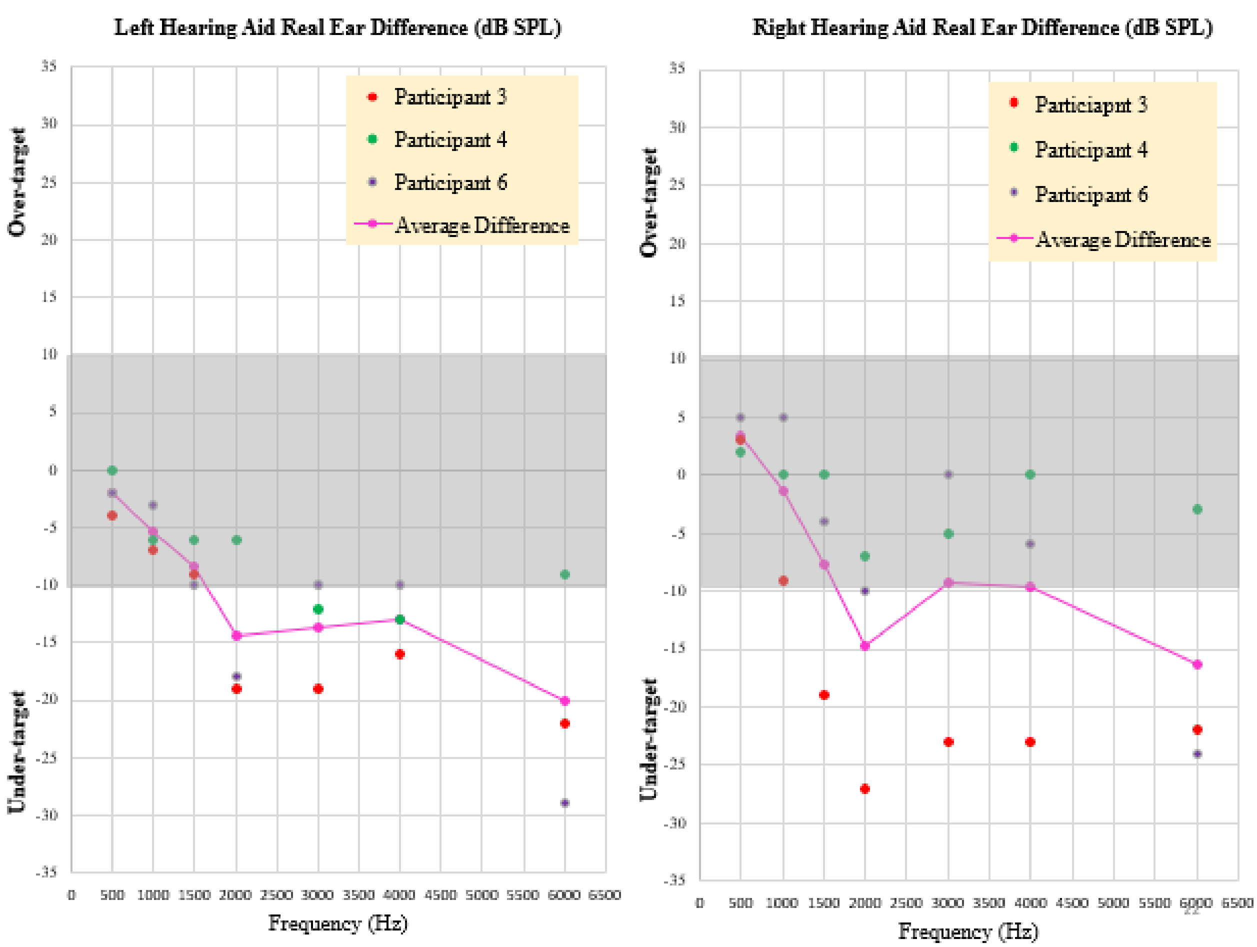


Figure 8: The grey box represents +/- 10 dB SPL from NAL-NL2 targets (Aazh, Moore, & Prasher, 2012). Point that are outside of the grey box represent significantly under-fit frequencies.

Materials. The AZBio sentences and NASA Task Load Index (NASA-TLX) were administered in the classroom. Behavioral outcome measures include the AZBio sentences from the Minimum Speech Test Battery for cochlear implant candidacy (Spahr et al., 2012). The AZBio sentences were selected as they provide an accurate estimation of one's performance that is parallel with their perception of their performance in everyday listening environments (Spahr et al., 2012). The AZBio sentences measure was also selected based on the data gathered from the focus groups in which participants expressed that the loop makes speech sound less distorted and clearer. The NASA-TLX was selected as the subjective measure (NASA-TLX; Hart & Staveland, 1988), which was included based on data gathered from the focus groups, where participants described feeling less stressed when using the loop. On the NASA-TLX, participants rate their experience of a task's workload in terms of mental, physical, and temporal demands, as well as frustration and effort.

Procedure. Following the completion of questionnaires, audiometric measurements, and verification measures, participants were taken to the classroom to partake in behavioral and subjective measures. Both subjective and behavioral testing was performed in 3 conditions. In condition one, participants wore their amplification in their user settings ("Without Telecoil"), sentences were presented through a Focal CMS 50 loudspeaker 96 inches in front of the participant. In condition two, participants wore their amplification in their t-coil setting with the AZBio sentences presented through a loudspeaker with a microphone[1] that was directly connected to the classroom loop placed 6 inches in front of the loudspeaker ("Telecoil+Room"). In condition three, participants wore their amplification in their t-coil setting with the AZBio sentences presented directly into the classroom loop, thus omitting the effects of the classroom acoustics on the signal (“Telecoil-only, direct connection”). Refer to Appendix B for a diagram illustrating each condition from above.

In each condition, one AZBio sentence list (40 items in 20 sentences; 5 sentences from each of the 4 talkers) was presented in noise (Sentences 60 dBA, Noise 50 dBA as measured from where the participant was seated), and one list was presented in quiet (Sentences 60 dBA). The noise in all conditions was presented through the four classroom ceiling loudspeakers[2]. The NASA-TLX was administered after the AZBio sentences in noise for each condition.

