NIH-NIDCD Smartphone based HearingAid Project
Clinical Testing and Results, Year 3
Prepared by
Linda Thibodeau
May 8, 2019

Data Collection Overview:

The algorithms on the Smartphone were evaluated by persons with normal and impaired hearing. All listeners received the signal via bilateral hearing instruments programmed for either normal hearing or for their specific hearing loss. Two manufacturer hearing aids, Starkey and Oticon, were evaluated in various wireless microphone arrangements.

Subject Recruitment:

The online SONA system was used to recruit students with normal hearing. It was designed to assist researchers at the University of Texas at Dallas to recruit participants in IRB approved studies. After the IRB was reapproved, an account was created on SONA containing information about the study and how students can sign-up. Participants with hearing loss were recruited through announcements to persons who attended previous research sessions at UTD or attended a presentation given by Dr. Thibodeau who often lectures at retirement centers and the support groups such as the local chapter of the Hearing Loss Association of America.

Normal hearing (NH) participants had clear ear canals as verified by otoscopy and passed a hearing screening at 250, 500, 1000, 2000, and 4000Hz at 25dB HL or less as tested with traditional audiometry using insert earphones. NH listeners wore made-for-iPhone (MFi) Hearing aids that were programmed to 10 dB HL thresholds from 250-2000Hz and 15 dB HL from 3000-8000Hz using NAL-NL2 fitting formula. The age range for normal hearing participants was 18-65 years of age.

Hearing impaired (HI) participants also had clear ear canals as verified by otoscopy. For participants with stable hearing thresholds (verbally confirmed), their most recent audiogram was used for programming the MFi hearing aids. For all other participants, a hearing test was completed using traditional audiometry. In order to evaluate the benefit of smartphone algorithms persons with a range of hearing loss degrees and types were recruited. The hearing thresholds ranged from normal hearing in the low frequencies to profound hearing loss in the high frequencies, asymmetrical hearing loss, and mixed or sensorineural hearing loss. The thresholds of the better ear are shown in Figure 1. The MFi hearing aids were programmed accordingly using NAL-NL2 fitting formula and verified using real-ear measures on the Verifit 1. The age range for hearing impaired participants was 18-85 years of age.

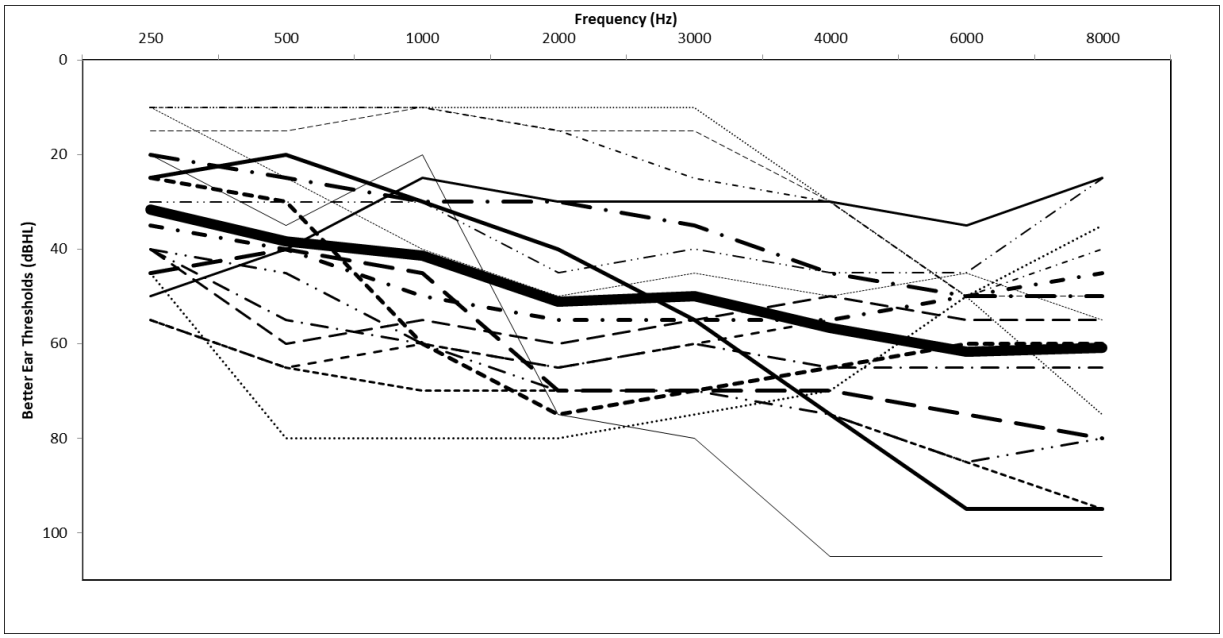


Figure 1. Thresholds of the better ear for participants with hearing loss. The thick solid line represents the average of all 18 participants with hearing loss.

