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# Difference in Speech Recognition between a Default and Programmed Telecoil Program

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**Abstract**

**Background:** Hearing loss can lead to isolation and social withdrawal. The telephone oftentimes connects persons with hearing loss to society; however, telephone use is impeded by narrow bandwidth, loss of visual cues, electromagnetic interference, and inherent phone-line noise. In the past, research assessing telephone communication has consistently reported that switching from the microphone to a telecoil will typically result in the acoustic signal being discernibly softer. Properly used telecoils improve the signal-to-noise ratio (SNR), decrease the chance for acoustic feedback, and overcome the impact of distance and reverberation creating an opportunity for clearer telephone communication. Little research, however, has examined matching the telecoil frequency response to the prescribed target of the microphone frequency response (National Acoustics Laboratories, Non-Linear, version 1 [NAL-NL1]).

**Purpose:** The primary goal of this study was to determine if differences exist in speech recognition for sentences (AZ-BIO) and consonant–vowel nucleus-consonant monosyllabic words (CNC) between two telecoil conditions (default and programmed). A secondary goal was to determine if differences exist in speech recognition for sentences between male and female talkers.

**Research Design:** A single-blinded randomized controlled trial.

**Study Sample:** Twenty experienced adult hearing aid users with bilateral symmetric slight to severe sensorineural hearing loss were recruited from Washington University in St. Louis School of Medicine. In addition, ten normal-hearing participants were recruited to determine the presentation level of the speech stimuli for the hearing aid participants.

**Data Collection and Analysis:** Participants underwent real-ear measures to program the microphone frequency response of a receiver-in-the-canal hearing aid to NAL-NL1. Using the manufacturer software, one telecoil program remained as the manufacturer default and a second telecoil program was programmed so the sound pressure level for an inductive telephone simulator frequency response matching the microphone's frequency response to obtain as close to a 0 dB relative simulated equivalent telephone sensitivity value as possible. Participants then completed speech recognition measures including AZ-BIO sentences (male and female talkers) and CNC monosyllabic words and phonemes, using both telecoil programs. A mixed model analysis was performed to examine if significant differences in speech recognition exist between the two conditions and speech stimuli.

**Results:** Results revealed significant improvement in overall speech recognition for the programmed telecoil performance compared with default telecoil performance ($p < 0.001$). Also, improved performance in the programmed telecoil was reported with a male talker ($p < 0.001$) and performance for sentences compared with monosyllabic words ($p < 0.001$) or phonemes ($p < 0.001$).

**Conclusions:** The programmed telecoil condition revealed significant improvement in speech recognition for all speech stimuli conditions compared with the default telecoil (sentences, monosyllables, and phonemes). Additional improvement was observed in both telecoil conditions when the talker was male.



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**Key Words:** amplification, hearing aids, telecoil, telephone

**Abbreviations:** ANSI = American National Standards Institute; CI = confidence interval; CNC = consonant–vowel nucleus–consonant; EM = electromagnetic; HRPO = Human Research Protection Office; mA/M = milliampere per meter; NAL-NL1 = National Acoustic Laboratories nonlinear version 1; REM = real ear measures; REUG = real-ear unaided gain; RSETS = relative simulated equivalent for telephone sensitivity; SD = standard deviation; SNR = signal-to-noise ratio; SPL = sound pressure level; SPLITS = sound pressure level for an inductive telephone simulator; T/M = telecoil/ microphone split program; TMFS = telephone magnetic field simulator; WRS = word recognition score

## INTRODUCTION

Hearing loss impacts 360 million people worldwide (World Health Organization, 2012). Hearing loss can lead to isolation, detachment, and social withdrawal (Dalton et al, 2003). Advancements in medicine and technology allow people to live longer and more independently. With independence, there may be an increased dependence on the telephone as a source of contact with friends, family, business, and health-care and legal providers. Telephone use by patients with hearing loss can be difficult because of limitations in telephone performance and the challenges associated with hearing loss.

The telecoil is a feature to assist hearing aid users with using the telephone without any additional battery drain or requiring the user to purchase or wear any special devices or accessories. Although the telecoil is considered older technology compared with Bluetooth® streaming technology, it is still a viable option as reflected in a recent update to chapter 24 of the Delaware Code. This update requires audiologists to educate patients about the benefits of the telecoil in addition to providing written information about venues with telecoil access, telephone compatibility, and additional assistive listening technology at the time of the initial evaluation (Delaware Code § 24, 2016).

The telecoil was engineered to provide a coupling mechanism between hearing aids and the telephone. Integrated into hearing aids for the first time in 1938, telecoils rely on electromagnetic (EM) leakage emitted from telephone receivers to operate (Lybarger, 1947; Ross, 2005; Levitt, 2007). The telecoil is a small coil of wire wrapped numerous times around a metal pole. To complete the transmission process, the EM leakage from the telephone receiver is detected by the telecoil. In turn, the EM leakage generates an electric current as it flows through the telecoil, is amplified and then transduced to an acoustic signal. This acoustic signal is then heard by the user via the hearing aid receiver (Yanz and Preves, 2003; Ross, 2005). When active, the telecoil picks up only the EM signal from the telephone and nothing from the microphone.

The telecoil is the coupling method to the hearing aids for the telephone and is also used for signal transmission to the hearing aids from room and neck loops. Room loops send the signal from a microphone to an amplifier that sends a current to the perimeter loop; thus, creating an EM field which is picked up by the hearing aid telecoil (McBride, 2014). Alternatively, if room loops are not available, a loop of wire can be worn around the neck of the hearing aid user to create an EM field so the hearing aid can pick up the signal from the microphone or audio device. According to Kochkin et al (2014), 70% of respondents of a survey stated induction loops improved sound quality, speech recognition, concentration, and reduced the effect of background noise. Both of these additional listening conditions require a telecoil to transmit the signal to the hearing aids and have the benefits as telecoil to telephone coupling (i.e., no acoustic feedback and improved signal-to-noise ratio [SNR]).

Using a telecoil can provide significant benefit to the user who will no longer hear amplified background noise through his/her hearing aid, thus creating an improved SNR (Ross, 2005). Because the telecoil is an integrated feature that uses induction instead of Bluetooth® streaming, there is no additional hearing aid battery drain. Another benefit of the telecoil is that this feature eliminates acoustic feedback. Feedback occurs when the microphone of the hearing aid is placed against a surface causing the acoustic signal of the hearing aid to be reamplified (Preves, 1994). Specific limitations of telephones affecting patients with hearing loss include narrow bandwidth, amount of EM signal strength, inherent noise in the phone line, and reduced visual cues. Specific hearing aid–related limitations include the telecoil orientation within the hearing aid(s) (Mueller et al, 1992). Additional user challenges include optimal placement of the telephone handset adjacent to the telecoil, low telecoil activation rate and remembering to change the hearing aid from the microphone program to the telecoil program, and then returning to the microphone program on completion of the telephone conversation if an automatic telecoil is not available (i.e., for room loops or weaker telecoil signals). Telecoil orientation is important for optimal signal transmission, where vertical telecoil placement is best for induction loop systems and horizontal placement is best for telephone use because these orientations are parallel to the EM leakage. Limited bandwidth of 250–3000 Hz adds an additional challenge to telephone listening by limiting the high-frequency emphasis contained in many consonants and reducing some of the low fundamental frequencies causing an unnatural listening experience (Barnett, 1999; Rix and Hollier, 1999). These limitations compounded with the inability to use visual cues during telephone conversations negatively effects speech recognition.

