Bimodal Hearing Evidence Summary

Cochlear® | ReSound GN

Smart Hearing Alliance

Volume 1 | 2022

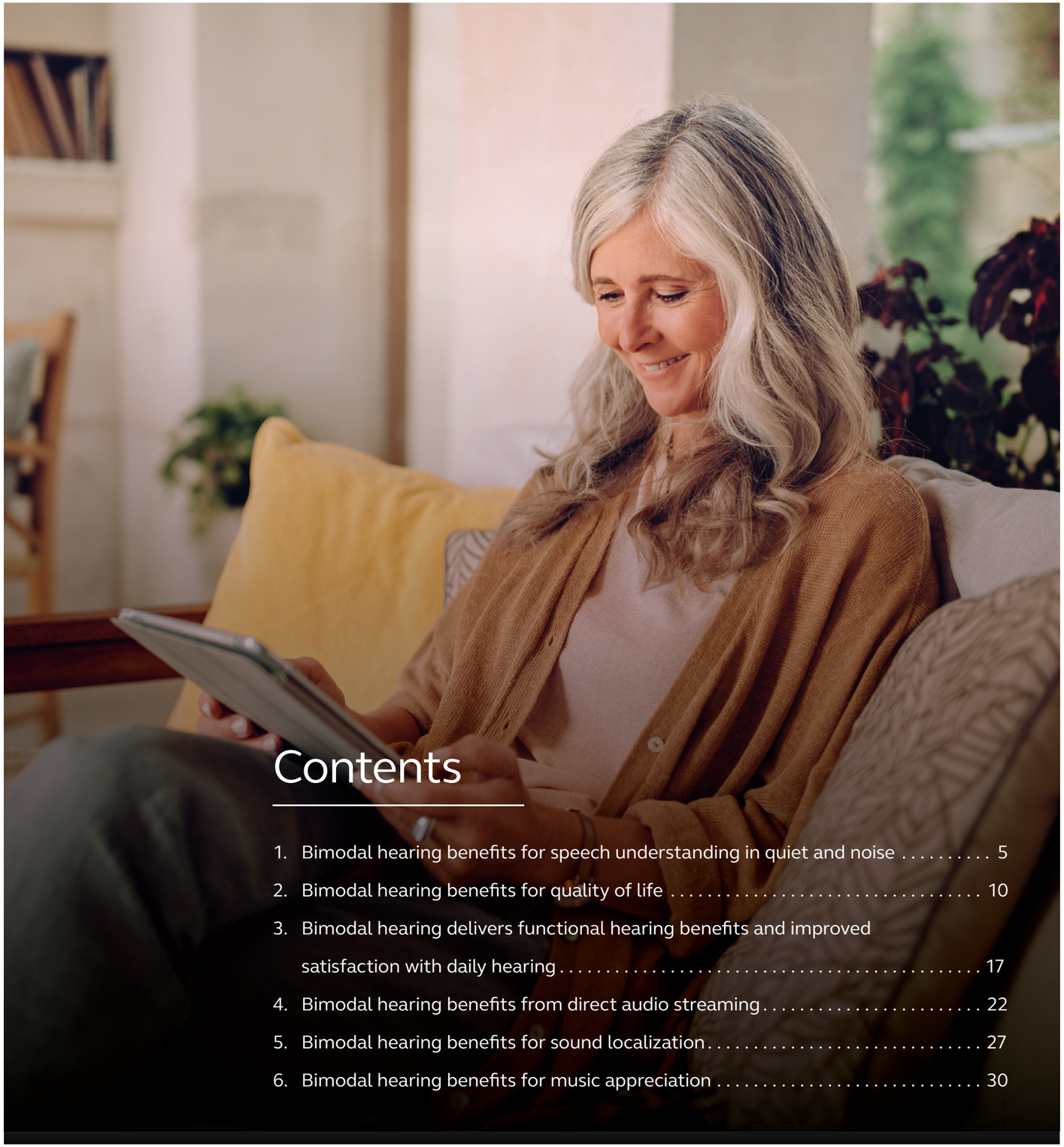
Better hearing with both ears

For many people, a bimodal hearing solution with a cochlear implant (CI) on one ear and a hearing aid (HA) on the other is the combination that provides them with their best hearing.[1-7]

Since 2011, Cochlear and ReSound have collaborated in the Smart Hearing Alliance to provide hearing solutions for people with all types of hearing loss. Whether the need is for hearing aids, hearing implants, or a combination of the two, our solutions work together seamlessly. Through the Smart Hearing Alliance, we are committed to improving bimodal hearing care in partnership with you. Our solutions are evidence-based and designed to help you effectively meet the changing needs of your patients over time.

This document summarizes some key insights from research studies about the benefits of bimodal hearing solutions for adult CI users.

1. Farinetti A, Roman S, Mancini J, et al. Quality of life in bimodal hearing users (unilateral cochlear implants and contralateral hearing aids). Eur Arch Otorhinolaryngol (2015 Nov); 272, 3209–3215.
2. Ching TY, Incerti P, Hill M. Binaural benefits for adults who use hearing aids and cochlear implants in opposite ears. Ear Hear (2004 Feb); 25, 9–21.
3. Potts LG, Skinner MW, Litovsky RA., et al. Recognition and localization of speech by adult cochlear implant recipients wearing a digital hearing aid in the nonimplanted ear (bimodal hearing). J Am Acad Audiol (2009 Jun); 20, 353–373.
4. Morera C, Cavalle L, Manrique M, et al. Contralateral hearing aid use in cochlear implanted patients: Multicenter study of bimodal benefit. Acta Otolaryngol (2012 Jun); 132, 1084–1094.
5. Gifford RH, Dorman MF, McKarns SA, Spahr AJ. Combined electric and contralateral acoustic hearing: Word and sentence recognition with bimodal hearing. Journal of Speech, Language, and Hearing Research. (2007 Aug) 1;50(4):835-43.
6. Sucher CM, McDermott HJ. Bimodal stimulation: benefits for music perception and sound quality. Cochlear Implants International. (2009 Jan); 1;10(S1):96-9.
7. Buchman CA, Herzog JA, McJunkin JL, et al. Assessment of Speech Understanding After Cochlear Implantation in Adult Hearing Aid Users: A Nonrandomized Controlled Trial. JAMA Otolaryngol Head Neck Surg. Published online (2020 Aug). doi:10.1001/jamaoto.2020.1584.



Contents

> “On the day I got the ReSound hearing aid, a friend even told me 'Hey, I get the impression that you understand me better' and I really enjoyed hearing that.”
>
> *Fleur D., Smart Hearing Alliance bimodal user*

Bimodal hearing benefits for speech understanding in quiet and noise

Hearing well with both ears can offer significant benefits, from safely crossing the street to having confident conversations in quiet or noisy places, or hearing voices at a distance. Ears work together as a team, and research shows that the brain needs both ears to effectively process sound.

Listening with both ears can help a person to understand more when speech occurs in background noise. This is due to binaural advantages including head diffraction, binaural squelch, and binaural redundancy.