In all conditions for the AZBio sentences, participants were instructed to repeat aloud the sentences they heard, take guesses when needed, and to look straight ahead without leaning forward or backward. For the NASA-TLX participants were instructed to select the subscale that was most demanding to the task (AZBio sentences in noise) and then rate each subscale using a 100-point scale. Participants gave a verbal response to each prompt and question on the NASA-TLX. The NASA-TLX is scored by multiplying the rating of the subscale by the number of times the participant selected that respective subscale as most demanding. To obtain a score for each subscale, this described formula is performed.

Results

Speech Perception. On average, speech perception scores improved in both quiet and noise in both t-coil conditions in comparison to the Without T-coil condition. In quiet, the average scores improved from 89.2% (SD = 15.57) Without T-coil to 92.96% (SD = 3.56) T-coil+Room. Interestingly, when the room acoustics were omitted (T-coil Only) the average AZBio score in quite improved to 98.18% (SD = 0.94). In noise the average AZBio scores improved from 81.1% (SD = 24.6) Without T-coil to 94.74% (SD = 7.89) T-coil+Mic and 94.86% (SD = 2.27) T-coil Only. While more improvement was observed in the noise conditions, in noise there was no difference in average scores between the T-coil+Room and T-coil Only condition, suggesting that room acoustics were not as impactful in the noise. Figure 9 demonstrates the average scores for the AZBio sentences for all conditions. Refer to Appendix C for individual participant scores.

Figure 9: Average AZBio Scores

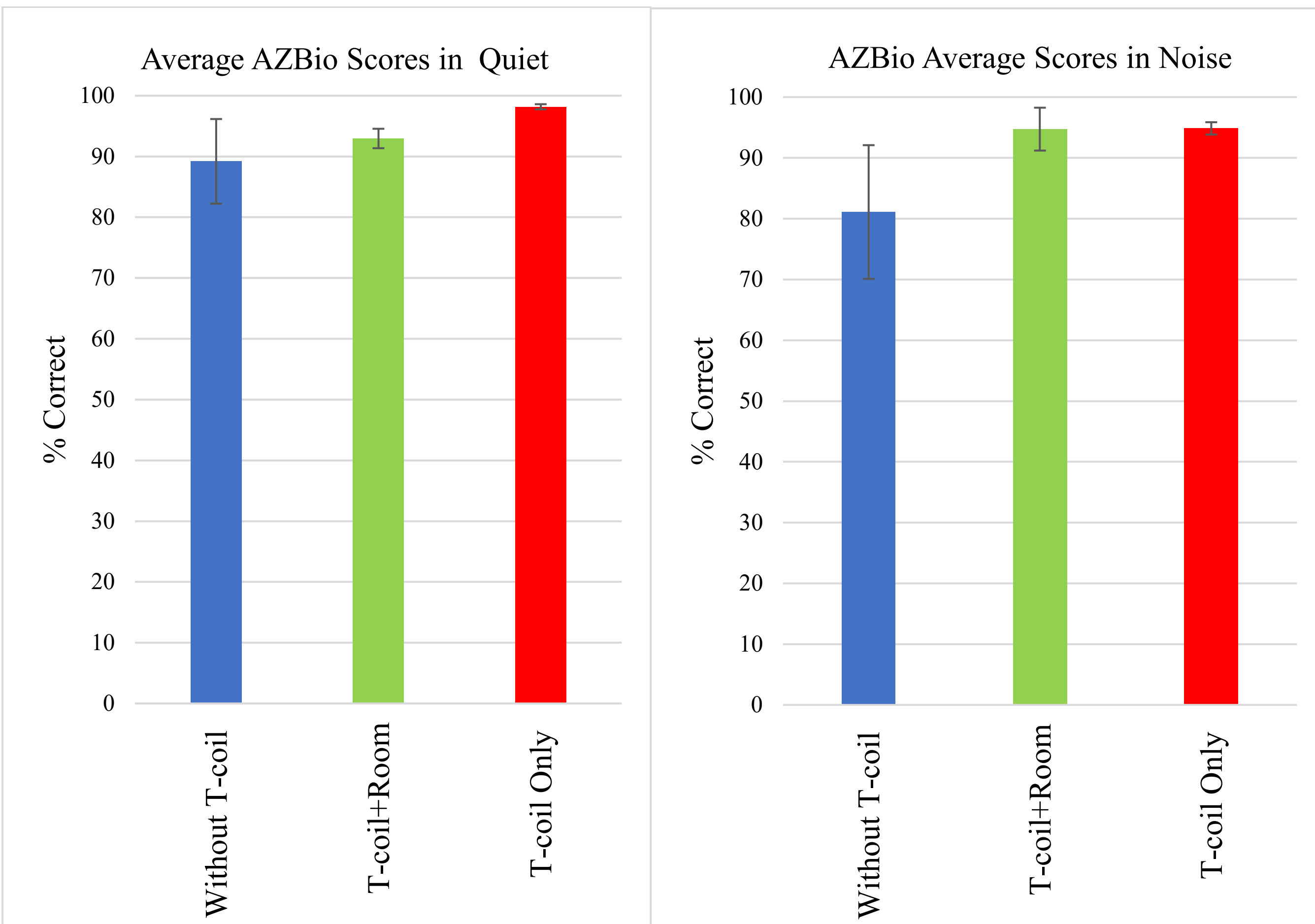


Figure 9: Error bars represent standard error.

Speech perception scores were also analyzed in terms of benefit by subtracting the Without T-coil condition scores from each of the respective T-coil conditions. As shown in figure 10, participants benefited with the t-coil in noise and quiet; however, more benefit was observed in the noise condition. There was a larger difference in benefit between T-coil Only and T-coil+Room in quiet than in noise.