Current nonclinical strategies to improve telecoil program performance over the identified telephone/telecoil limitations include increasing volume on the hearing aid or telephone, moving the handset away from the ear, removing the hearing aids or using the speakerphone on a cellphone or landline telephone (Compton, 1994). Clinical fitting strategies can be used to enhance the telecoil feature beyond ordering hearing aids with telecoil integrated in them. Dissatisfaction with telecoil performance was investigated by Tannahill (1983), and Rodriguez et al (1985; 1991; 1993) who repeatedly found that the default telecoil output strength was lower compared with the microphone frequency response. These studies suggest that when a patient switches from the microphone to the telecoil the acoustic signal from the telephone will be audibly softer. Most audiologists do not verify microphone performance to a validated prescriptive target (Mueller and Picou, 2010) and because the telecoil frequency response is typically based on the microphone frequency response, this simply compounds the problem. This practice will often lead to a microphone frequency response that is below a validated prescriptive target causing the telecoil signal to be amplified softer than the microphone signal.

Currently, there is no best practice for programming the telecoil. The need to further investigate how the telecoil is programmed is justified by the use of the telephone by hearing aid users who continue to express overall low telecoil satisfaction. In addition, to the best of our knowledge the following study aims have not been investigated. The present study investigated differences in speech recognition for sentences and words between a telecoil programmed to match the frequency response of the microphone previously programmed to a valid prescriptive target and manufacturer default. A second question focused on possible differences based on the gender of the talker and differences between male and female speech stimuli.

Considering these questions, the primary null hypothesis of the investigation is that no significant differences will be present in speech recognition for sentences, CNC words and phonemes, or the gender of the talker between a programmed and default telecoil. A secondary null hypothesis of the investigation is that no significant differences will be present in speech recognition for sentences, CNC words and phonemes, or the gender of the talker within a programmed and default telecoil.

## METHODS

### Participants—Normal Hearing

Ten normal-hearing participants were recruited to determine the presentation level of the speech stimuli for the participants with hearing aid experience. These participants were recruited from Washington University in St. Louis School of Medicine via word of mouth and a community flier approved by Human Research Protection Office (HRPO). Each participant signed an informed consent form approved by HRPO at the initial visit. To qualify, each participant was required to (a) have hearing thresholds ≤20 dB HL at octave and mid-octave frequencies from 250–8000 Hz, (b) be at least 18 years old, and (c) be a native English speaker. Pure-tone air conduction screening was completed for each ear at 20 dB HL at 250–8000 Hz.

### Participants—Experienced Hearing Aid Users

Twenty experienced hearing aid users were recruited from the Division of Adult Audiology at Washington University in St. Louis School of Medicine via personal communication in the clinic, telephone, community flier, or a letter approved by the HRPO. Each participant signed an informed consent approved by HRPO at the initial visit. To qualify, each participant was required to (a) have a slight to severe bilateral symmetrical sensorineural hearing loss, (b) word recognition scores (WRSs) ≥60% in the test ear, (c) at least 1 month of consistent hearing aid use, (d) ≥18 years old, and (e) be a native English speaker. Participants were excluded if they had (a) no previous hearing aid use, (b) asymmetrical hearing loss, (c) unilateral hearing loss, or (d) conductive hearing loss.

A comprehensive audiometric evaluation via pure-tone audiometry from 250–8000 Hz in octave and mid-octave frequencies, speech recognition thresholds, and WRSs was completed to determine if a participant qualified for the study if a previous audiometric evaluation had not occurred within 6 months before entering the study. Mean hearing thresholds of the test ear (±1 standard deviation [SD]) are shown in Figure 1 for the seven female (mean = 69 years; SD = 12.6 years; range = 50–82 years) and 13 male (mean = 74.5 years; SD = 6 years; range = 64–86 years) hearing aid user participants. The mean hearing aid use experience was 3.5 years (SD = 4.9 years; range = 0.25–15 years).

### Equipment

The Frye 8000 hearing aid test system was used to complete real-ear measures (REM) to program the test aid to a prescriptive target for each participant. The Frye was also used to complete 2cc coupler measures to assess the performance of various hearing aid features.

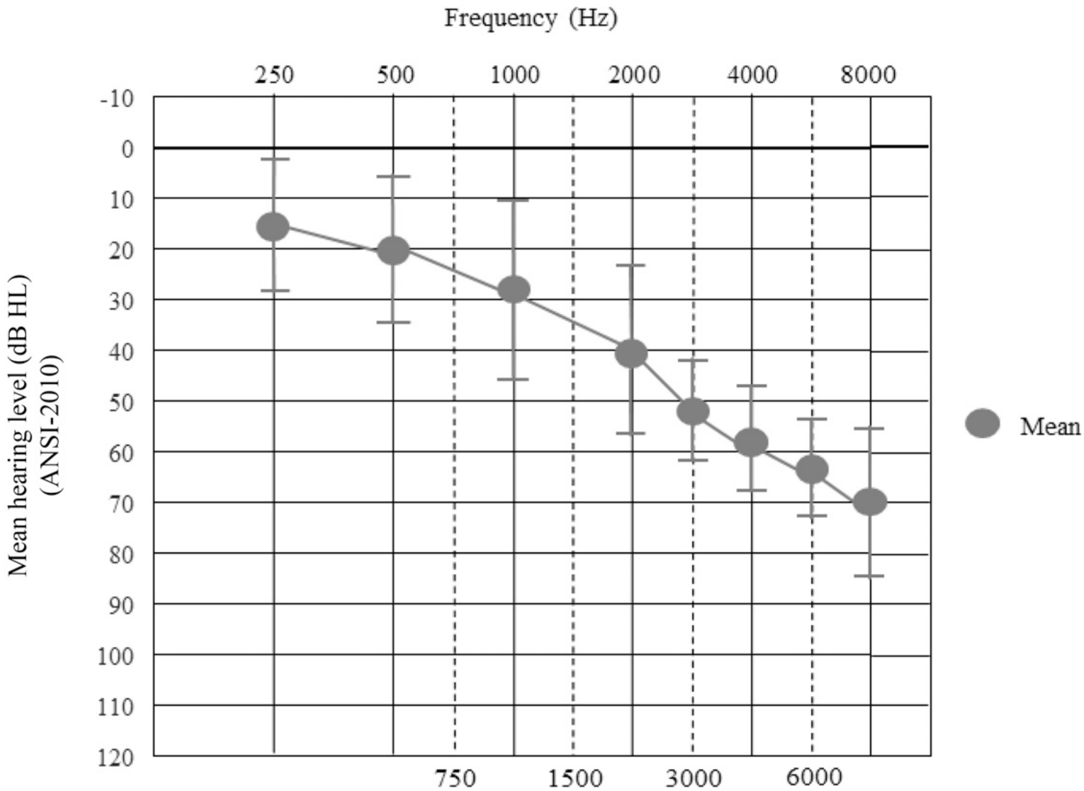


**Figure 1.** Mean hearing threshold levels for test ear of the hearing aid participants. Error bars = ±1 SD.

Widex Unique 440 Fusion receiver-in-the-canal hearing aids were used as the test hearing aids for the study. This hearing aid was selected because it has the ability for real-time programming (eliminating the need to save and disconnect to test whenever a change is made in the software) and has 15 channels, digital noise reduction, and directional microphones. Each participant had the hearing aid coupled to his/her ear with a dome appropriate for the size of the ear canal and degree of hearing loss. Open-fit domes were used in 8 participants and closed domes were used in 12 participants.