The studies summarized on the following pages show that for unilateral cochlear implant users with residual hearing in the non-implanted ear, access to these benefits is possible by fitting a hearing aid to that ear. In addition to hearing better in noise, bimodal hearing is also shown to improve the range and quality of the sound being heard.

Longitudinal outcomes of cochlear implantation and bimodal hearing in a large group of adults: A multicenter clinical study. *Kelsall D et al.*

Kelsall et al. described before implantation and after implantation outcomes for 96/100 adults from 13 U.S. centers participating in a trial evaluating the Cochlear™ Nucleus® CI532 implant and Nucleus® 7 Sound Processor. Before implantation, participants demonstrated bilateral, moderate sloping to profound hearing loss, poor speech understanding with appropriately fitted bilateral hearing aids, and dissatisfaction with amplification. After implantation, participants wore a ReSound HA contralaterally (CI+HA/ bimodal hearing) daily for at least 6-months.

Before implantation, speech understanding was assessed with a HA and bilateral HAs. After implantation evaluations occurred at 3-, 6-, and 12-months in CI-alone and bimodal conditions. Tests included Consonant- Nucleus-Consonant (CNC) words (quiet at conversational level) and AzBio sentences (noise at +10 and +5dB signal-to-noise ratios [SNR]).

Compared to before implantation, the 6-month bimodal group mean score showed a 40-percentage point improvement ($p < 0.001$), with 87% of participants demonstrating a significant improvement over their speech score with two HAs ($p < 0.05$). Bimodal mean scores at 6- and 12-months for both AzBio noise conditions were also statistically significantly better ($p < 0.001$) compared with before implantation scores.

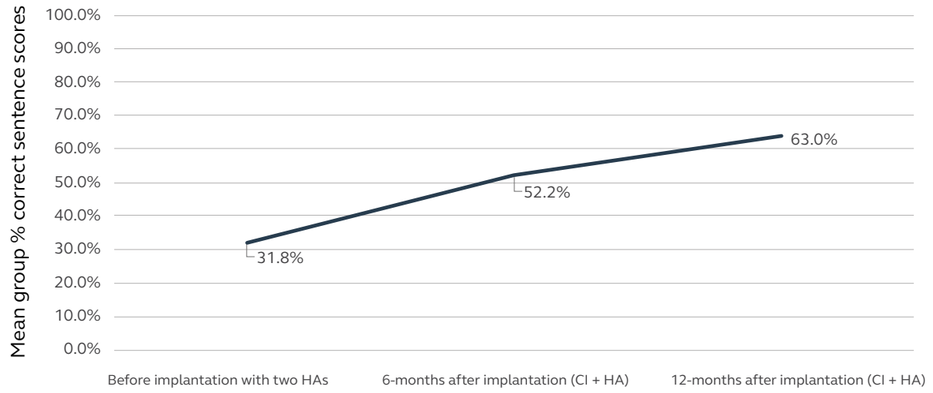
Compared to after implantation using CI-alone, the bimodal 6- and 12-month group mean AzBio sentence scores were statistically significantly better ($p<0.001$), revealing 12-16 percentage point mean gain (+5 and +10 dB SNR), respectively. Bimodal mean scores continued improving between 6- and 12- months ($p < 0.001$) after implantation with bimodal hearing.

Conclusion: Compared to before implantation bilateral HA outcomes, after implantation bimodal hearing had significantly improved scores on all measures at 6- and 12-months. Bimodal hearing provided additional, significant benefits over CI-alone at 6- and 12-months, especially on difficult speech-in-noise tests. Due to sizeable bimodal hearing improvements over CI-alone and bilateral acoustic conditions, before implantation counselling should include discussion about the potential benefits of listening with an implant and HA in the other ear for daily listening.

Key finding: Bimodal hearing is on average, significantly better than CI-alone hearing in quiet and especially in noisy situations

Bimodal hearing benefits for speech understanding in quiet and noise

AzBio sentences at +10 dB SNR, before implantation (N=96), 6-months (N=94) and 12-months (N=83)*



*Graph reproduced using the data provided in the study.

Kelsall D, Lupo J, Biever A. Longitudinal outcomes of cochlear implantation and bimodal hearing in a large group of adults: A multicenter clinical study. 2021 Am J Otolaryngol. 2021 Jan-Feb; 42(1):102773. doi: 10.1016/j.amjoto.2020.102773 Epub 2020 Oct 22. PMID: 33161258.

Bimodal benefit for cochlear implant listeners with different grades of hearing loss in the opposite ear. *Hoppe U et al.*

In this retrospective, single-site study, investigators reviewed data from 148 implanted postlingual adult participants who used bimodal hearing (CI+HA). Using World Health Organization (WHO) classifications, they categorized participants according to pure tone average (PTA) on the hearing aid side. Four groups resulted: Group 1 PTA 25 < PTA ≤40 (best hearing), Group 2 40 <PTA ≤60, Group 3 60 <PTA ≤80, and Group 4 PTA >80 dB HL (poorest hearing). At 6-months or more after implantation, investigators assessed performance with German sentences measured with CI-, HA-alone and bimodal listening conditions. Participants scoring above 60% in quiet, were also tested adaptively in noise, to determine the signal-to-noise ratio ($SNR_{50\%}$) providing a 50% speech reception threshold (SRT). Bimodal summation scores in quiet and noise were calculated. The noise summation score was defined as the difference in SRT between monaural and bimodal conditions, with a positive score representing a bimodal benefit.

Generally, participants demonstrated better bimodal sentence understanding scores in quiet and noise than HA- or CI-alone.

HA-alone condition: median speech scores in quiet decreased as degree of hearing loss increased: All participants in Group 1, 95% of Group 2, 79% of Group 3 and 43% of Group 4. Just under two thirds, 66% (98/148) were evaluated in noise. Median $SNR_{50\%}$ was poorer as degree of hearing loss increased, with greater variability shown in Groups 3 and 4. Groups with more aidable hearing in the HA-ear had better sentence-in-noise scores on average than groups with poorer aided thresholds.

CI-alone condition: for the cohort, median sentence scores in quiet were 86%, with a 7.2 dB SRT ($SNR_{50\%}$) in noise, with the trend for decreased median performance and increased variability with larger degrees of hearing loss.

Bimodal summation: A large number of Group 1 and Group 2 participants could not be evaluated in quiet due to ceiling effects. Group 2 respondents showed bimodal summation in quiet of 57% compared with Groups 3 and 4 who showed 45% and 31% respectively. In noise, Groups 1 and 2 showed bimodal summation with respect to the better ear of 0.8-1.0 dB improvement in SRT, with those in Groups 3 and 4 showing 1.5-1.8 dB improvements respectively.

HA-only and bimodal performance correlated with hearing across all frequencies. Combined hearing thresholds in higher and lower frequency ranges explained 34% of the variance in noise and 40% in quiet for HA-only mode.