Figure 10: Average Speech Perception Benefit Score

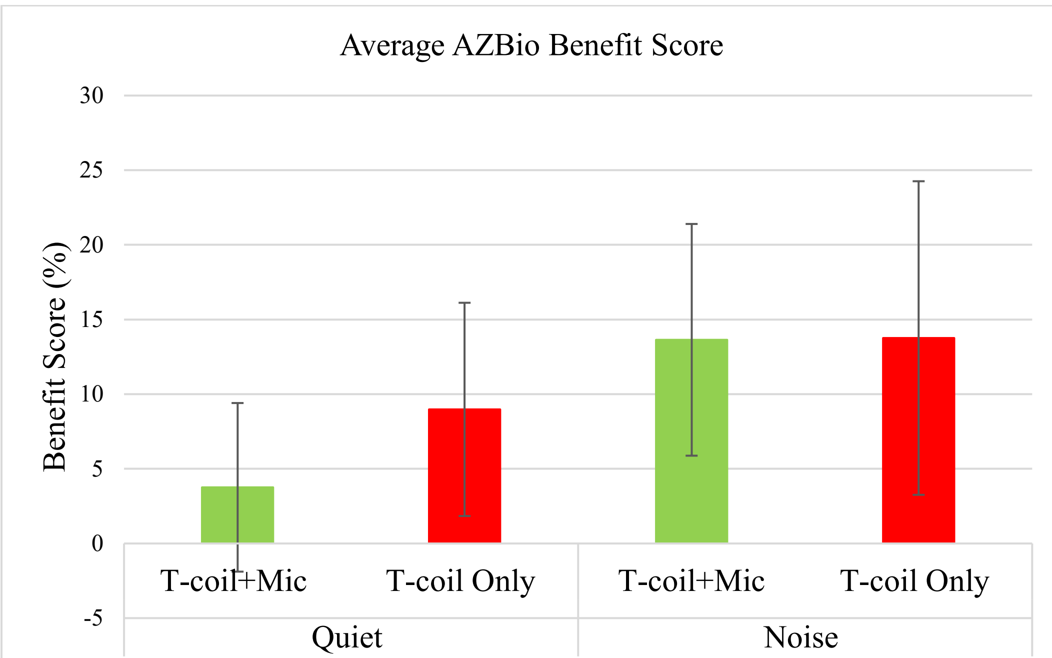


Figure 10: Error bars represent standard error.

Subjective Workload. On the NASA-TLX, participants reported an average reduction in temporal demand and increase in performance when using the t-coil in comparison to when not using the t-coil (Without T-coil). Temporal demand refers to how much time pressure participants felt due to the pace at which the task, repeating aloud the AZBio Sentences in noise, occurred (Hart & Staveland, 1988). Whereas performance examines how successful the participant felt they were in accomplishing the task, repeating aloud the AZBio sentences in noise (Hart & Staveland, 1988). Figure 11 shows the average scores for each subscale of the NASA-TLX.

Figure 11: NASA-TLX Average Scores

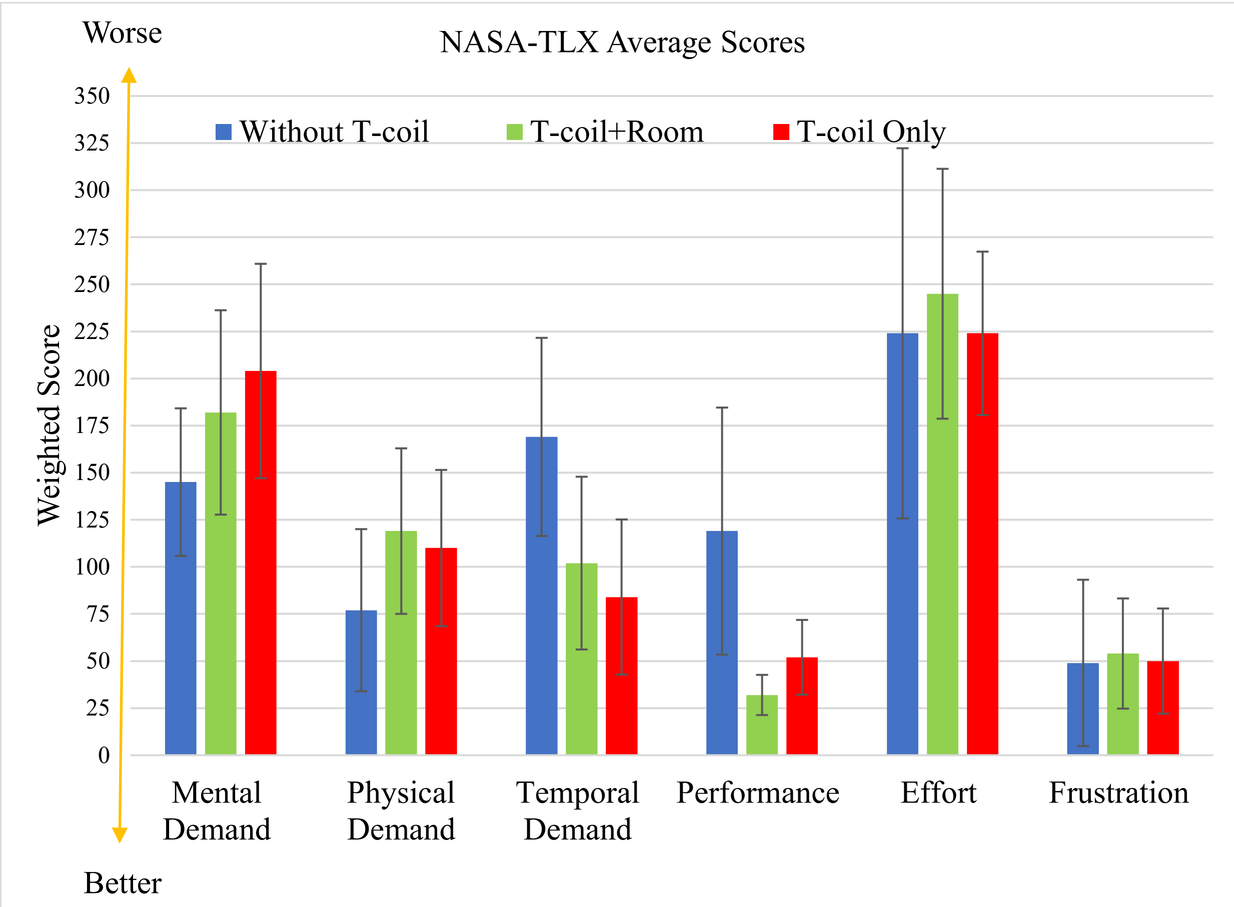
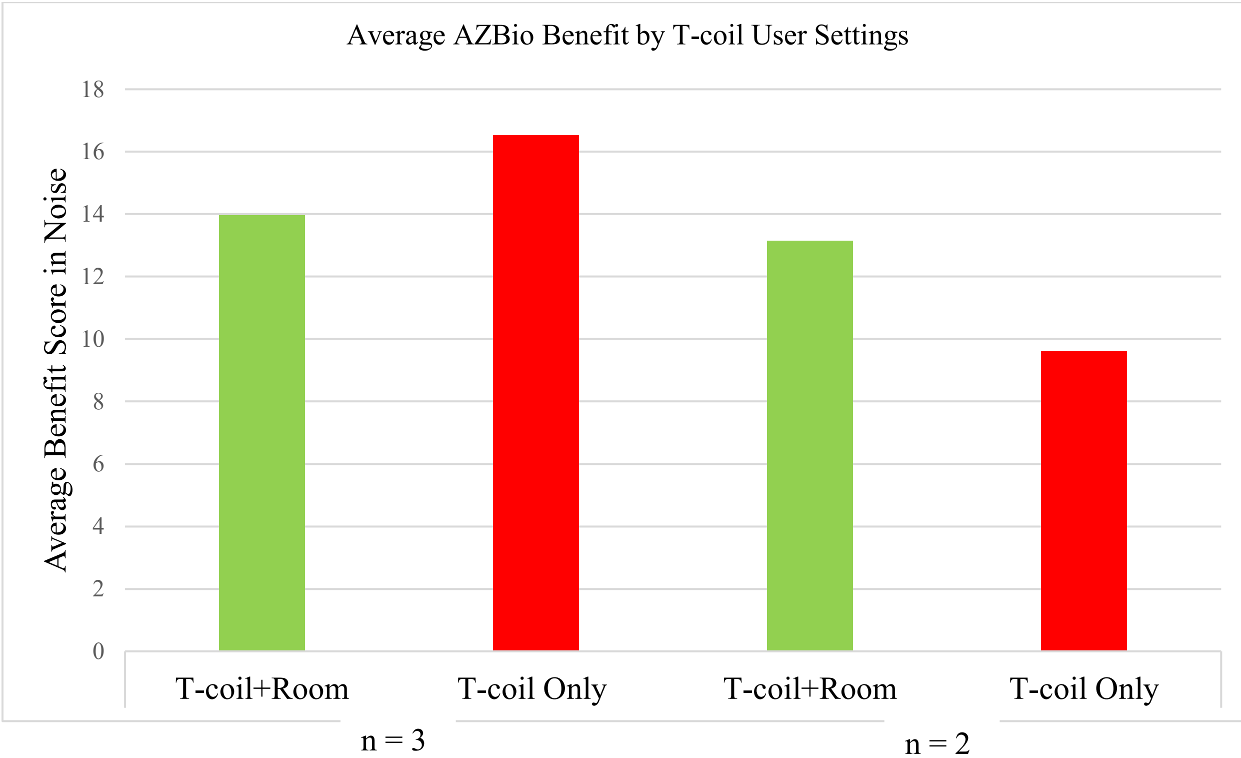