The Rainbow Passage (Fairbanks, 1960), AZ-BIO sentences and CNC word lists were presented to the participants via a Lucent Avaya 6210 telephone handset (Murray Hill, NJ). The telephone handset was connected to an Ameriphone HA-40 telephone handset amplifier (Garden Grove, CA) that was connected to a JK Audio Inline Patch (Sandwich, IL) and connected to the earphone output of a two-channel audiometer as shown in the top panel of Figure 2. A SONY 5-Disc CD player (Minato, Tokyo, Japan) was connected to the audiometer via an external source (i.e., external B). The signal from the CD was transmitted to the audiometer preserving calibration as the signal was transmitted to the Lucent Avaya 6210 telephone handset mounted on a custom-made headband (bottom panel of Figure 2). The telephone handset was mounted on the headband to provide close proximity to the telecoil located in the hearing aid and to ensure the handset did not move during testing because movement of the handset would alter the loudness of the signal picked up by the telecoil.

### Assessing Presentation Level Using Normal-Hearing Listeners

Normal-hearing participants were seated in a double-walled sound suite and verification of the optimum telephone handset placement occurred. To accomplish this, a probe tube attached to a calibrated probe microphone from a Frye 8000 real-ear analyzer was inserted to approximately 4–5 mm from the tympanic membrane and then taped in place to ensure consistent placement of the probe tube when manipulating the telephone handset. The “calibrate microphone” menu was selected on the Frye 8000 and the audiometer attenuator was adjusted to 70 dB HL. Then, a 1000-Hz calibration tone was presented and the telephone handset was maneuvered against the pinna at different angles and positions until the highest dB sound pressure level (SPL) was visualized on the monitor.

The participant was then instructed to respond using a seven-point loudness scale to his/her loudness judgment of “The Rainbow Passage” (Fairbanks, 1960). The intensity of the passage was adjusted in 5-dB HL steps until a loudness judgment of 4 or “comfortable” was obtained. Once this level was obtained, the loudness judgment process was repeated using a 2-dB HL step-size until a loudness judgment


**Figure 2.** Equipment used to preserve calibration of speech stimuli from the audio CD player to the telephone handset (top panel). Telephone handset affixed to a custom-manufactured moveable headband providing consistent placement during testing of speech recognition (bottom panel). Ledda, Kimberly. "Custom-made headband." 2016. Digital File Type.

of 4, or "comfortable," was once again measured. The probe measurement, handset adjustment, and loudness judgment process using 2- and 5-dB HL step-sizes were then measured in the opposite ear. Once these most comfortable levels were measured in each ear, participation by these normal-hearing participants was complete. The mean most comfortable levels for the right ear was 60 dB HL (SD = 5.2 dB HL) and left ear was 60 dB HL (SD = 3.9 dB HL) for 5-dB HL step-size. There were no differences between mean scores obtained between the 5-dB HL and 2-dB HL step-sizes.

## Microphone Programming Using REM

To program the experimental aid (i.e., Widex Unique 440 Fusion receiver-in-the-canal), the Widex® Compass™ GPS 2.1.1134.0 programming software was used. The test ear was selected by the participant's ear preference for using the telephone. If the participant did not have a preference, the ear with the better WRS from the audiometric evaluation was used. In the event the intraear WRS values were equivalent, the participant's handedness determined the test ear. This procedure was used to provide a listening environment similar to what would be used outside of the testing environment (i.e., use of the preferred hand or ear the participant hears better with). Using the same procedure for each participant via a checklist, the hearing aid was connected to the programming software via a wireless neckloop. Once connected, in situ audiometry was performed via the Sensogram™. Then the acclimatization feature, a progressive increase in applied gain, was deactivated. Next, three programs were saved to the hearing aid: Program 1: microphone and labeled "Universal"; Program 2: programmed telecoil; and Program 3: default telecoil.

Next, Program 1 was programmed to National Acoustics Laboratories, Non-Linear, version 1 (NAL-NL1; Dillon, 1999) via REM with a Frye 8000 hearing aid analyzer (Version 2.6), after entering the participant's audiogram and correcting for a bilateral fitting and channel summation (Dillon, 1999). NAL-NL2 was not used because of a software limitation of the Frye in which only NAL-NL1 is available. The reference and probe microphones underwent quarterly calibration to ensure accuracy. All participants were seated approximately 12″ from the real-ear analyzer loudspeaker placed directly in front of the participant at a level approximately equal to the bridge of the nose. The reference microphone was placed on top of the participant's pinna and the probe tube from the probe microphone was placed in the ear canal to a depth of approximately 4–5 mm from the tympanic membrane. Then, the reference microphone, probe microphone, and loudspeaker were calibrated via the "Level" function of the analyzer.

To verify proper probe tube placement, the real-ear unaided gain (REUG) was measured. A REUG measure of approximately 0 dB (±3 dB) at 6000 Hz identified proper tube placement (Valente et al, 1991). The probe tube was held in place by tape and the REUG was remeasured and saved to ensure the placement was maintained during the taping process. The hearing aid was placed over the pinna and the receiver placed in the ear canal using the appropriate size dome. Next, the hearing aid was activated and connected to the programming software. Once connected, a 65-dB SPL DigiSpeech signal was presented though the loudspeaker to program the frequency response of the microphone to NAL-NL1. The frequency response of the microphone was programmed using the 15 bands of the experimental hearing aid to match NAL-NL1 within ±5 dB at 250–8000 Hz. The program was then saved and used as the reference to create Program 2 (i.e., programmed telecoil).

## HA-1 Coupler Measures

The programmed hearing aid was placed in the Frye 8000 test box connected to an HA-1 2cc coupler. To prevent unwanted EM interference while programming the telecoil, the lights in the testing room were turned off and the monitor was angled away from the test box. To accurately measure the relative simulated equivalent for telephone sensitivity (RSETS), a Frye telephone magnetic field simulator (TMFS) was used to deliver the EM signal to the telecoil. The RSETS is the difference (in dB) between the telephone frequency response and the microphone frequency response at 1000, 1600, and 2500 Hz. The TMFS was positioned close to the hearing aid and was manipulated until the high-frequency average of the sound pressure level for inductive telephone simulator (SPLITS) value on the Frye monitor was the highest which verified optimum hearing aid placement. The high-frequency average-SPLITS is the average of the SPLITS output at 1000, 1600, and 2500 Hz. Programming the telecoil continued until a RSETS value of 0 dB was measured and the SPLITS response matched the shape of the microphone frequency response while the hearing aid was attached to a 2cc coupler. SPLITS is the frequency response output of the telecoil with an EM input (31.6 mA/M) equivalent to the microphone at 60 dB SPL. The programming software was used to increase or decrease the output of the telecoil to match the previously programmed microphone frequency response within ±5 dB and the resulting American National Standards Institute (ANSI) S3.22-2003 measure was recorded. Next, a second ANSI S3.22-2003 sequence was completed to compare the programmed microphone response with the default telecoil SPLITS for Program 3. Thus, the completed coupler tests measured the frequency response of the programmed microphone, SPLITS and RSETS for the programmed telecoil and the SPLITS and RSETS for the default telecoil.

The graphic data for each of the three programs were converted to numerical data to obtain 100-Hz segments for data analysis. To accomplish this, the multicurve option was activated in the Frye 8000 and used to produce the three frequency response curves, programmed microphone, programmed telecoil, and default telecoil (Figure 3). A 60-dB SPL pure-tone sweep at 250–8000 Hz was presented with the hearing aid in Program 1, which created a frequency response curve of the microphone labeled as "Curve 1."