Conclusion: All participants, regardless of HA outcomes, showed benefit from CI. Bimodal hearing in quiet and noise showed advantages over monaural hearing. Those with better acoustic hearing demonstrated significant gains from CI. Bimodal benefit in quiet correlates with hearing thresholds across all frequencies. For bimodal benefit in noise, no correlation with hearing thresholds was found.

Key finding: Most participants showed improved speech perception scores in quiet and in noise in the bimodal condition compared to the hearing aid-only or cochlear implant-only condition

Hoppe U, Hocke T, Digeser F. Bimodal benefit for cochlear implant listeners with different grades of hearing loss in the opposite ear. Acta Oto-Laryngol 2018, 138, 713–721.

Bimodal hearing or bilateral cochlear implants? Ask the patient. *Gifford RH et al.*

This single center study evaluated 49 adult bimodal listeners using different test setups. A "clinical set-up" used a single loudspeaker in front to present the speech or speech in noise signal. A "real world set-up" used a single front speaker to deliver speech, with seven surrounding loudspeakers to present the competing restaurant-noise signal. When listening in the "clinical set-up", participants repeated Consonant-Nucleus-Consonant (CNC) words in quiet and AzBio sentences in quiet and +5dB signal-to-noise ratio (SNR) in HA-, CI-alone and bimodal conditions. In the "real-world set-up", they repeated the Hearing in Noise Test (HINT) sentences. This adaptive test keeps the noise level constant, while adapting the sentence levels to find the point at which a 50% correct speech reception threshold (SRT) is obtained.

At the end of testing, each bimodal listener was asked: "Do you think you need a second CI?"

With the "clinical test set-up", the best performance for words in quiet and sentences in noise was shown for the bimodal or CI-alone conditions compared to the HA-alone condition. CI-alone and bimodal hearing performance results were not significantly different.

In the "real-world set-up", HINT scores on average were significantly better in the bimodal condition compared to HA- or CI-alone. It was also reported that while all participants could complete HINT sentences in the bimodal condition and most could do it with the CI-alone, very few could complete it with the HA-alone condition.

Participant's answers to the question "Do you think you need a second CI?" were mixed. When analyzed together with their performance data, this question correctly identified those who could benefit from a second CI and those who continue to benefit with bimodal stimulation.

Results highlight the effectiveness of simulating challenging listening conditions when evaluating potential bilateral candidacy, using test environments that reproduce difficult everyday listening situations and the importance and additional benefits of both ears when listening. The outcomes from these tests can support counselling and decision making by each person with their hearing care professional.

Conclusion: Bimodal hearing delivered improved hearing outcomes compared to listening with a CI-alone in complex listening situations. A simplified "clinical test set-up" cannot accurately evaluate performance in daily life listening situations; multiple loudspeakers presenting noise at the same time are required. When a "real-world set-up" isn't possible, investigators recommend simply asking a recipient the question "Do you think you need a second CI?" to support clinical decision making.

Key finding: In a challenging noise set-up, bimodal hearing on average, delivered better hearing outcomes than when using a hearing aid or cochlear implant alone

Gifford RH, Dorman MF. Bimodal hearing or bilateral cochlear implants? Ask the patient. Ear Hear. 2019 ; 40(3): 501–516.

Bimodal hearing benefits for quality of life

Severe to profound hearing loss can have a significant impact on many aspects of a person’s life beyond just the ability to hear. Hearing loss can contribute to social withdrawal and isolation, functional decline, and diminished enjoyment of music. As part of delivering a person-centered approach to hearing care, treatment should look beyond the person's ability to hear, reflecting a broader view which addresses the impact of hearing loss on the person’s overall quality of life.

The studies summarized on the following pages assess quality of life outcomes using a variety of established self-report scales. They examine the overall well-being of participants in several health-domains including daily hearing function and its impact on everyday life. The evidence shows on average, statistically significant benefits for bimodal hearing users on quality-of-life measures compared to their daily listening condition when using one or two hearing aids or a cochlear implant alone.

Assessment of speech understanding after cochlear implantation in adult hearing aid users: A nonrandomized controlled trial.
Buchman CA et al.

This multicenter prospective study evaluated 100 experienced adult HA users with postlinguistic, moderate sloping to profound sensorineural loss who received little benefit from HAs. Before implantation, all participants wore and were tested with one or two HAs using single syllable (CNC) words in quiet and AzBio sentences in noise (+10 dB SNR). After implantation, participants wore a ReSound HA in the opposite ear and were tested at 6-months with their CI-alone and bimodal hearing (CI+HA). Before and 6-months after implantation, participants completed evaluations to check their general quality of life {Health Utilities Index Mark 3 (HUI3)} and hearing ability in everyday situations {Speech, Spatial and Qualities of Hearing Scale 49 (SSQ49)}. Participants (N = 81) were tested with the Montreal Assessment of Cognitive Ability (MoCA) at before implantation and 6-months after implantation.

After implantation, group mean scores for CNC words and AzBio sentences (+10dB SNR) with CI-alone and bimodal hearing increased significantly and were clinically important compared to before implantation scores. Bimodal hearing scores were significantly better compared to those for CI-alone. Following 6-months of bimodal hearing, significant mean group improvements in ^HUI3 index scores for hearing and speech domains (0.30 (0.25 to 0.36) and 0.08 (0.04 to 0.12) respectively) and overall health (0.18 (0.14 to 0.22)) were observed.

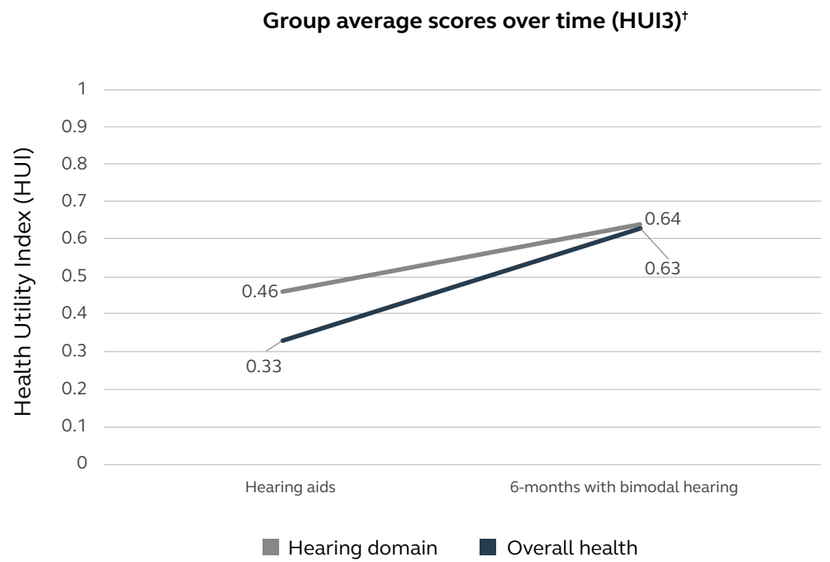
The emotion area also showed a statistically significant, but not clinically important, change. The group mean SSQ49 ratings across different listening conditions in speech understanding, spatial hearing and sound quality revealed significant and clinically important improvements in these areas and in the total score.