Hearing Instruments

During the third year of testing the smartphone algorithms, hearing aids from two manufacturers were tested. Starkey Halo I/II and Oticon OPN1 +telecoil were programmed for either normal hearing (NH) or individual hearing impairment (HI) accordingly using NAL-NL2 fitting formula and verified $\pm$ 5 dB using real-ear measures on the Verifit 1 for the HI participants. In all wireless microphone/smartphone conditions, the participants' external/local hearing aid microphones were muted so that only the processed auditory signals by the microphone/smartphone would be available. The NH participants wore noise-cancellation headphones (except in the hearing aid alone trial) to reduce the contribution of their natural hearing.

Smartphone

The iPhone 7, IOS 11.2??, was used for all testing. Two microphone options, standard and video, were evaluated to determine if one provided more benefit because of an increased dynamic range. The standard microphone is located at the base edge of the phone and the video microphone is located near the top on the screen face. However, after testing NH and HI with the video microphone in the SHARP app, it was determined that there was no additional benefit. Therefore, all the results presented below for Phase 1 and 2 were obtained using the standard microphone with the SHARP app.

Stimuli

Lists of ten HINT sentences were presented at a constant level of 65 dB SPL (at the listener's head) through KEMAR with a voice simulator at 0 degrees azimuth to the listener. Use of this KEMAR allowed the speech to be radiated across the microphone opening as would naturally happen in real-world settings. Restaurant noise was delivered at

180 degrees azimuth from a loudspeaker at various signal-to-noise ratios (SNR) ranging from –10 to +15 depending on the participants' performance in either the hearing aid alone or the SHARP app condition.

General Testing Procedures

Participants were seated at a desk as indicated in Figures 2 and 3 and utilized a computer to type their responses. A practice list in quiet was always completed first and followed by randomized conditions including hearing aids alone, SHARP app, Live Listen, and Connect Clip (Oticon OPN1 + telecoil only). Because the Oticon Connect Clip is worn clipped to the shirt, the benefit of using the iPhone in a lanyard position was also evaluated as shown in Figure 3. There were ten sentences per list and percent words correct was calculated.