For the two telecoil SPLITS frequency responses, the signal parameters of the test box were changed. On the test box, "Curve 2" was selected, Program 2 (i.e.,

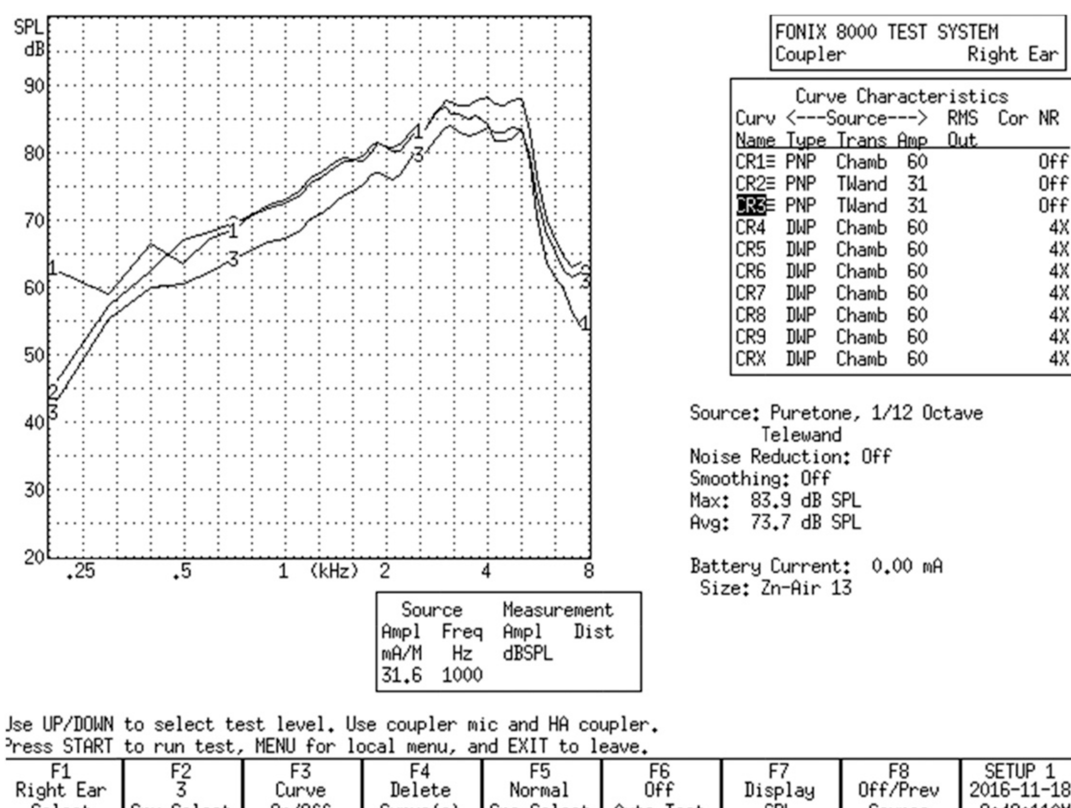


**Figure 3.** Frye 8000 multicurve graph showing the three response curves for a participant. Curve 1 is the microphone frequency response, Curve 2 is the programmed telecoil frequency response, and Curve 3 is the default telecoil frequency response.

programmed telecoil) was activated on the hearing aid, the selected transducer to be used was changed to telewand (TMFS), and the EM field signal strength selected to 31.6 mA/M, which is the equivalent input level for a 60 dB SPL acoustic signal. The resulting curve was the SPLITS and RSETS for Program 2 (i.e., programmed telecoil). Finally, "Curve 3" was selected Program 3 was activated on the hearing aid, the telewand remained the selected transducer, and the signal strength remained at 31.6 mA/M. The resulting curve was the SPLITS and RSETS for Program 3 (i.e., default telecoil). Each of these curves were converted to data format in the Frye 8000 software and inputted into a spreadsheet.

### Measuring Speech Recognition

Participants in the hearing aid user group were randomly assigned and blinded to each of the two telecoil conditions to control for order and learning effects. Once the first telecoil condition was completed, the participants crossed over to the other telecoil program. All 15 AZ-BIO test lists were eligible to be used for the study and nine of ten CNC lists were eligible to be used for the study (list 9 was excluded). The order of the test conditions, the order of the CNC, and AZ-BIO sentence lists were also randomized.

Using the probe microphone already placed in the participant's ear canal from the previous real-ear measure, the optimal telephone handset placement was determined. The hearing aid housing was placed on the participant's pinna and the receiver was inserted in his/her ear canal. The participant then placed the headband attached to the telephone handset on his/her head with the handset resting on the hearing aid housing. Under the "microphone calibration" screen in the Frye 8000, the corresponding right or left probe microphone was selected. On the audiometer, the intensity dial was placed at 70 dB HL and a 1000-Hz calibration tone was presented. The telephone handset was maneuvered against the hearing aid at different angles and positions until the highest dB SPL value was obtained relative to other positioning attempts. The participant was then instructed to leave the handset in that position while the first telecoil condition was selected on the hearing aid based on the randomization strategy.

The participant was instructed to repeat the words or sentences presented via the telephone. The AZ-BIO sentence list and CNC word list determined by the randomization was presented at an intensity of 60 dB HL, which was measured at 72 dB SPL at the head outside the ear canal via probe measures. The CNC words were recorded by a native male English speaker and presented in quiet. These phonetically balanced word lists comprise monosyllable words structured in the consonant–vowel nucleus–consonant pattern (Lehiste and Peterson, 1959). The AZ-BIO sentences were recorded by two male and two female native English speakers and presented in quiet. The average speaking rate ranged from 4.4 to 5.1 syllables per second which is representative of the average conversational speaking rate (Spahr et al, 2012). After one half-list of 25 CNC words and one list of 20 AZ-BIO sentences were completed, the other telecoil condition was activated and a second half-list of CNC words and full list of AZ-BIO sentences were presented.

Each word repeated correctly for the AZ-BIO was counted to generate a total percent correct score. Then, each word repeated correctly for the male talker was separated from those repeated correctly for the female talker to generate male and female total scores. For the CNC test, each word spoken by the participant was written by the investigator. The total number of correct words was used to calculate the total percent correct score and each correct phoneme was calculated for the total percent phoneme score. For example, if the test word was "nice" and the participant said "lice," the word would not be counted toward the total percent correct score but two correct phonemes would count toward the total correct phoneme score.

### Data Analysis

Data distribution was explored through histograms and analyzed through the Kolmogorov–Smirnov test. Median and range were used to describe distribution of the scores for each test at each condition. A Wilcoxon signed rank test was used to test for significant differences between the test conditions, and the median of the pairwise differences and the 95% confidence interval (CI) are reported as a measure of effect size. Box and whisker plots were used to graphically display and compare the distribution of scores. In addition, a mixed model analysis using the SAS Proc Mixed procedure was applied to the data to explore possible significant differences between the main effects and interaction of the two conditions (programmed and default) and the speech tests (AZ-BIO total, male and female talkers; CNC words and phonemes). The mixed model analysis allows for accommodation of fixed and random effect factors and exploration of interactions. Participants were the only random factor in the mixed model and an autoregressive covariance structure was used to accommodate the hierarchical design with nested repeated measures.