Before implantation, 48/81 (59%) participants had a cognitive MoCA score ≤ 25 suggesting mild impairment. At 6-months after implantation, there was a significant improvement compared to before implantation.

In addition, Wick et al. (2021)* analyzed a sub-group of participants 65 years or older (N = 70) from this larger cohort. They showed older participants obtained similar and significant improvements as for the larger group with bimodal hearing compared to CI-alone for words in quiet and sentences in noise. They also had comparable results on HUI3 and SSQ49 tests with bimodal hearing after implantation.

Conclusion: Cochlear implants were safe and effective. Bimodal hearing increased speech understanding in quiet and noise and improved quality of life in individuals with and without small degrees of cognitive impairment.

Key finding: With bimodal hearing, on average, participants showed significant speech understanding increases, quality of life improvements and better everyday hearing skills compared to two hearing aids



†Graph reproduced using the data provided in the study.

*Wick CC, Kallogjeri D, McJunkin JL, et al. Hearing and quality-of-life outcomes after cochlear implantation in adult hearing aid users 65 years or older: A secondary analysis of a nonrandomized clinical trial. JAMA Otolaryngol Head Neck Surg. Published online August 27, 2020. doi:10.1001/ jamaoto.2020.1585.

^Changes of at least 0.03 in the multiattribute health index and at least 0.05 in single domains between test intervals are considered clinically important. (Drummond M. Introducing economic and quality of life measurements into clinical studies.Ann Med. 2001;33(5):344-349. doi:10.3109/ Ireally 7853890109002088).

Buchman CA, Herzog JA, McJunkin JL, et al. Assessment of speech understanding after cochlear implantation in adult hearing aid users: A nonrandomized controlled trial. JAMA Otolaryngol Head Neck Surg. Published online August 27, 2020. doi:10.1001/jamaoto.2020.1584.

Hearing impairment and quality of life in adults with asymmetric hearing loss: Benefits of bimodal stimulation. *Sanhueza I et al.*

This retrospective study compared quality of life changes for participants using bimodal hearing (N = 31) with different amounts of residual hearing in the contralateral ear compared to a control group using CI-alone (N = 30). Both groups had two years or more CI experience. Researchers categorized the bimodal group into sub-groups based on the degree of sensorineural hearing loss (SNHL) in the better ear. These three groups were moderate SNHL (N = 13), severe SNHL (N = 8) and severe-profound SNHL (N = 10). Participants completed quality of life measures at their routine annual evaluations. Questionnaires were the Abbreviated Profile of Hearing Aid Benefit (APHAB), the Speech, Spatial and Qualities of Hearing Scale (SSQ49) and the Health Utility Index (HUI3).

The APHAB includes four subscales: ease of communication, background noise, reverberation, and aversiveness to noise. Subscales are scored and a global score is obtained.

APHAB results showed that self-perceived hearing impairment was significantly lower with bimodal hearing compared to CI-alone.

Keeping in mind that the numbers are small for each sub-group, the bimodal sub-group with moderate SNHL exhibited significantly better outcomes than the other two sub-groups with respect to the global score, and to subscale scores for ease of communication and reverberation.

SSQ49 results were significantly better for the bimodal hearing group than for the CI- alone groups across all subcategories and for the total score. The moderate SNHL bimodal sub-group displayed better results than bimodal users with severe and severe- profound hearing losses on the Qualities of Hearing subscale. No significant differences were found on HUI3 quality of life ratings for the bimodal hearing and CI-alone group or across the bimodal hearing sub-groups with different degrees of hearing loss.

Conclusion: Bimodal stimulation (CI+HA) led to superior results on measures of hearing ability in everyday life compared to hearing with a CI-alone. Bimodal hearing benefits were perceived for patients with minimal and moderate levels of residual hearing in the HA-ear.

Key finding: Bimodal hearing in patients with asymmetrical hearing loss significantly reduced the effects of hearing impairment on daily activities compared to hearing with only one ear

Sanhueza I, Manrique-Huarte R, Calavia D, Huarte A, Manrique M. Hearing impairment and quality of life in adults with asymmetric hearing loss: Benefits of bimodal stimulation. J Int Adv Otol. 2019 Apr;15(1):62-69. doi: 10.5152/iao.2019.6224. PMID: 31058597; PMCID: PMC6483429.

Cochlear implantation in adults with asymmetric hearing loss: Speech recognition in quiet and in noise, and health related quality of life. *Sladen DP et al.*

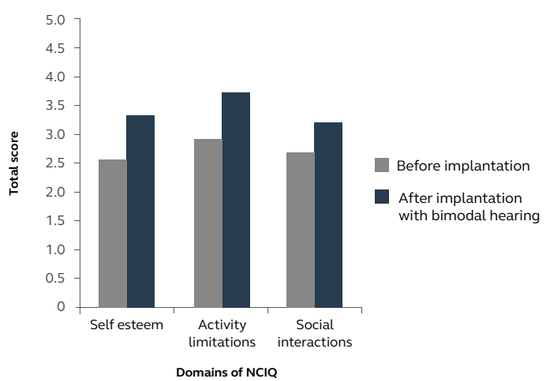
In this retrospective study, researchers evaluated possible Health Related Quality of Life (HRQoL) benefits for postlinguistically deafened adults with asymmetric hearing loss who used bimodal hearing (CI+HA). For study inclusion, patients required an AzBio sentence in quiet score of < 50% in the ear to be implanted and > 50% in the contralateral, non-implanted ear. Forty-five adults meeting the criterion and had their bilateral HAs before implantation and 6-months after implantation with bimodal hearing scores reviewed. Researchers used the Njimegen Cochlear Implant Questionnaire (NCIQ), a questionnaire developed for CI recipients that measures the physical, psychological, and social domains, each including subdomains.

A sub-group of N = 33 (73%) recipients completed the questionnaire before implantation and 6-months after implantation. Results indicated significantly better outcomes for all six subdomains of the NCIQ for bimodal hearing compared to bilateral HAs.

A principal outcome of this investigation was examination of the differences in effect sizes across clinical benefit measures following CI treatment. The CI provided substantial benefit primarily for HRQoL measures (NCIQ), followed by speech recognition improvements for words in quiet and finally for sentences in noise. This emphasizes the importance of including a self-report measure of HRQoL when evaluating CI adults in combination with traditional speech recognition measures. This information is valuable to discuss when counselling CI- candidates on possible benefits of CI with a HA in the contralateral ear.

Conclusion: Results demonstrated significant benefit of CI and a contralateral HA for adults with asymmetric hearing loss. Benefits included not only speech understanding in quiet and noise, but significant improvements in HRQoL.