Figure 11: Error bars represent standard error.

Analysis by T-coil User Settings. Although the data set was small, and the t-coil user settings were not evenly distributed as three users had a t-coil only setting and two had a t-coil+mic setting, speech perception benefit was also analyzed by user t-coil settings. In terms of user settings (t-coil or t-coil+mic), on average, there was more benefit observed for the three participants in the t-coil setting, coincidentally all hearing aid users, than for the two participants in the t-coil+mic setting (cochlear implant user). However, this difference should be further analyzed as this is a small sample size that is not proportionally distributed. Figure 12 shows the average AZBio benefit score in noise based on user settings.

Figure 12: Average AZBio Scores Based on T-coil User Settings



Analysis by Amplification Type. Speech perception benefit scores were analyzed in terms of amplification type (Hearing Aids or Cochlear Implants). The three, hearing aid users demonstrated more benefit in both quiet and noise for both t-coil conditions. This benefit could be attributed to the fact that the hearing aid users were fit under-target or to the fact that there was one more hearing aid user than cochlear implant users. Additionally, in quiet, cochlear implant users' speech perception benefit scores showed little to no benefit in the t-coil conditions. This lack of benefit is likely attributed to a ceiling effect as the cochlear implant users performed very well in the Without T-coil condition.

Additionally, temporal demand and performance workload benefit was evaluated by amplification type. The benefit was calculated by subtracting each of the respective t-coil conditions (T-coil+Room and T-coil Only) score from the Without T-coil condition scores for each participant. Cochlear implant users (n = 2), demonstrated more benefit in both t-coil conditions in terms of temporal demand when compared to most hearing aid users' benefit. Additionally, all of the hearing aid user's (n = 3) benefited in terms of performance, whereas only one cochlear implant user benefited. Refer to Appendix D for each participant's individual benefit scores.

DISCUSSION

The primary purpose of this study was to evaluate the benefits of looping for adults with hearing loss in a university classroom using a patient-centered outcomes research approach. This study verified a classroom loop (Phase One), facilitated focus groups (Phase Two), and measured the benefit of t-coils for adults with hearing loss using behavior and subjective measures (Phase Three). It was hypothesized that participants would benefit both behaviorally and subjectively when using a hearing loop.

Based on the findings in this study, on average, speech perception scores improved from the Without T-coil condition to both t-coil conditions (T-coil+Room & T-coil Only) in quiet and noise. These findings are consistent with the Alfakir et al. (2015) study, which found significant improvement in participants' speech perception scores for both noisy and quiet conditions when using the t-coil setting. Alfakir et al. (2015) and this current study's findings are also consistent with the previous literature on other assistive listening systems that an increased signal to noise ratio is beneficial to those who use spoken language (Dillon, 2012). Both Alfakir et al. (2015)

and this current study evaluated behavioral and subjective t-coil benefit in a classroom setting using a +10 dB SNR. However, Alfakir et al. (2015) demonstrated benefit in a traditional lecture hall whereas this study showed benefit in a collaborative learning space.

The current study differs from previous literature on the benefit of looping in a classroom in several different ways. First, it evaluated both cochlear implant and hearing aid users. This is important as hearing aid users do not represent all who may benefit from a hearing loop. Also, hearing aid technology differs from cochlear implant technology; therefore, evaluating only one technology is not generalizable to all who could potentially benefit. Additionally, this study used a PCOR approach in that the NASA-TLX and AZBio sentences were selected based on participants input at the focus groups.