## RESULTS

### Programmed versus Default Telecoil Conditions

#### *AZ-BIO Total Score*

The median, minimum, and maximum AZ-BIO total scores (% correct) for the programmed and default telecoil conditions are reported in the whisker box plot in Figure 4. For the programmed fitting, a median score of 92.8% (minimum = 51.0%; maximum = 96.6%) was revealed whereas for the default fitting a median score of 86.7% (minimum = 27.0%; maximum = 91.3%) was revealed. A significant median advantage of 8.9% (95% CI = 5.8–11.9%; $p < 0.001$) favoring the programmed fitting was revealed by the Wilcoxon signed ranks test.

### *AZ-BIO Male Talker*

The median, minimum, and maximum AZ-BIO male talker scores (% correct) for the programmed and default telecoil-fitting strategies are reported in the whisker box plot in Figure 5. For the programmed fitting, a median score of 96.2% (minimum = 66.7%; maximum = 100%) was revealed whereas for the default fitting, a median score of 89.0% (minimum = 35.3%; maximum = 97.1%) was revealed. A significant median advantage of 6.9% (95% CI = 3.2–14.4%; $p < 0.001$) favoring the programmed fitting was revealed by the Wilcoxon signed ranks test.

### *AZ-BIO Female Talker*

The median, minimum, and maximum AZ-BIO female scores (% correct) for the programmed and default telecoil fitting strategies are reported in the whisker box plot in Figure 5. For the programmed fitting, a median score of 89.7% (minimum = 34.8%; maximum = 97.2%) was revealed whereas for the default fitting, a median score of 80.8% (minimum = 15.1%; maximum = 90.3%) was revealed. A significant median advantage of 8.3% (95% CI = 5.2–12.9%; $p < 0.001$) favoring the programmed fitting was revealed by the Wilcoxon signed ranks test.

### *Consonant–Nucleus–Consonant (CNC)*

*Words:* The median, minimum, and maximum CNC word score (% correct) for the programmed and default

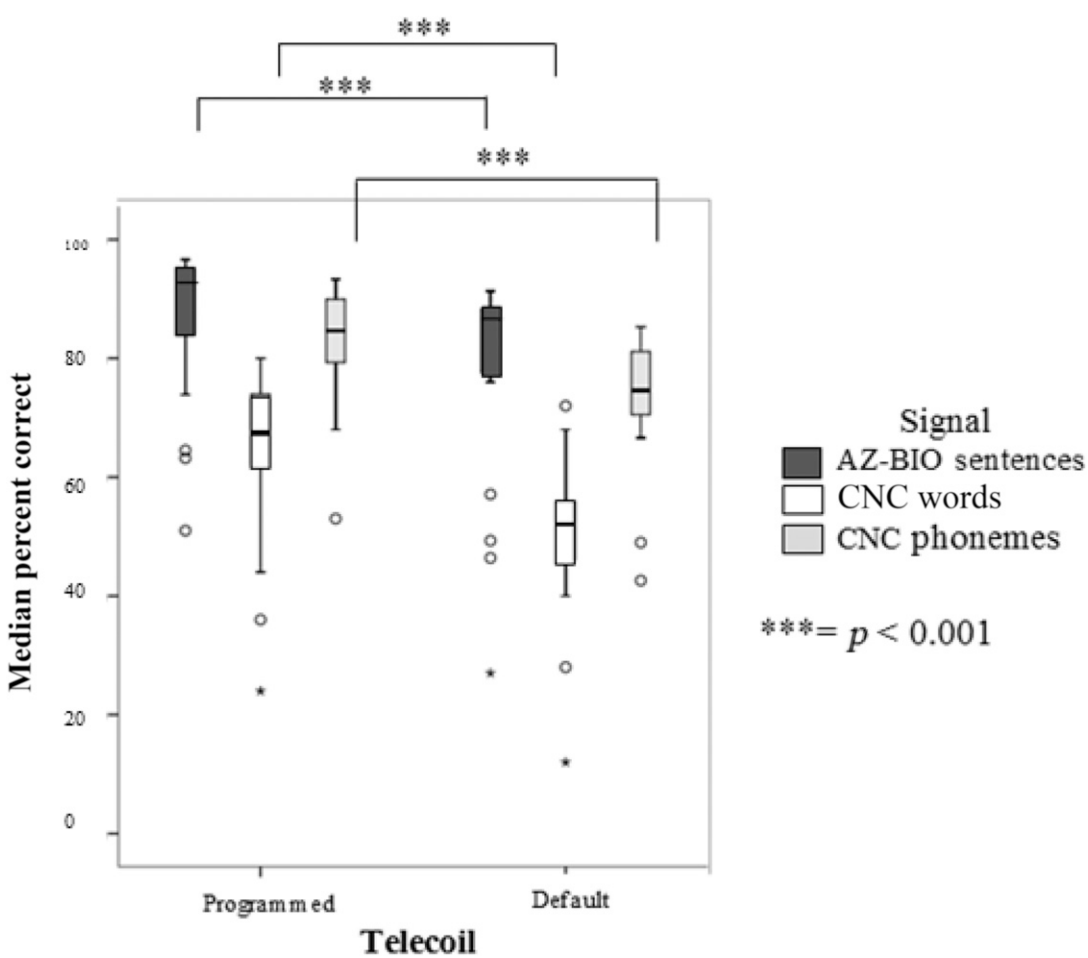


**Figure 4.** Median percent correct for AZ-BIO, CNC Words, and CNC Phonemes for the programmed and default telecoil conditions. In each box whisker plot, the black horizontal line represents the median; the upper and lower boundaries of the box represent the 75th and 25th percentiles, respectively. The whiskers expand 1.5 box lengths below and above the interquartile range. The circles and stars are outliers. ***$p < 0.001$.