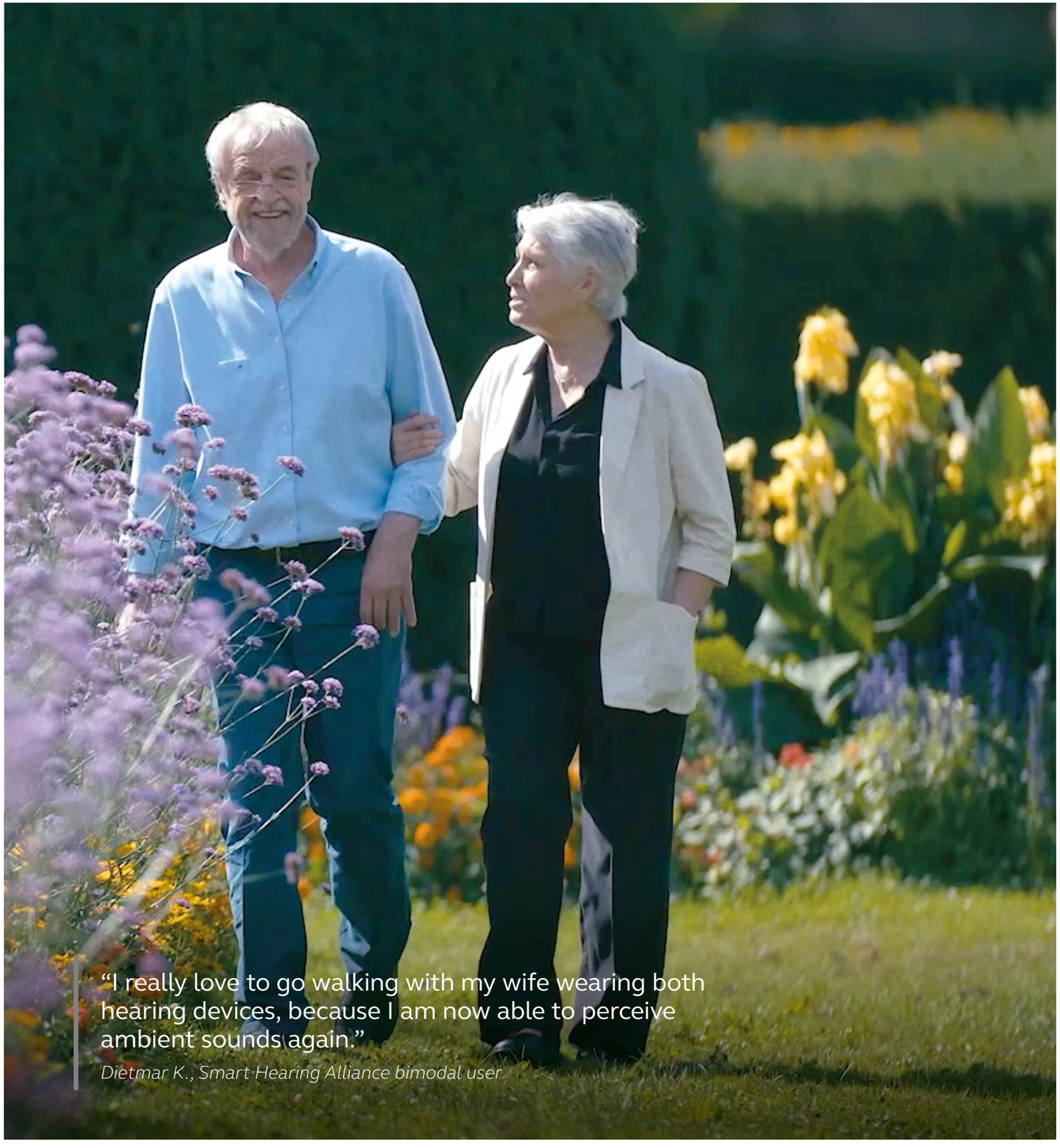
Change from baseline to 6-month study visit for primary and secondary outcome measures*



*Graph reproduced using the data provided in the study.

Key finding: Bimodal hearing listeners reported significant group mean increases in health-related quality of life benefits compared to bilateral hearing aids

Sladen DP, Carlson ML, Dowling BP, Olund AP, DeJong MD, Breneman A, Hollander S, Beatty CW, Neff BA, Driscoll CL. Cochlear implantation in adults with asymmetric hearing loss: Speech recognition in quiet and in noise, and health related quality of life. Otol Neurotol. 2018 Jun;39(5):576-581. doi: 10.1097/MAO.0000000000001763. PMID: 29683995.



Bimodal hearing delivers functional hearing benefits and improved satisfaction with daily hearing

For those using a bimodal hearing solution, access to binaural hearing can provide a range of functional hearing benefits in their daily life – benefits they might not experience with a single hearing device. Whilst speech discrimination benefits may be primarily provided by the hearing implant, the studies on the following pages demonstrate that when the implant is used in combination with a hearing aid on the contralateral ear, it can positively impact the hearing-impaired adult's satisfaction with their daily hearing.

The evidence shows that a significantly higher number of bimodal hearing users report being satisfied or very satisfied with their hearing ability during a variety of daily listening activities, compared to their satisfaction when using hearing aids. In addition to reduced listening fatigue, the studies also demonstrated significant and clinically important improvements for hearing speech in daily life, quality of sound, and localization of sounds for bimodal hearing users, compared to when they used one or two hearing aids.

Influence of contralateral acoustic hearing on adult bimodal outcomes after cochlear implantation. *Plant K et al.*

This single center study explored the benefits of bimodal hearing including activities in real-world daily life for adults implanted with a CI. The study enrolled 40 CI adults, deafened after acquiring spoken language (i.e. postlinguistically) who had substantial levels of hearing in the opposite ear. The opposite ear was considered outside typical CI candidacy criteria. Before implantation, most adults wore bilateral HAs. After implantation, CI users listened daily with either a HA in the contralateral ear (bimodal hearing) or without a HA (natural acoustic hearing). Participants completed the International Outcome Inventory (IOI) 12-months after implantation and the customized Device Use Questionnaire (DUQ) at before implantation and 12-months after implantation. Both questionnaires capture self-report on listening in daily life.

After implantation, 36/40 (90%) participants completed the IOI. The majority, N = 26 (72%), reported more than eight hours of daily CI use. Most participants indicated the CI "helped them very much" when listening in environments where they really wanted to hear better, that the CI was "very much worth" the trouble, and that the CI helped to increase their overall enjoyment of life.

Comparing DUQ responses at before implantation and after implantation, results indicate most participants reported improved hearing ability when listening in quiet (79%); in background noise (61%); to the radio and TV (71%); and to soft sounds (71%). About one third (34%) reported improved listening for localization of sound and about one fifth (21%) reported better hearing on the telephone after implantation compared to before implantation. Most participants used the telephone in their non-implanted ear, either with a HA or without. Some participants reported they used bimodal hearing for listening on the telephone, via a telecoil, speakerphone or Bluetooth® streaming to both devices. Only a few participants used the CI only on the telephone.

Conclusion: This study found significant improvements with bimodal hearing in a group of CI adults with substantial hearing in the opposite ear, as reported for real world daily activities 12-months after implantation compared to before implantation.