The NASA-TLX results revealed that participants reported on average, reduced temporal demand and increased performance. Recall temporal demand refers to how much time pressure participants felt due to the pace at which the task occurred (Hart & Staveland, 1988). The rate of speech for the AZBio sentences is 4.4 to 5.1 syllables per second, which is representative of the average conversational speaking rate (Spahr et al., 2012). This means that on average, participants reported less temporal demand with an increased SNR, and the pace of the speech remaining the same. Additionally, participants that demonstrated a ceiling effect in the Without T-coil conditions still reported improved performance on the NASA-TLX for the t-coil conditions.

Upon verification of the hearing aid participants' t-coils, it was revealed that all of the participants' t-coils did not meet the ANSI (S3.22) standard in that the t-coil frequency output did not match the microphone frequency output. However, research has shown a significant improvement in speech recognition as measured by AZBio sentences and CNC words for twenty adults with hearing loss when using a programmed t-coil (microphone frequency output matched the t-coil frequency output) in comparison to a default t-coil (Ledda, Valente, Oeding, & Kallogjeri, 2019). There are currently no clinical guidelines from the American Academy of Audiology or American Speech-Language and Hearing Association for verifying t-coils. However, the findings of Ledda and colleagues (2019) suggest that participants in this study could have had better speech perception scores and or different subjective outcomes if their hearing aid t-coils were programmed to ANSI standards.

Another important finding of this study was that some focus groups participants described there being a lack of societal education regarding hearing loops and that many people with t-coils are not aware of this feature or how to use it. Focus groups participants recalled that they learned about t-coil and loops from local hearing loss support organizations, and not their hearing health care professionals. This topic was also discussed by Ross (2004) who stated that this issue of the lack of education is related to the fact that many hearing health care professionals dispensing hearing aids only think of t-coils for the purpose of a landline phone use and neglect to think about t-coils as a convenient assistive listening system.

Additionally, t-coils and hearing loops need to be thought of as interdependent. That is, if facilities do not provide induction loops universally, the amount of benefit one can gain from t-coils diminishes (Ross, 2004). Similarly, if hearing aids do not have t-coils, then there is less motivation for facilities to provide a hearing loop. Thus, there are multiple critical elements needed for a person to experience benefits from a t-coil. Benefits from a t-coil require a facility with a working hearing loop, amplification with an active t-coil and willingness to use it.

One strength of this study design is that it included the engagement of community partners and the approach of patient-centered outcomes research. During the focus groups (phase two), adults with hearing loss who are actively use hearing loops in the community were able to express their experiences with hearing loops and to document these for research purposes. Furthermore, the PCOR approach lead to the selection of the subjective and behavioral measures for phase three based on outcomes from phase two.

It is not possible to investigate qualitative outcomes on hearing loops without involving participants who have accessed and used this assistive listening system. To address potential concerns with sampling bias, care was taken to use neutral language in the recruitment of participants regarding their experience with hearing loops rather than specifically recruiting in the context of statements regarding benefit. It could be argued that the positive results from the focus groups were due to the fact that the community organizations have many advocacy efforts for hearing loops. To avoid potential sampling bias the recruitment for the subsequent phase was broadened and included participants who are not affiliated with the local hearing loss support organizations.

Although the findings from this study provide a starting point for further patient-centered outcomes research surrounding the benefit of t-coils, the current study does have a few limitations. For one, the sample size of this study was small, with five participants and the audiometric data presented had a large variation (moderate to profound). However, the large variation in audiometric data was partially due to the ecological design as many members in the community that use hearing loops wear cochlear implants. The effect size and generalizability should be further evaluated with a larger cohort study based on the means and standard deviations from this pilot study.

Furthermore, speech perception was tested using only one AZBio list (20 sentences) for each noise condition (one list for noise, one list for quiet). Spahr and colleagues (2012) have demonstrated that confidence intervals are reduced when two lists are used instead of one list per condition. In particular, when using one list there has to be a score change of 15% points in order for the change to be significant were as with the use of two list there only has to be an 11% points change for the difference to be significant whereas (Spahr et al., 2012). Therefore, in this study, the difference between average scores between Without T-coil and T-coil Scores in quiet (T-coil+Room or T-coil Only) are not significant and would not have been even with using two sentences list for the same scores. However, in noise, the difference between average Without T-coils score and average T-coil scores (T-coil+Room or T-coil only) would have been significant with the use of two sentence lists per noise condition. Consequently, future studies assessing the benefit of looping should use two instead of one AZBio list per condition.

Given that a ceiling effect was achieved for some participants further research needs to be conducted under more difficult SNR to evaluate the speech perception and workload benefit of t-coils. Initially, the +10 dB SNR was chosen as it was used in prior studies that evaluated assistive listening systems benefit (Alfakir et al., 2015). By avoiding the ceiling effect and using a lower SNR a more sensitive measure of t-coil benefit could potentially be achieved as this would change one's performance level on the psychometric function. However, Wu, Stangl, Chipara, Hasan, Welhaven, and Oleson (2018) reported the mode SNR value of +10 dB for 894 situations measured from twenty older adults with mild to moderate hearing loss as measured by a chest level microphone in daily life for five to six weeks. Interpreting the findings of Wu et al. (2018) in context of the current pilot study additional noise condition SNRs to be evaluated could include SNRs between +2 and +8 dB.

In addition, verification measures of the hearing aids and t-coils revealed that a majority of hearing aids and t-coils were under-target. However, while there are clinical guidelines for fitting hearing aids there is currently no clinical guideline for fitting or verifying t-coils. The American Academy of Audiology does state in their 2011 clinical guidelines for remote microphone hearing technologies for children and youth that a supplement for fitting and verifying hearing loops is under development. Nevertheless, research has documented that speech perception scores improve when t-coils are fit to match the frequency output of the hearing aid microphone (Ledda et al., 2019). In this study, user settings were not changed to fit the hearing aids and t-coils to target as that would abolish the ecological validity of the design. Despite the hearing aids and t-coils being on average under-target, t-coil benefit was still observed. In the future, one may consider changing user settings to match them to prescriptive targets and ANSI standards, as this could remove a confounding variable at the expense of ecological validity.

Similar to Alfakir and colleagues (2015), this study did not take into consideration participants' experience with t-coils and their study even included two participants whose hearing aids did not have a t-coil. Therefore, some of our participants may have used t-coils regularly and had experience with them over others who may have hardly ever used their t-coil. It is unknown whether there is an acclimatization or adjustment period for t-coil listening in the same way as for acoustic listening with a hearing aid or cochlear implant (Dillon, 2012).