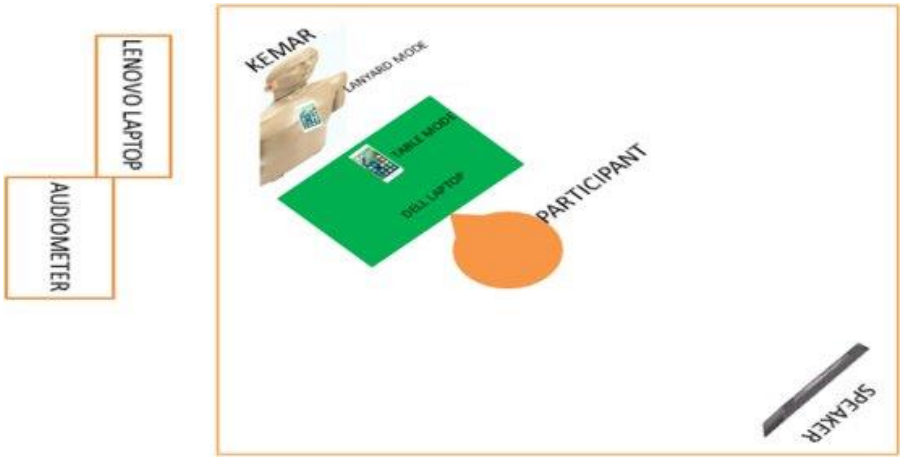


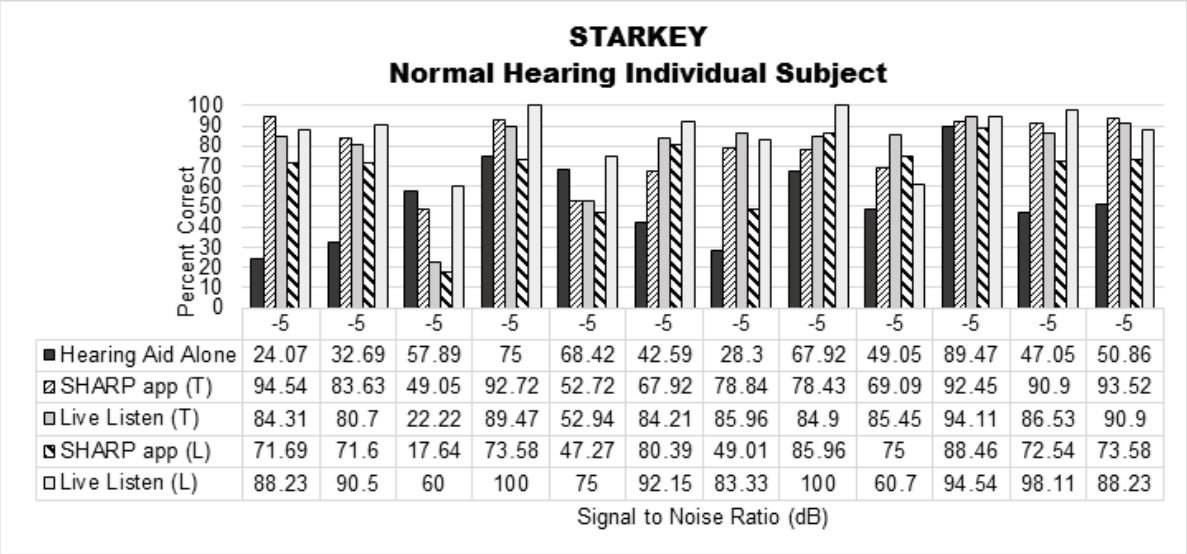
Figure 2. The testing arrangement for table iPhone conditions. The iPhone was placed touchscreen-side-up with standard microphone conditions (how individuals usually talk on the phone) closest to KEMAR. The iPhone was placed touchscreen-side-down with the video microphone conditions closest to KEMAR.

Figure 3. Testing arrangement for the lanyard position iPhone 7 conditions (left). The phone was slipped into the lanyard so that the standard microphone facing upward towards KEMAR's mouth. The standard microphone was approximately 8-10" away from KEMARs mouth. The Connect Clip (right) was clipped on to the t-shirt of KEMAR and was approximately 6" away from KEMAR's mouth.

Phase 1: Comparison of Microphone/Processing options with Starkey Halo Hearing aids

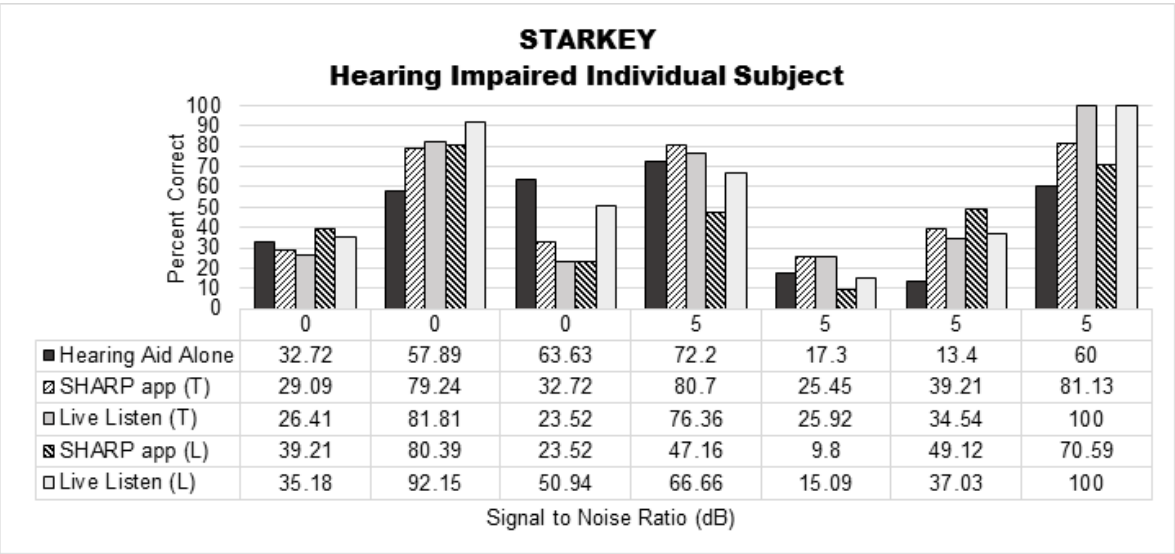
The purpose was to compare the performance of NH and HI listeners when using ONLY Starkey Halo hearing aids versus the aids being connected to the remote microphone options on the iPhone including SHARP App and Live Listen, when the phone was placed on the table and in lanyard position.

The data and graphs shown in Figure 4 represent the individual scores of 12 participants with normal hearing (top) and 7 participants with hearing loss (bottom). All normal hearing participants were tested at -5 dB SNR while hearing-impaired participants were tested at 0 or 5 dB SNR. Each participant completed the following conditions: hearing aid alone, SHARP app table (T), Live Listen table (T), SHARP app lanyard (L), and Live Listen (L) condition.