Key finding: Demonstration of benefits for daily life from bimodal hearing using real world measures, may offer audiologists confidence to discuss and consider bimodal stimulation for CI candidates with useable hearing in the contralateral ear

Plant K, van Hoesel R, McDermott H, Dawson P, Cowan R. Influence of contralateral acoustic hearing on adult bimodal outcomes after cochlear implantation. Int J Audiol. 2016 Aug;55(8):472-82. doi: 10.1080/14992027.2016.1178857. Epub 2016 May 23. PMID: 27216386.

Self-reported usage, functional benefit, and audiologic characteristics of cochlear implant patients who use a contralateral hearing aid. *Neuman AC et al.*

Investigators developed a questionnaire to analyze experiences of adults implanted with a CI who wore a HA in the opposite ear for at least 3 months. The questionnaire was sent to 101 CI adults with a return rate of 93% (94/101).

The majority of respondents, N = 80 (85%) indicated continued use of a CI + HA (bimodal hearing) with the remaining 14 (15%) reported no longer actively using their HA. Most bimodal participants wore their HA immediately after CI activation and acclimated to both devices by 3-months. 81% of respondents indicated using bimodal hearing > 10 hours/day and 17% between 5 - 10 hours/day. 54% of bimodal users reported never using their HA-alone, while 44% said they might "sometimes". More than half (53%) reported using the CI-alone "sometimes" while 41% reported never using the CI-alone.

Most bimodal hearing users indicated hearing better compared to using one device for listening: in quiet, noisy and reverberant (echoey) environments, and when listening to music. When listening to music, 15% expressed preference for listening with their HA-alone and 16% reported no preference.

When queried about the ability to identify the direction of sound with bimodal hearing, 10% responded they could localize "almost always", 20% "often", 44% "sometimes", while 25% reported not being able to identify the direction of sound.

Bimodal hearing users reported important advantages over CI-alone that included: the overall ability to hear better, benefits of hearing with both ears (i.e. bilaterally), improved sound quality and increased quality of life.

Most participants felt they coped with hearing loss much better following implantation. Bimodal hearing users reported that they coped well with their hearing: "much or all of the time" in 40% of cases before implantation compared to 86% after; "some of the time" in 37% before implantation compared to 13% after.

Similarly, those who used a CI-alone also indicated coping "much better" after implantation compared to before implantation overall. Specifically, CI-alone users reported that they coped well with their hearing: "much or all of the time" in 21% of cases before and 92% after; "some of the time" in 36% of cases before and 0% after; and "not at all" in 43% of cases before implantation to 8% after.

Conclusion: The evidence from this study group indicated that the majority of CI recipients provided with a contralateral HA experienced important bimodal hearing advantages in daily life compared to using a CI-alone.

Key finding: Based on self-reported hearing benefits, it is recommended that patients who are receiving a unilateral cochlear implant continue to use their hearing aid on the contralateral ear

Neuman AC, Waltzman SB, Shapiro WH, Neukam JD, Zeman AM, Svirsky MA. Self-Reported Usage, Functional Benefit, and Audiologic Characteristics of Cochlear Implant Patients Who Use a Contralateral Hearing Aid. Trends Hear. 2017 Jan;21:2331216517699530. doi: 10.1177/2331216517699530. PMID: 28351216; PMCID: PMC5435367.

Comprehensive hearing aid assessment in adults with bilateral severe-profound sensorineural hearing loss who present for Cochlear implant evaluation. *Lupo JE et al.*

A multicenter clinical trial, described by *Buchman et al. (2020), examined the long- term benefits and safety of a CI for a large adult population with bilateral moderate sloping to profound hearing loss. Co-investigators, Lupo et al., 2020, reported on a self-assessment outcome measure, the Device Use Questionnaire (DUQ), which measures an individual's hearing satisfaction in daily listening situations using hearing devices. The DUQ contains three sections: Hearing Performance, Telephone Use, and Music. Before implantation, participants (N = 95) completed the DUQ with bilateral HAs and 6-months after implantation using bimodal hearing. In addition to overall hearing performance, investigators focused on five questions targeting common, everyday listening conditions: hearing in background noise, listening to music, understanding over the phone, comprehending small group conversations, and following what is said on TV. As HA users often describe feelings of tiredness, fatigue or exhaustion after lengthy listening and communication experiences in noisy or other demanding conditions, investigators reported on participants' level of fatigue after daily listening using ratings from "very tired" to "very alert".

The figure shows proportions of participants describing hearing satisfaction before implantation and 6-months after implantation.

With bimodal hearing, most participants were satisfied or very satisfied with understanding in small groups (79%), listening to TV (76%), to music (68%), and over the phone (71%) in strong contrast to less than 15% expressing satisfaction with bilateral HAs in the same situations.

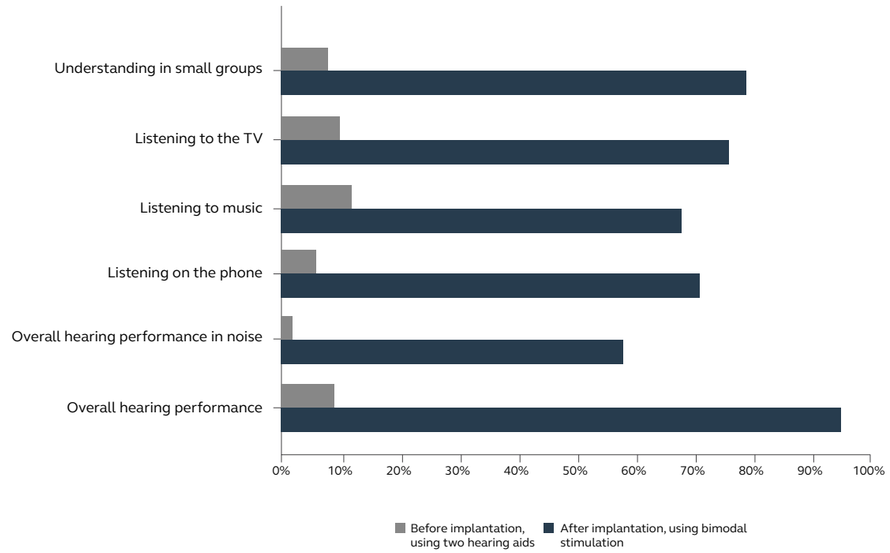
Overall hearing satisfaction increased significantly from N = 9 (9%) adults with bilateral HAs to N = 90 (95%) with bimodal hearing being satisfied/very satisfied. For the challenging "understanding speech in noise" situation, N = 2 (2%) were satisfied using two HAs compared to N = 55 (58%) when using bimodal hearing. When using HAs before implantation, N = 77 (81%) reported they were fatigued compared to N = 34 (36%) for daily listening with bimodal hearing.

Conclusion: Information gained from self-reported satisfaction with hearing ability and reports of daily listening fatigue showed the significant bimodal advantages adult CI recipients can obtain compared to when using bilateral HAs.