Lastly, many participants from the focus groups in phase two noted that they learned about t-coils and loops from local hearing loss support organizations. While this is an important resource for patients and community members, it is important to remember that not all patients nor communities have access to h support group. Additionally, some states such as Arizona do require that clinicians and patients acknowledge whether they have an active t-coil, inactive t-coil, or no t-coil. However, not all states require that their hearing health care professionals counsel patients on t-coils and hearing loops or include this information in their Bill of Sale. Future researchers should consider surveying hearing health care professionals regarding their self-confidence in counseling patients regarding t-coil/loops and verifying them to ANSI Standards as this is perhaps a gap in hearing health care professionals' clinical education and training.

Clinical Implications and Conclusion

Given that hearing loss can affect one's quality of life and impacts 38.65 million Americans people ages 60 years and older (Goman & Lin, 2016) it is increasingly important that patients have access to assistive listening systems such as a t-coils to prevent them from further activity restrictions and participation limitations. Audiologists, as hearing health care providers, can help by dispensing hearing aids with t-coils, verifying t-coils, counseling patients on how to use a t-coil, and providing education to patients and community members about using t-coils as assistive listening systems.

This pilot study demonstrates that adults with hearing loss, can benefit by using a t-coil in terms of speech perception and perceived workload. It also found that even when patients experience a ceiling effect as measured by speech perception scores, they can still show benefits in terms of perceived performance and temporal demand. This finding suggests that clinicians should look beyond speech perception scores when recommending whether their patients should have t-coil capabilities in their device.

In conclusion, this doctoral project brings together three phases of research on the potential benefit of hearing loops in a classroom for adults with hearing loss using a patient-centered outcomes research approach. This study begins to fill in gaps in previous limited research and addresses patient and community concerns. If this study where to continue in the future, it has the potential to bridge a gap in evidence-based practice regarding hearing aid and cochlear implant technology selection.