	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5
Hearing Aid Alone	24.07	32.69	57.89	75	68.42	42.59	28.3	67.92	49.05	89.47	47.05	50.86
SHARP app (T)	94.54	83.63	49.05	92.72	52.72	67.92	78.84	78.43	69.09	92.45	90.9	93.52
Live Listen (T)	84.31	80.7	22.22	89.47	52.94	84.21	85.96	84.9	85.45	94.11	86.53	90.9
SHARP app (L)	71.69	71.6	17.64	73.58	47.27	80.39	49.01	85.96	75	88.46	72.54	73.58
Live Listen (L)	88.23	90.5	60	100	75	92.15	83.33	100	60.7	94.54	98.11	88.23

Signal to Noise Ratio (dB)



	0	0	0	5	5	5	5
Hearing Aid Alone	32.72	57.89	63.63	72.2	17.3	13.4	60
SHARP app (T)	29.09	79.24	32.72	80.7	25.45	39.21	81.13
Live Listen (T)	26.41	81.81	23.52	76.36	25.92	34.54	100
SHARP app (L)	39.21	80.39	23.52	47.16	9.8	49.12	70.59
Live Listen (L)	35.18	92.15	50.94	66.66	15.09	37.03	100

Signal to Noise Ratio (dB)

Figure 4. Normal hearing participants using Starkey Halo I/II hearing aids (top). Hearing impaired participants using Starkey Halo I/II hearing aids (bottom). The SHARP app was using the standard microphone in both the table and lanyard position. The volume on the iPhone was selected by each participant and remained consistent across their test conditions. The Beta setting was .9.

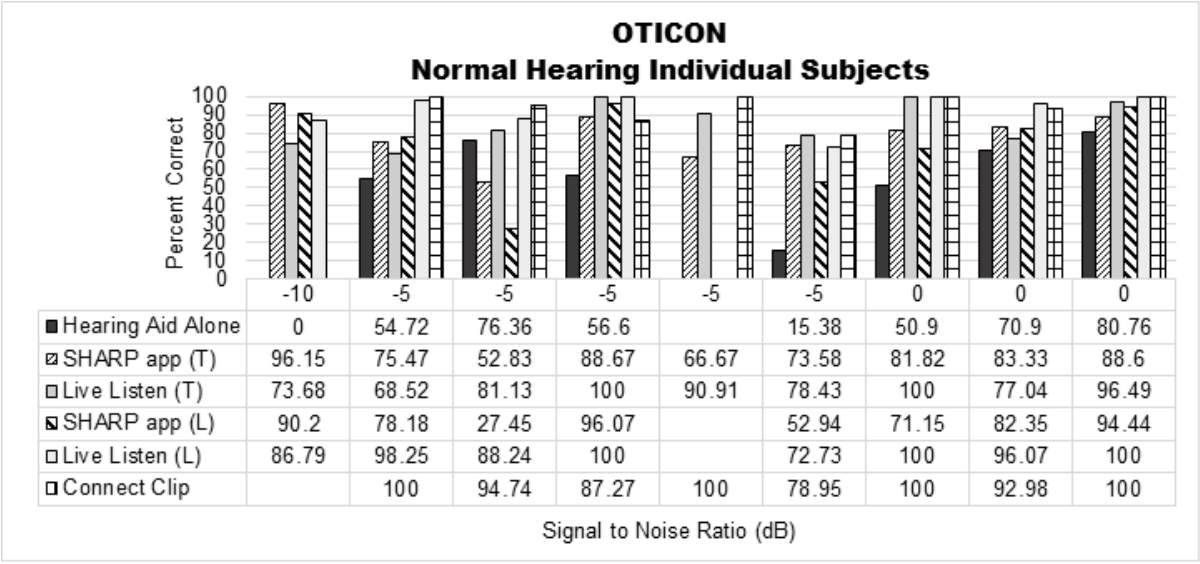
Conclusion Phase 1:

The average percent correct performance with the hearing aid alone was 52.78 for the NH and 45.31 for the HI. The lanyard condition was slightly better than the table position for the Live Listen but not for the SHARP App. Because of variability in the data, patterns of individual performance will be reviewed rather than conducting statistical analysis. Of interest was the comparison of the SHARP app to the Live Listen. For the NH listeners, 8 of the 12 had similar performance (±10%) for the SHARP App and Live Listen. For the HI listeners, 6 of the 7 had similar performance (±10%) for the SHARP App and Live Listen.