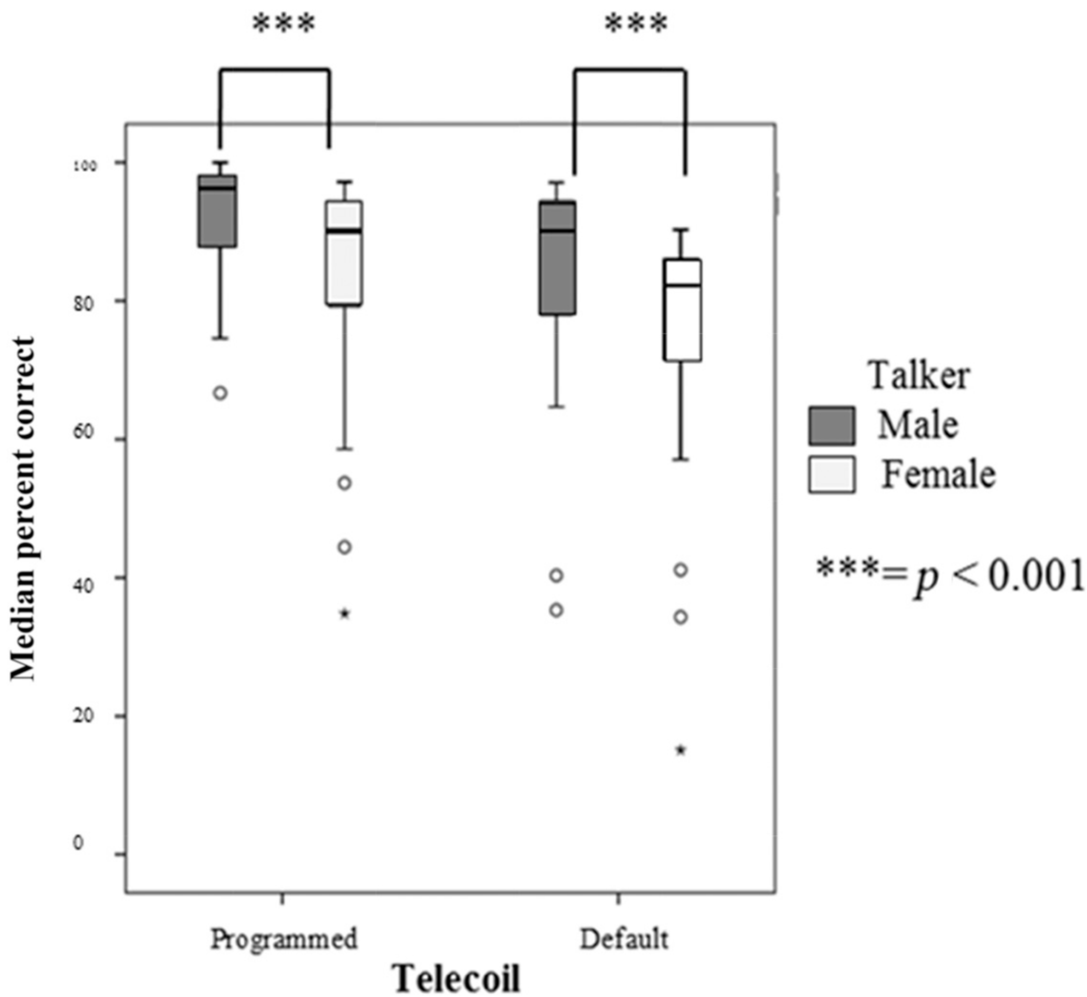


**Figure 5.** Median percent correct for male and female talkers for the programmed and default telecoil conditions. In each box whisker plot, the black horizontal line represents the median; the upper and lower boundaries of the box represent the 75th and 25th percentiles, respectively. The whiskers expand 1.5 box lengths below and above the interquartile range. The circles and stars are outliers. ***$p < 0.001$.

telecoil conditions is reported in the whisker box plot in Figure 4. For the programmed fitting, a median score of 68.0% (minimum = 24.0%; maximum = 80.0%) was revealed whereas for the default fitting a median score of 52.0% (minimum = 12.0%; maximum = 72.0%) was revealed. A significant median advantage of 16.0% (95% CI = 10.0–20.0%; $p < 0.001$) favoring the programmed fitting was revealed by the Wilcoxon signed ranks test.

*Phonemes:* The median, minimum, and maximum AZ-BIO total score (% correct) for the programmed and default telecoil conditions are reported in the whisker box plot in Figure 4. For the programmed fitting, a median score of 84.7% (minimum = 53.0%; maximum = 93.3%) was revealed whereas for the default fitting a median score of 74.6% (minimum = 42.6%; maximum = 85.3%) was revealed. A significant median advantage of 9.0% (95% CI = 6.2–12.0%; $p < 0.001$) favoring the programmed fitting was revealed by the Wilcoxon signed ranks test.

## Sentences versus Words

The mixed model analysis using the SAS Proc Mixed procedure explored differences in percent correct scores for AZ-BIO, CNC Words and CNC phonemes across the two telecoil conditions (programmed and default). The interaction between the speech tests and telecoil conditions was not significant ($p = 0.1048$). There was, however, a significant main effect of speech tests ($p < 0.001$) independent of telecoil program. Specifically, the marginal mean percent correct for total AZ-BIO sentences was 25.3% greater than CNC words (95% CI = 21.1–29.4%; $p < 0.001$) and 4.6% greater than CNC phonemes (95% CI = 1.3–7.9%; $p = 0.007$). Also, the marginal mean CNC phonemes were greater than the mean CNC words by 20.6% (95% CI = 18.4–22.9%;

$p < 0.001$). In addition, there was a significant main effect of telecoil condition ($p < 0.001$). That is, independent of speech tests, the programmed telecoil was the higher performing condition by a mean of 10.8% (95% CI = 8.5–13.0%; $p < 0.001$).

The mixed model analysis also explored differences in percent correct scores between the male and female talker on the AZ-BIO and between the two telecoil conditions. The interaction between talker and conditions was not significant ($p = 0.8625$). There was, however, a significant main effect of the gender of the talker ($p < 0.001$) indicating that independent of the condition, the percent correct was higher if the talker was a male by a median of 9.8% (95% CI = 5.8–13.9%; $p < 0.001$). The percent correct of the male talker was higher than the female talker even within the programmed condition when a difference was 8.3% (95% CI = 4.3–15.7%; $p = 0.002$) and within the default condition the median difference was 9.9% (95% CI = 4.1–16.3%; $p = 0.006$).

Finally, there was a significant main effect of condition ($p < 0.001$) indicating that independent of gender, the programmed strategy yielded a median improvement of 8.9% compared with the default condition (95% CI = 5.9–12.1%; $p < 0.001$).

## DISCUSSION

This study investigated whether there were significant differences in speech recognition scores when hearing aid users listened to speech tests through a telecoil programmed to match the prescribed target of their verified microphone program as opposed to listening to speech tests through a telecoil program that was not adjusted. Results indicated that speech recognition was significantly better in the programmed telecoil condition, for all speech stimuli conditions, than the default telecoil condition (Figures 4 and 5). Results also indicated that across the experimental conditions, speech recognition was significantly better when the talker was male in comparison with when the talker was a female. In addition, results indicated that across the experimental conditions, speech recognition was significantly better when the signal was a sentence in comparison with when the signal was a word or phoneme. Finally, it was found there was improved speech recognition when assessing phoneme performance when compared with word performance. There were no statistically significant differences between the programmed and default conditions for male versus female talkers or with the interaction between the speech tests and the two fitting strategies.

The finding that the programmed performance was significantly better than default performance aligns with patient dissatisfaction with the telecoil feature of hearing aids (Tannahill, 1983; Rodriguez et al, 1985; Rodriguez et al, 1991; Rodriguez et al, 1993; Takahashi, 2005; Kochkin et al, 2014). Patient dissatisfaction with the telecoil was reported to be high because of the audibly softer signal patients heard when the default telecoil was used instead of the microphone (Tannahill, 1983; Rodriguez et al, 1985; Rodriguez et al, 1991; Rodriguez et al, 1993; Takahashi, 2005; Kochkin et al, 2014). By programming the telecoil from the softer default setting to match the previously programmed microphone frequency response, the added gain/output provided through programming improved speech recognition for all speech stimuli by providing additional audibility.

The mean RSETS value for the default telecoil condition was −3.6 dB (SD = 2.6 dB) versus the programmed condition of 0.1 dB (SD = 0.5 dB) and is shown in Figure 6. Figure 6 depicts the RSETS values for both telecoil conditions from the hearing aids of the 20 hearing aid users, as well as the mean (±SD) RSETS values for both conditions. Note that the RSETS values for the default telecoil condition are negative (−2 to −8 dB) for 19 of 20 hearing aids, indicating that the telecoil output was lower than the microphone output. Although not reported here, the shape of the frequency response for the three conditions (i.e., microphone, default and programmed telecoil) was similar, but the output for the default telecoil was 0.4–5.8 dB lower from 200–800 Hz.