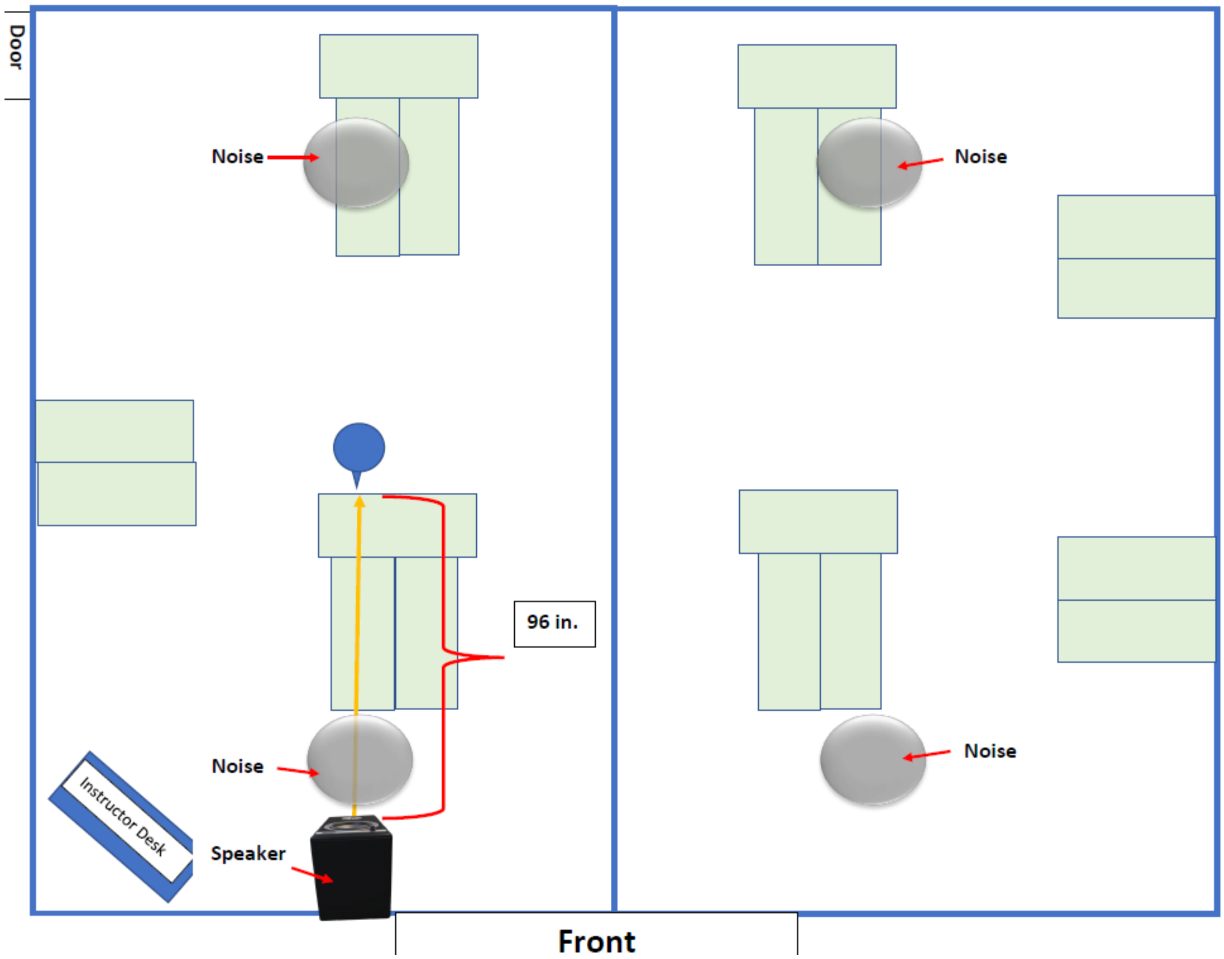
APPENDIX A

QuickSIN and WARRM Scores for Each Participant

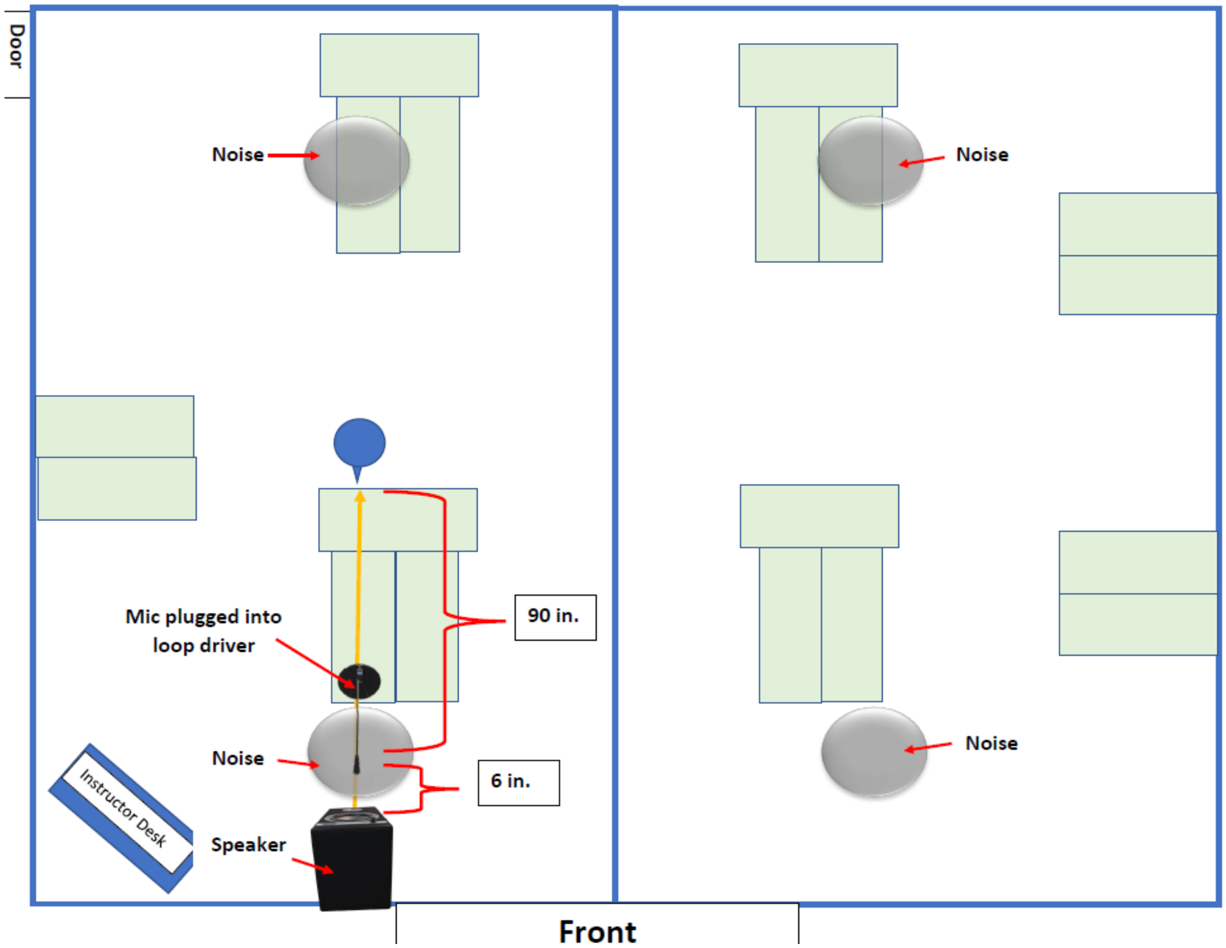
	QuickSin SNR Loss (dB)	WARRM (% Correct)		
		Word Recognition	Judgment	Recall
Cochlear Implant Users				
Participant 2	-------------------------	79	79	46
Participant 5	-------------------------	83	86	45
Hearing Aid Users				
Participant 3	10	71	71	45
Participant 4	5	92	92	50
Participant 6	4.5	95	95	54

APPENDIX B

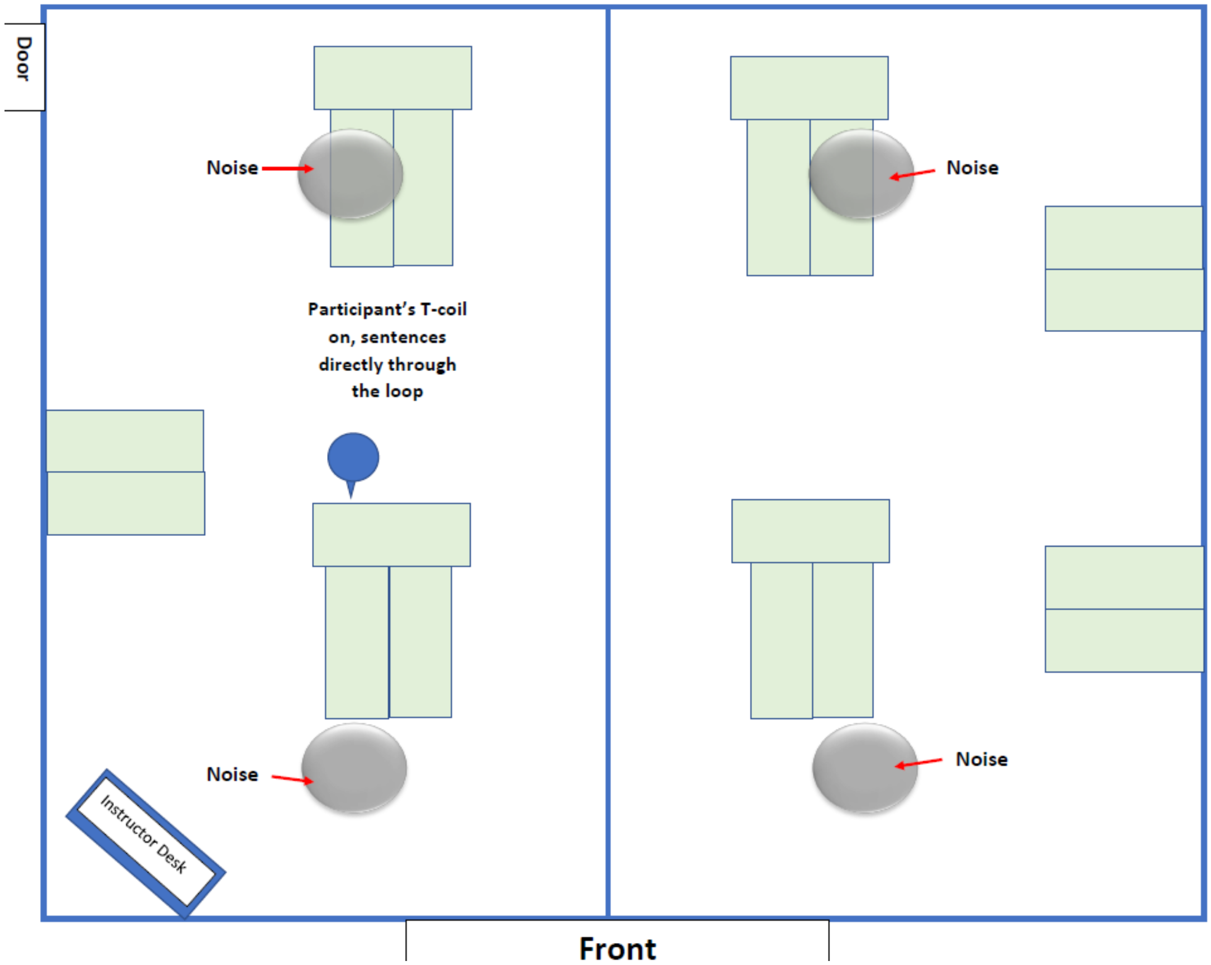
Overhead View of Condition One (Without T-coil)