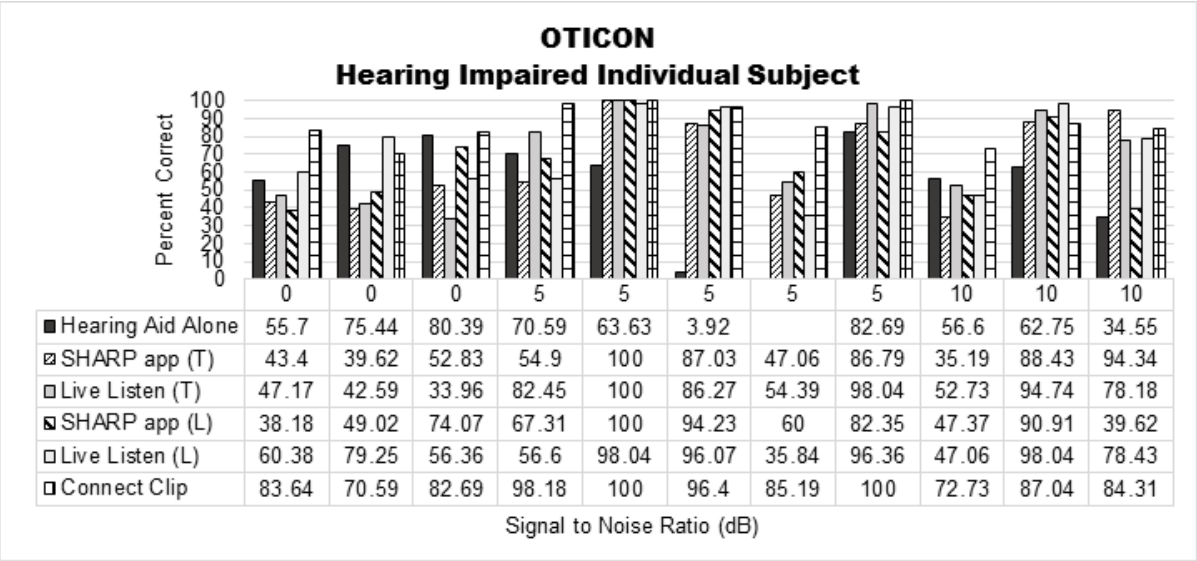
Phase 2. Comparison of Microphone/Processing options with Oticon OPN Hearing aids

The purpose was to compare the performance of NH and HI listeners when using ONLY Oticon OPN1 hearing aids versus the aids being connected to the remote microphone options on the iPhone including SHARP App and Live Listen, when the phone was placed on the table and in lanyard position. In addition, the Oticon Connect Clip microphone was added for comparison of a manufacturer specific microphone.

The data and graphs shown in Figure 5 represent the individual scores of 9 participants with normal hearing and 11 participants with hearing loss. Normal hearing participants were tested at -10dB – 0dB SNR while hearing impaired participants were tested at 0dB – 10dB SNR. Each participant completed a hearing aid alone, SHARP app table (T), Live Listen table (T), SHARP app lanyard (L), Live Listen (L), and Connect Clip condition.



	-10	-5	-5	-5	-5	-5	0	0	0
Hearing Aid Alone	0	54.72	76.36	56.6		15.38	50.9	70.9	80.76
SHARP app (T)	96.15	75.47	52.83	88.67	66.67	73.58	81.82	83.33	88.6
Live Listen (T)	73.68	68.52	81.13	100	90.91	78.43	100	77.04	96.49
SHARP app (L)	90.2	78.18	27.45	96.07		52.94	71.15	82.35	94.44
Live Listen (L)	86.79	98.25	88.24	100		72.73	100	96.07	100
Connect Clip		100	94.74	87.27	100	78.95	100	92.98	100



	0	0	0	5	5	5	5	5	10	10	10
Hearing Aid Alone	55.7	75.44	80.39	70.59	63.63	3.92		82.69	56.6	62.75	34.55
SHARP app (T)	43.4	39.62	52.83	54.9	100	87.03	47.06	86.79	35.19	88.43	94.34
Live Listen (T)	47.17	42.59	33.96	82.45	100	86.27	54.39	98.04	52.73	94.74	78.18
SHARP app (L)	38.18	49.02	74.07	67.31	100	94.23	60	82.35	47.37	90.91	39.62
Live Listen (L)	60.38	79.25	56.36	56.6	98.04	96.07	35.84	96.36	47.06	98.04	78.43
Connect Clip	83.64	70.59	82.69	98.18	100	96.4	85.19	100	72.73	87.04	84.31

Figure 5. Normal hearing participants using Oticon OPN1 + telecoil hearing aids (top). Hearing impaired participants using Oticon OPN1 (bottom). The SHARP app was using the standard microphone in both the table and lanyard position. The volume on the iPhone was selected by each participant and remained consistent across their test conditions. The Beta setting was .9. A blank cell indicates the condition was not completed due to time constraints or technology malfunction.