In addition, the type of signal (i.e., sentences versus words; phonemes versus words) was found to be significant where participants performed better when repeating sentences than when repeating words. Also, within CNC word lists, phoneme scores were higher than word scores possibly due to phonemic intensity and spectral region differences. The improved scores while listening to sentences are likely related to the opportunity for participants to use auditory closure skills or the context within the sentence.

Significant differences between male and female talkers within each telecoil condition were found (i.e., male scores higher than female scores for both programmed and default condition), but no significant differences were found between male versus female talkers between the programmed and default conditions. This is not surprising, given previous research reporting the limited bandwidth of the telephone (i.e., 250–3000 Hz; Mueller et al, 1992). This limited telephone bandwidth may prevent the emergence of differences in speech characteristics between male and female talkers due to the inability of the transmission via a telephone to take advantage of the additional output provided by the programmed telecoil at 4000–6000 Hz. This frequency region, in combination with lower frequencies, is essential for improved performance with a female talker. In addition, it is possible the intensity differences of 0.5–2.0 dB in the 4000–6000 Hz region were insufficient to yield improved understanding of

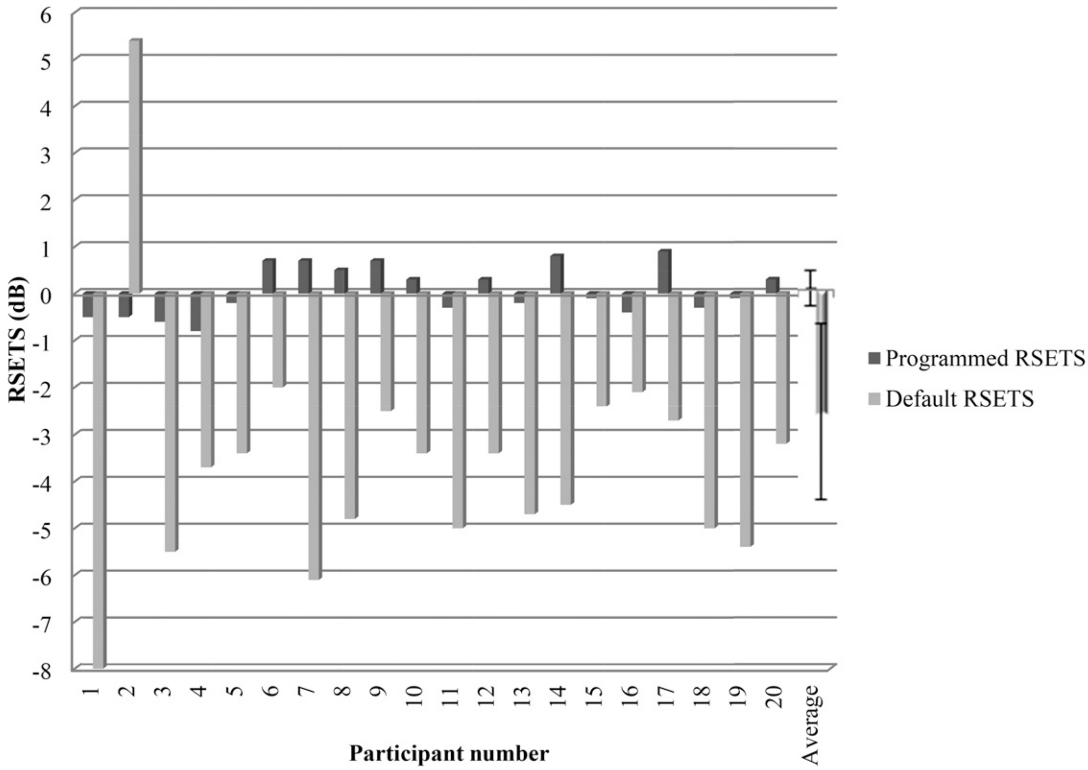


**Figure 6.** RSETS values for the programmed and default conditions for each hearing aid user. The average RSETS (±SD) is reported at the far right.

the male or female talker in the programmed versus default conditions.

The results of the present study suggest several steps may be necessary to improve aided telephone performance. First, it is critical to dispense hearing aids with a telecoil and be certain the telecoil is activated at the hearing aid fitting. Second, it is important to counsel patients concerning the benefits and proper placement of the telephone headset and practice the experience during telephone communication at the hearing aid fitting. Third, the telecoil should be programmed via coupler measures after programming the hearing aid microphone via REM to a prescriptive target to achieve as close to 0 dB RSETS as possible. Finally, the patient should be re-counseled and the use of the telecoil demonstrated for telephone and loop environments, which require manual activation of the telecoil instead of via the automatic telecoil. The need for proper counseling is supported in the update of Chapter 24 of the Delaware Code (Delaware Code § 24, 2016), which was passed because citizens reported their frustration with the lack of counseling on the use of the telecoil.

## Limitations

Several limitations are present in the present study. First, only one telephone handset was used. Telephone headsets vary in their EM strength and this study used a headband to ensure the placement of the headset was at its maximum strength. Thus, using one telephone headset may not represent telephone variability within the same model and across models that patients typically encounter. Second, only one hearing aid manufacturer and one model was used. This is a limitation because each manufacturer uses a different proprietary algorithm to generate the default telecoil response. Thus, it is possible that using a hearing aid from a different manufacturer might have resulted in even greater differences in performance between the programmed and default fittings. Third, the results in the present study are limited to behind-the-ear hearing aids only, as custom devices were not used in this study. The use of custom devices could generate different results because of the difficulty accessing the telecoil due to the position of the aid in the concha bowl and the orientation of the telecoil within the aid because of size.

Fourth, testing was completed using the telecoil instead of Bluetooth® or other streaming devices including those with direct connection to cellphones. In 2003 the Federal Communications Commission enacted hearing aid compatibility recommendations (Federal Communications Commission, 2003). These recommendations required less static, less interference, and better telecoil connections for landline and cellphones.

From these recommendations the cellphone rating system was developed. The rating system provided a numerical rating from one to four for each the microphone and telecoil conditions. In addition, the hearing aid manufacturer also provides a microphone and telecoil rating from one to four for each of the microphone and telecoil conditions with use of the telephone. Adding the cellphone rating and the hearing aid rating in either the telecoil or microphone condition would provide a numerical value which would indicate the expected performance with the combination of devices (Federal Communications Commission, 2003). In recent years, the frequency of cellphone communication has increased and the use of landline devices for communication has decreased. The exception to this appears to be with communications at places of business. The technology used in this study is a limitation because the use of telecoil for telephone connectivity is probably on the decline. Future research should focus on the current technology and strategies for improvement outside of the cellphone rating system.

Fifth, the hearing aid analyzer (i.e., Frye 8000) used in this study is not as widely used as other analyzers. One limitation of the Frye 8000 is that the most recent derivative of the National Acoustics Lab prescription version 2 (NAL-NL2) is not available. Thus, NAL-NL1 was used to program the microphone response of the hearing aid using REM and the resulting programmed microphone response served as the target for programming the telecoil using coupler measures. Other prescriptive targets are available that, if used, would have changed the microphone frequency response and subsequently the programmed telecoil. Using other prescriptive targets would change the SPLITS frequency response that may result in different sentence, word, and phoneme scores. One advantage of the Frye 8000, however, is its ability to allow the user to view the SPLITS simultaneously with the microphone frequency response when performing ANSI (2003) measures whereas other analyzers from other manufacturers do not have this feature. This is the primary reason the Frye 8000 was chosen. Unfortunately, several hearing aid analyzers do not allow for simultaneous presentation of the microphone and SPLITS responses while performing ANSI measures and the resulting RSETS value. This shortcoming could impact the ability to efficiently program the telecoil to achieve a 0 dB RSETS.