Key finding: Bimodal hearing can offer hearing performance advantages in daily life as well as reduced fatigue

Bimodal hearing delivers functional hearing benefits and improved satisfaction with daily hearing

Proportion of subjects reporting satisfaction (DUQ)^



^Graph reproduced using the data provided in the study.

*Buchman CA, Herzog JA, McJunkin JL, et al. Assessment of speech understanding after cochlear implantation in adult hearing aid users: A nonrandomized controlled trial. JAMA Otolaryngol Head Neck Surg. Published online August 27, 2020. doi:10.1001/jamaoto.2020.1584.

Lupo JE, Biever A, Kelsall DC. Comprehensive hearing aid assessment in adults with bilateral severe-profound sensorineural hearing loss who present for Cochlear implant evaluation. Am J Otolaryngol. 2020 Mar-Apr;41(2):102300. doi: 10.1016/j.amjoto.2019.102300. Epub 2019 Sep 11. PMID: 31761407.

Bimodal hearing benefits from direct audio streaming

Many bimodal users can hear and understand well in quiet environments, especially when they can see the individual speaking. However, listening and participating in conversations in noisy places or on a phone can be more challenging. In these situations, wireless assistive listening technologies which stream the audio signal directly to both the cochlear implant sound processor and hearing aid, can assist bimodal users in communicating more effectively.

The studies on the following pages demonstrate the advantages of direct audio streaming for bimodal users when compared to using a cochlear implant alone. Results indicate wireless audio streaming accessories may offer further improvement in speech understanding in noisy situations when used with bimodal hearing compared to the cochlear implant alone. Performance with direct audio streaming of phone calls to bimodal devices was also shown to improve communication ability on the phone compared when using only an implant.

> “Direct streaming my phone calls makes it a lot easier in harsh environments like windy conditions or if it's noisy in a bar or a restaurant.”
>
> *Kasper N., Smart Hearing Alliance bimodal user*

Evaluation of a wireless remote microphone in bimodal cochlear implant recipients. *Vroegop JL et al.*

Cochlear™ and ReSound® upgraded their wireless microphone systems that transmit sound output from any external audio source to a sound processor and a hearing aid simultaneously. In this prospective study, Vroegop and colleagues evaluated 13 experienced bimodal postlingual adult participants who wore a Nucleus® 6 Sound Processor and a ReSound HA in different listening conditions.

Participants listened to Dutch sentences in noise with their CI-alone and bimodally with and without the Cochlear Wireless Mini Microphone. Researchers utilized an adaptive procedure to determine the signal-to-noise ratio (SNR) for 50% correct words speech reception threshold (SRT). See table below for 'Evaluation of listening conditions on the telephone'.

Sentences in noise results showed a significant 5.4 dB SRT improvement for the group when using the CI-alone paired to the Mini Microphone compared to using the CI without the Mini Microphone. With the Mini Microphone paired to the CI and HA, an additional 2.2 dB SRT improvement resulted compared to the Mini Microphone paired to the CI-alone.

Ten (77%) participants used the Mini Microphone connected to both devices during a three week at-home trial. They recorded information using a visual analog scale documenting if the Mini Microphone decreased or increased speech understanding in a given situation.

Researchers found significant improvements for the Mini Microphone compared to no Mini Microphone for one-on-one conversations in quiet and noise, for group conversations in quiet, for listening from a distance and for listening using a smartphone or tablet. Recipients reported a clinically meaningful benefit for everyday listening environments when using the Mini Microphone compared to not using it.

Conclusion: The Mini Microphone provided clear improvements for hearing with a CI-alone and bimodal conditions compared to listening without the Mini Microphone. Results with bimodal listening with the Mini Microphone were superior to those when only a CI-alone was used.

Evaluation of listening conditions on the telephone

Devices	Mini Microphone	No Mini Microphone
Unilateral CI only	✓	✓
Bimodal hearing (CI + HA)	✓	✓

Key finding: Using the Mini Microphone with bimodal hearing in noisy situations results in better group mean speech understanding over the phone

Vroegop JL, Dingemanse JG, Homans NC, Goedegebure A. Evaluation of a wireless remote microphone in bimodal cochlear implant recipients. Int J Audiol. 2017 Sep;56(9):643-649. doi: 10.1080/14992027.2017.1308565. Epub 2017 Apr 10. PMID: 28395552.

Speech recognition of bimodal cochlear implant recipients using a wireless audio streaming accessory for the telephone. *Wolfe J et al.*

In this prospective study, Wolfe and colleagues investigated use of the Cochlear™ Wireless Phone Clip with 12 adult bimodal listeners when communicating with an iPhone. For all evaluations, participants used a Nucleus® 6 Sound Processor and a ReSound HA in the contralateral ear (bimodal hearing).

Investigators evaluated participants' Consonant-Nucleus-Consonant (CNC) word recognition in quiet and in 65 dBA classroom noise, with the iPhone receiver held to the sound processor (SP) microphone and HA in contralateral ear. Also, they evaluated participants in quiet and 65 dBA classroom noise with the iPhone signal wirelessly streamed via the Cochlear Phone Clip to the sound processor and HA. See table below for 'Evaluation of word scores via a mobile phone with and without wireless accessories'.

Statistical analysis of data from these 12 participants revealed significantly better bimodal speech understanding in quiet compared to in noise. Significantly better bimodal performance was observed in quiet and noise when the phone signal was streamed via the Phone Clip.