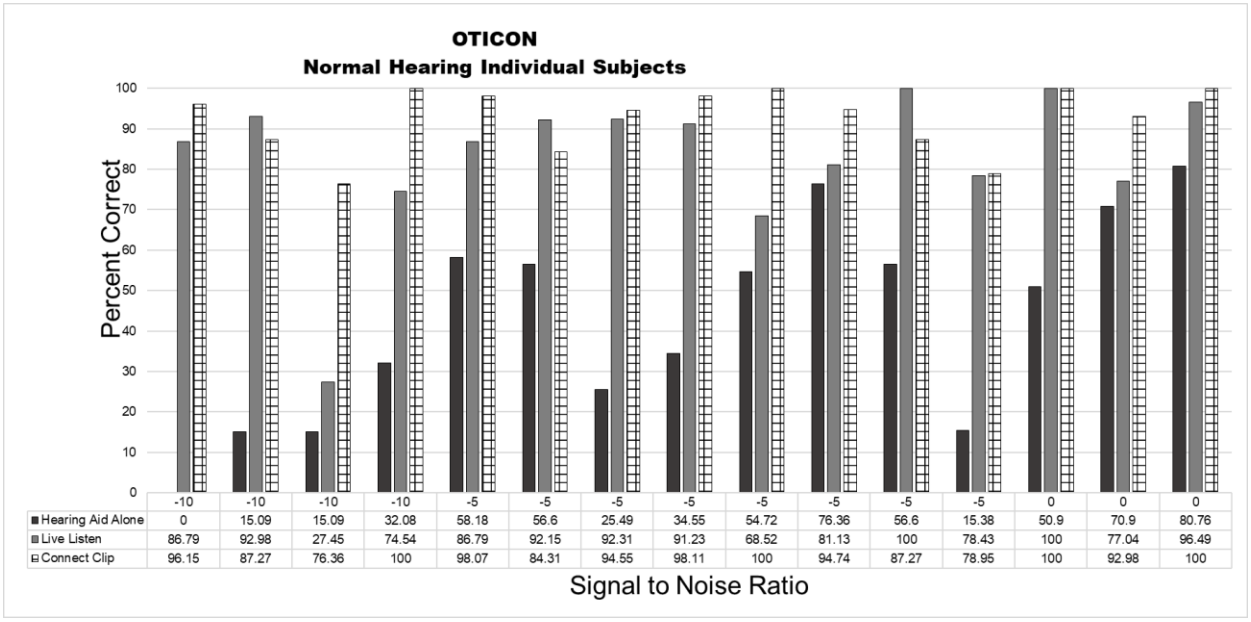
Conclusion Phase 2:

The average percent correct performance with the hearing aid alone was 50.70 for the NH and 58.63 for the HI who were tested at easier SNRs. There were no consistent differences for the lanyard versus the table conditions. Again, it was of interest to compare the SHARP app to the Live Listen. For the NH listeners, 3 of the 9 had similar performance (±10%) for the SHARP App vs Live Listen. For the HI listeners, 6 of the 11 had similar performance (±10%) for the SHARP App vs Live Listen. Of all the conditions, participants performed the best with the Connect Clip by Oticon. On average, the NH scored 94.24% and the HI performed 87.34% with the Connect Clip microphone. This is not surprising given the transmission is proprietary digital streaming with no recognizable delay. In contrast, listening through the SHARP app or Live Listen requires the Bluetooth LE connection which has ?? delay that may affect performance.