Overhead View of Condition Two (T-coil+Mic)

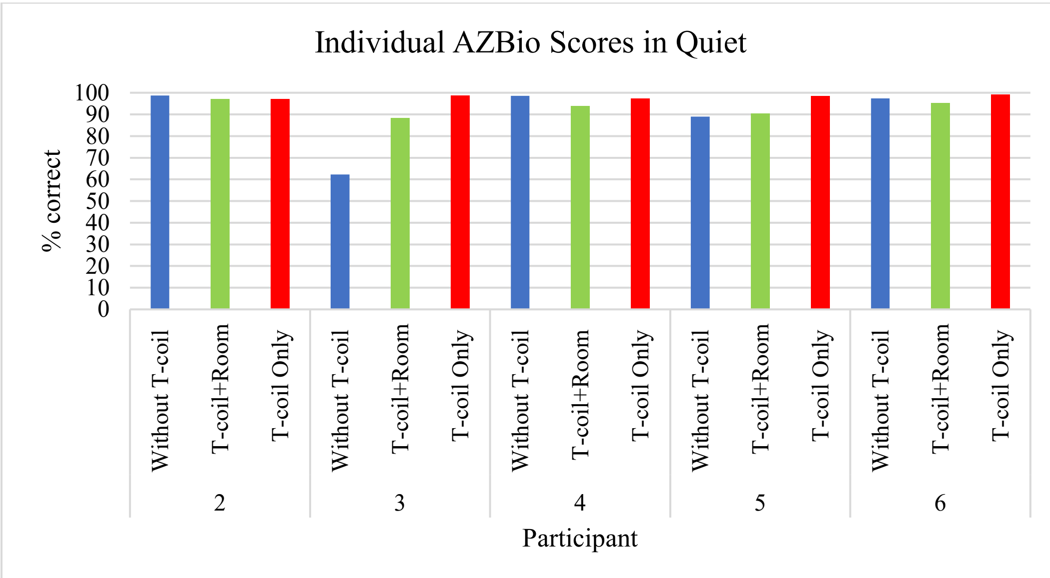


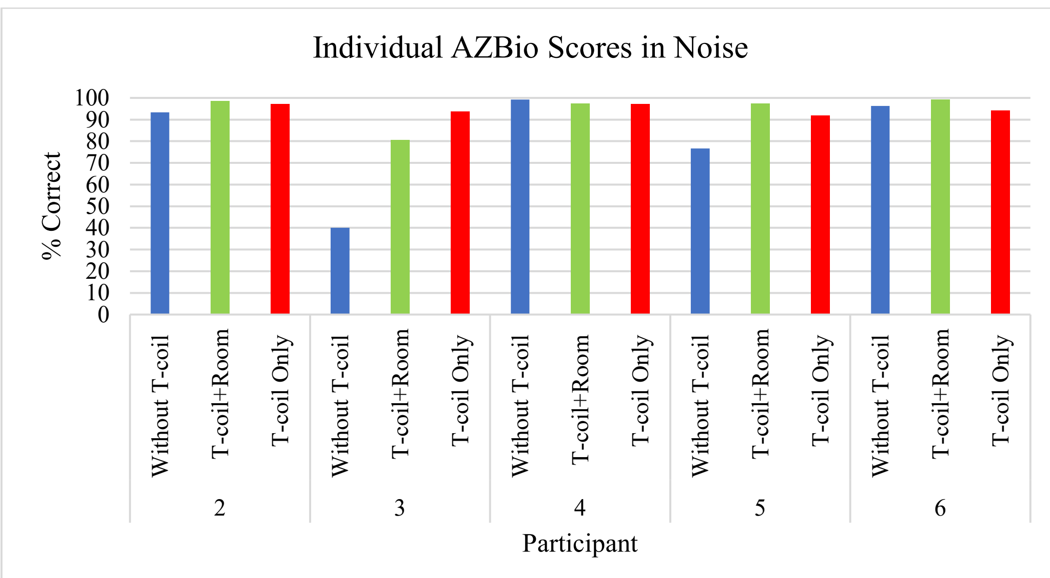
Overhead View of Condition Three (T-coil Only)



APPENDIX C

AZBio Individual Participant Scores





APPENDIX D

Individual Participant Benefit Scores

Measure	AZBio Benefit Score in Quiet		AZBio Benefit Score in Noise		Temporal Demand Benefit (NASA-TLX)		Performance Benefit (NASA-TLX)	
T-coil Condition	T-coil+Room	T-coil Only	T-coil+Room	T-coil Only	T-coil+Room	T-coil Only	T-coil+Room	T-coil Only
Cochlear Implant Users								
Participant 2	-1.6	-1.6	5.4	3.9	70	70	-10	-70
Participant 5	1.4	9.5	20.9	15.3	160	160	80	70
Hearing Aid Users								
Participant 3	26	36.4	40.7	53.8	160	160	325	325
Participant 4	-4.8	-1.3	-1.8	-2.2	-30	20	10	10
Participant 6	-2.2	1.9	3	-2	-25	15	30	0

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