Sixth, this study corrected NAL-NL1 for a bilateral fitting and channel summation during REMs. Both of these corrections serve to reduce the target gain/output in comparison with when these corrections are not taken into account. It is unknown what percent of audiologist incorporate these corrections while performing REM. Seventh, a custom-made headband was used to decrease placement variability and improve optimal placement, which may produce results inconsistent with those where this device is not available. Eighth, both open and closed domes were used in this study chosen from the participant's low-frequency thresholds. Differences in gain are applied respective to the style of dome used, and it is possible the differences in low-frequency gain impacted speech recognition. Finally, probe measures allowed the investigator to objectively optimize the placement of the headset. Again, it is unclear the percent of audiologists using this procedure to ensure optimal placement of the telephone headset over the telecoil to be used as a tool to counsel patients.

## Future Research

Specific investigation should assess the impact noise in the listening environment has on telecoil performance in a T/M position. This study was completed using a telecoil-only listening situation where the microphone was not active simultaneously with the telecoil. The use of a T/M program where simultaneous signal input from the telecoil and microphone is emitted should be investigated. The impact of noise on speech recognition should be investigated to have a better understanding of the influence of this type of listening environment on telecoil performance. Furthermore, the ability to manipulate the mixing ratio between the signal input from the microphone relative to the signal input to the telecoil via programming software for T/M programs should be investigated. In addition, further investigation of programming the telecoil to match the microphone frequency response, not programmed via REM, should be investigated to identify the difference in SPLITS output on speech understanding.

Another consideration for future research would be to complete a similar study using multiple hearing aid manufacturers and/or models. This would provide a more comprehensive understanding of the variation in proprietary telecoil algorithms. Recognizing the variability between manufacturers and/or models, 30 loaner hearing aids of varying ages, manufacturers, and models were tested as they had been last programmed in the clinic to obtain a SPLITS and RSETS value. Figure 7 reports the range of measured RSETS values, −7.2 to 13.8 dB, identified when testing the loaner hearing aids and supports the need for future research to investigate the effect of RSETS values on speech understanding independent of telecoil programming.

In addition, when assessing telecoil performance using ANSI S2.33-2003 or ANSI S2.33-2009, a pure-tone sweep is used. When a patient uses a telecoil, however, he/she typically listens to speech. Future research should consider if there is a difference in the SPLITS

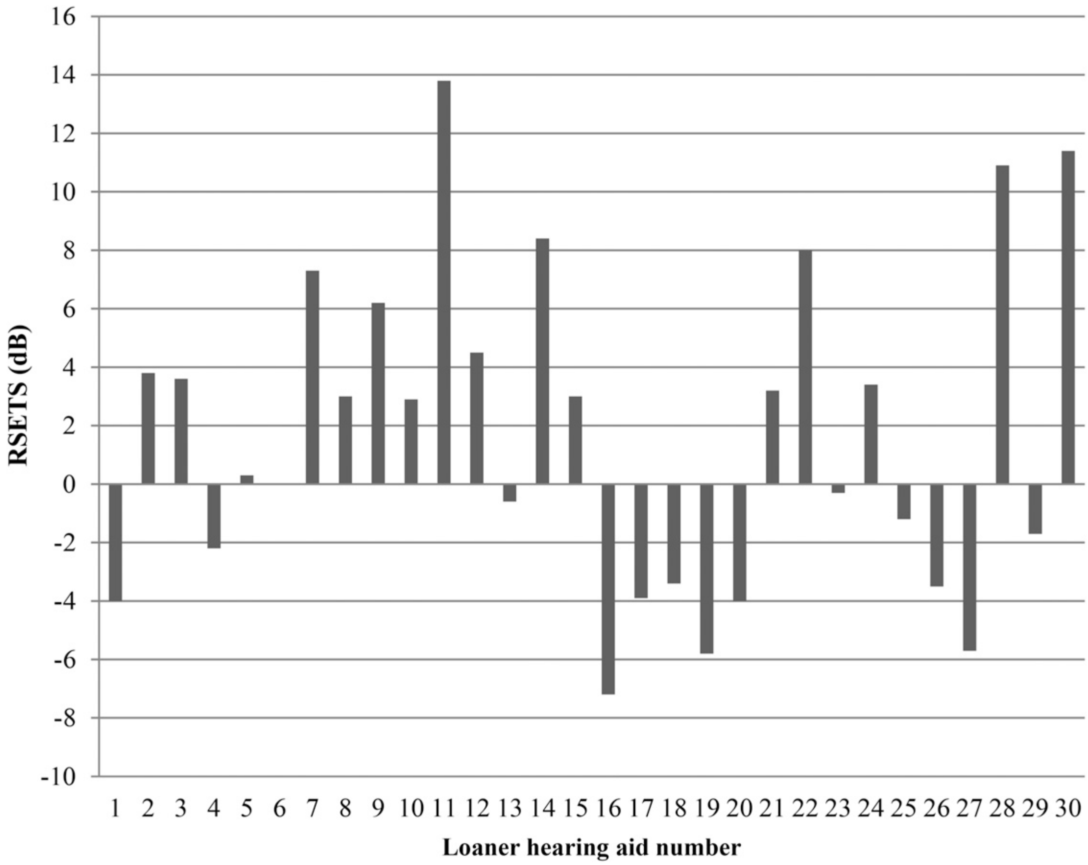


**Figure 7.** Bar graph of RSETS values measured from 30 loaner hearing aids previously programmed for patients in a clinic.

and RSETS and its impact on speech recognition if the test signal when completing coupler measures was changed from a pure-tone sweep to a speech-weighted signal. Putterman and Valente (2012) conducted a pilot study assessing the differences between using DigiSpeech and a pure-tone sweep via a Frye® 7000 hearing aid analyzer using REM for 39 hearing aids documenting the reduced gain at 200 and 400 Hz by default telecoils, but more research is needed to expand on these findings and consider the use of a speech weighted signal to use in ANSI (2009) to measure telecoil performance.

Finally, future research should consider other telecoil features such as the Widex® SmartToggle™. When this feature is activated, placing a telephone at one hearing aid streams the signal to the opposite hearing aid, thus, creating a bilateral listening situation. Investigating the impact this feature has on speech recognition would be prudent considering the increased prevalence of this feature across manufacturers. One related consideration for future research would be to investigate differences in speech recognition when using a programmed telecoil, default telecoil, and recent Bluetooth®-streaming ability of hearing aids. Streaming telephone conversations via Bluetooth® technology is becoming increasingly popular and its efficacy compared with conventional telephone coupling measures should be investigated. Regardless of the advancements of streaming technology, there still will be the need for a patient to manually activate his/her telecoil for use with current looping systems.

## CONCLUSION

The results of this study demonstrate the positive effects on speech recognition with programming the hearing aid telecoil output to a prescriptive target. When listening to speech presented using the default telecoil, there is degradation in speech recognition which causes listening difficulty, even if the acoustic signal is loud enough for the user and the default RSETS for a hearing aid results in a negative value that is equal or greater than the average RSESTS of −3.6 for the hearing aid used in this study. This study reported improved speech recognition when the SPLITS is programmed to a microphone frequency response that was previously programmed to a prescriptive target creating a potential clinical tool for helping hearing aid users with recognition on the telephone.

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