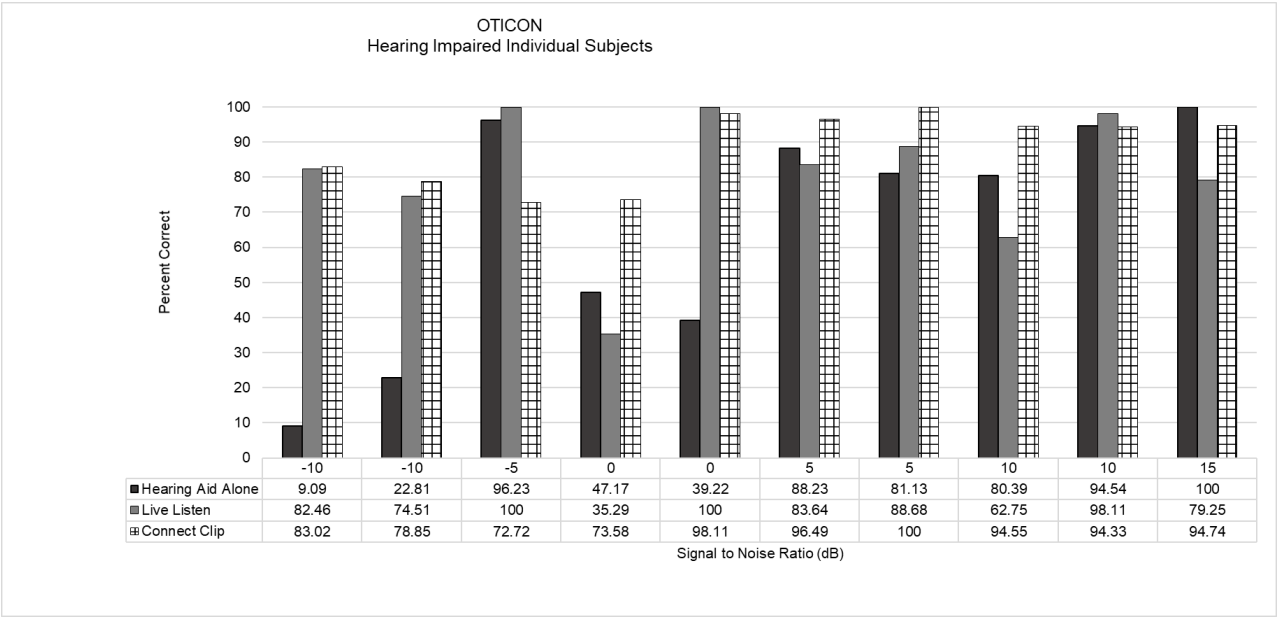
Phase 3. Comparison of Microphone/Processing options with Oticon OPN Hearing aids for Live Listen versus Connect Clip microphone.

The purpose was to compare the performance of NH and HI listeners in three conditions: 1) Oticon OPN1 hearing aids only, 2) the aids connected to the iphone via Live Listen, and 3) the aids connected to the Oticon Connect Clip microphone.

The data and graphs shown in Figure 6 represent the individual scores of 15 participants with normal hearing and 10 participants with hearing loss. Normal hearing participants were tested at -10 to 0 dB SNR while hearing impaired participants were tested at -10 to 15dB SNR. The SNR levels were determined based on a practice list such that the listener scored between 60 and 80%. The SNR remained fixed at that level for all three conditions. Each participant completed a hearing aid alone, Live Listen table, and Connect Clip condition in random order.



	-10	-10	-10	-10	-5	-5	-5	-5	-5	-5	-5	-5	0	0	0
Hearing Aid Alone	0	15.09	15.09	32.08	58.18	56.6	25.49	34.55	54.72	76.36	56.6	15.38	50.9	70.9	80.76
Live Listen	86.79	92.98	27.45	74.54	86.79	92.15	92.31	91.23	68.52	81.13	100	78.43	100	77.04	96.49
Connect Clip	96.15	87.27	76.36	100	98.07	84.31	94.55	98.11	100	94.74	87.27	78.95	100	92.98	100



	-10	-10	-5	0	0	5	5	10	10	15
Hearing Aid Alone	9.09	22.81	96.23	47.17	39.22	88.23	81.13	80.39	94.54	100
Live Listen	82.46	74.51	100	35.29	100	83.64	88.68	62.75	98.11	79.25
Connect Clip	83.02	78.85	72.72	73.58	98.11	96.49	100	94.55	94.33	94.74

Figure 6. Normal hearing participants using Oticon OPN1 hearing aids (top) and hearing-impaired participants using Oticon OPN1 (bottom) when listening in hearing aid alone, iPhone Live Listen, and Oticon Connect Clip Microphone conditions. The iPhone in all conditions was set to maximum volume.

Conclusion Phase 3:

With the Oticon OPN aids alone, the NH listeners obtained an average score of 42.85% correct compared to 65.88% for the HI. The Connect Clip again provided more benefit on average than the Live Listen condition for the NH (92.58 vs 83.06, respectively) and the HI (88.64 vs 80.47, respectively). Because various SNR levels were used, a "benefit" score was determined by subtracting the score in the hearing aid alone condition from each of the microphone conditions (Live Listen and Connect Clip). The average benefit for the NH listeners was 40.21 and

49.74% and 14.59 and 22.76% for the Live Listen and the Connect Clip conditions, respectively. The greater benefit was obtained by those with normal hearing as expected. Although the connection to the iPhone through Bluetooth LE wireless transmission is convenient for the user, the dedicated proprietary microphone, Oticon Connect Clip, that transmits directly to the Oticon OPN aids via digital streaming provides the greatest benefit.

General Conclusions across all three Phases

All the data were combined across all SNR and hearing aid conditions for the normal hearing- and hearing-impaired participants as shown in Figure 7. There was a total of 55 participants used in this data set with the exception of the Connect Clip which had only 36 participants total because the Starkey Halo aids were not compatible with the Connect Clip.

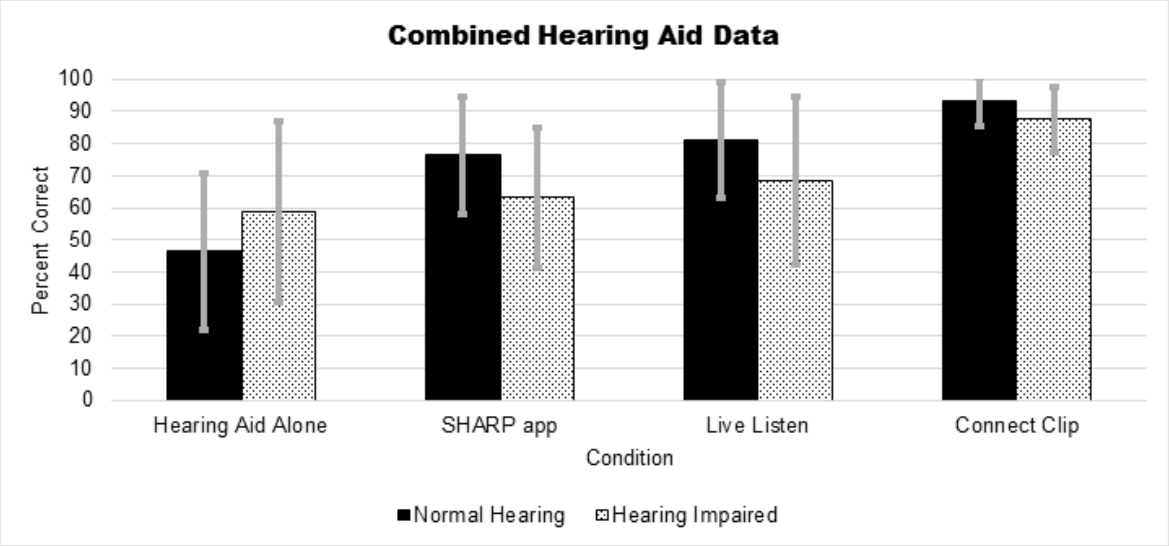


Figure 7. All participants data combined across hearing aids tested (Starkey Halo I/II and Oticon OPN1). The error bars represent ± one standard deviation. The iPhone microphone was either the standard or video microphone and the iPhone volume varied across the conditions but was held constant for each subject. The iPhone conditions shown are only for the table condition.

The combined results clearly show that the NH participants performed better than the HI as expected except for the hearing aid alone condition. This might have been related to the more difficult SNR levels used for testing the NH listeners so that ceiling effects could be avoided. The combined results also suggest that for both groups, the Connect Clip microphone provided the highest performance which is to be expected because it was specifically designed to be used with the Oticon OPN hearing aids. Performance with the SHARP app was similar to that with Live Listen when all data were combined for both the NH and HI participants. These results show a favorable outcome and suggest the need for continued testing with listeners with more homogenous hearing loss and larger subject groups.

Tasks to be addressed in Year 4

1) Continue evaluation of the SHARP app through use of a psychometric function of speech recognition in noise (SRiN) over a range of SNR levels is tested with each subject, -10 to +15 dB SNR.
2) Compare SRiN performance with SHARP app of homogenous group of listeners with hearing loss in mild sloping to severe, sensori-neural hearing loss to performance of a group of age-matched normal hearing listeners.
3) Compare SRiN performance with SHARP app in steady-state speech noise to performance in multi-talker babble to determine speech enhancement benefits as dynamic characteristics of the competition varies.
4) Evaluate SPiN learning effects by individuals with normal and impaired hearing in conditions without and with using the SHARP app to determine need for training experience to realize full benefits.
5) Measure real-ear SPLs in test conditions to confirm relatively equal audibility across conditions of hearing aid alone and SHARP app in listeners with hearing loss.
6) Develop protocol for electroacoustic evaluation of using smartphone as a remote microphone to confirm consistency across versions of the same phone.
7) Compare SRiN performance with SHARP app on iPhone versus Android phones in listeners with normal and impaired hearing.
8) Compare SPiN performance with SHARP app in listeners with normal and impaired hearing when listening through wired headphones and through made-for-iPhone hearing aids.
9) Evaluate SPiN performance with the SHARP app in listeners who use N7 Cochlear implants that can be wirelessly connected to an iPhone.
10) Develop SHARP2 workshop to share testing package including iPhone with SHARP app with latest features and instructions for testing protocol to gather feedback from third-party clinics, research programs, and manufacturers.