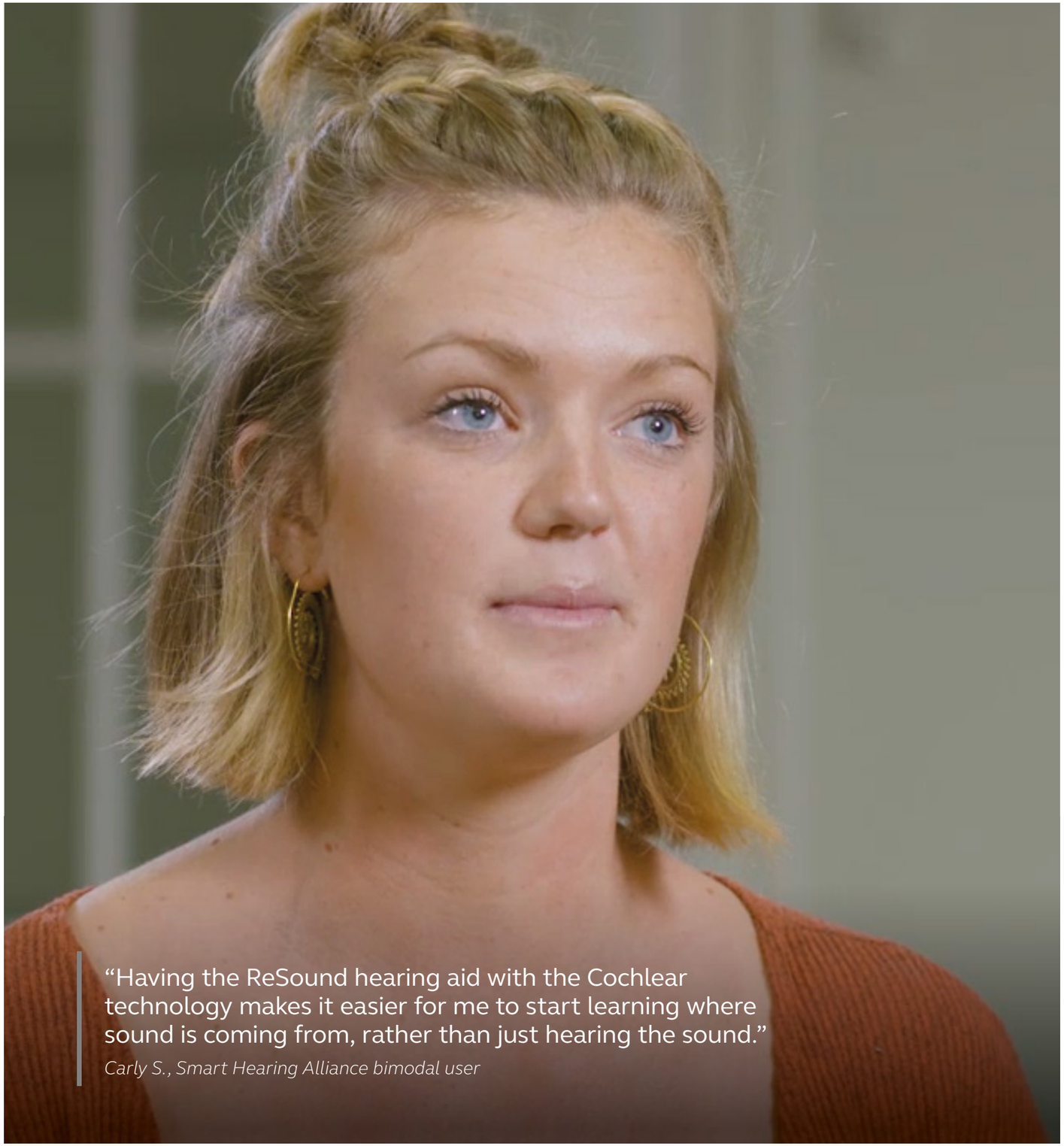
Conclusion: Bimodal speech comprehension using a mobile phone was significantly better when the signal was wirelessly streamed using a Phone Clip. On average, understanding of speech via the mobile phone with audio streaming improved by 25% in quiet and 23% in noise.

Evaluation of word scores via a mobile phone with and without wireless accessories

CNC Words	Tests in Quiet	Tests in Noise
iPhone receiver held to SP microphone; contralateral HA used	✓	✓
iPhone signal streamed by Phone Clip to SP & HA	✓	✓

Key finding: Wireless audio streaming over the phone can improve bimodal speech understanding compared to without streaming

Wolfe J, Morais M, Schafer E. Speech recognition of bimodal cochlear implant recipients using a wireless audio streaming accessory for the telephone. Otol Neurotol. 2016 Feb;37(2):e20-5. doi: 10.1097/MAO.0000000000000903. PMID: 26756151.



> “Having the ReSound hearing aid with the Cochlear technology makes it easier for me to start learning where sound is coming from, rather than just hearing the sound.”
>
> *Carly S., Smart Hearing Alliance bimodal user*

Bimodal hearing benefits for sound localization

Sound localization relies upon the brain receiving and processing audio signal information from both ears, so that individuals can identify where sounds are coming from. This enables them to orient toward sound sources or be alerted to potential danger in the environment.

For individuals using a single cochlear implant, the addition of a hearing aid on the other ear may offer sound localization benefits. In the studies on the following pages, the degree of binaural benefit for an individual in terms of sound localization is reported. The benefits obtained may be influenced by the level of hearing in each ear and the resulting degree of asymmetry between the ears.

Results in adult cochlear implant recipients with varied asymmetric hearing: A prospective longitudinal study of speech recognition, localization, and participant report. *Firszt JB et al.*

Firszt and colleagues evaluated 47 postlingual adults who had moderate-to-profound hearing loss in the poorer ear, scored < 50% on open-set sentences and exhibited a better-hearing ear. Asymmetry was based on the difference between the ears with the better ear ranging from normal to moderately-severe hearing impairment.

During the sound localization evaluation, participants were seated in the center of a 15 loudspeaker array, with a spoken word stimulus randomly presented from one of the loudspeakers. Participants were asked to identify which loudspeaker presented each word, with investigators calculating the root mean square (RMS) error score in degrees.

localization at 6-months after implantation in the everyday listening conditions significantly improved vs before implantation and remained stable to 12-months. Across listening conditions, group mean error scores for the better ear and bimodal hearing were significantly greater than chance, while mean CI-only scores were not different from chance. Typically, older participants demonstrated poorer localization than younger participants. Participants with early severe-to-profound hearing loss (SPHL) onset exhibited better bimodal localization than those with later SPHL.

In order to appreciate the influence of better ear hearing on bimodal performance, participants were grouped by better ear PTA: Group 1 PTA ≤ 40 dB HL, Group 2 = 41 to 55 dB HL, and Group 3 = 56 to 70 dB HL. Analyses revealed that bimodal localization at 6-months was significantly better than either ear alone for the three groups. Individual ear comparisons revealed Group 1 demonstrated better ear-alone localization than CI-alone localization; Groups 2 and 3 did not exhibit significant individual ear differences. Group 1 better ear-alone localization was significantly better than chance level, which was not the case for Groups 2 and 3.

Conclusion: For this group of postlingual adults with asymmetric hearing loss, bimodal hearing was effective at reducing errors in sound localization. Investigators suggest that clinical assessments for those with asymmetric hearing levels should include sound localization.

Key finding: On average, localization with bimodal hearing was significantly better than localization with hearing aids before implantation

Firszt JB, Reeder RM, Holden LK, Dwyer NY; Asymmetric hearing study team. Results in adult cochlear implant recipients with varied asymmetric hearing: A prospective longitudinal study of speech recognition, localization, and participant report. Ear Hear. 2018 Sep/Oct;39(5):845-862. doi: 10.1097/AUD.0000000000000548. PMID: 29373326; PMCID: PMC6103899.

Effect of aided hearing in the nonimplanted ear on bimodal hearing. *Jang JH et al.*

Jang and colleagues evaluated sound localization abilities in 17 participants (N = 8 prelingual, N = 5 perilingual and N = 4 postlingual); all wore a HA in the contralateral ear prior to implantation.localization was assessed in CI-alone and bimodal listening conditions.

Investigators evaluated localization ability in four conditions: unilateral CI in quiet and noise conditions and bimodal hearing in quiet and noise. Disyllabic words were presented from one of 12 randomly selected loudspeakers that were positioned in a horizontal arc surrounding participants. The bimodal mean angle difference was significantly smaller for disyllabic words in quiet compared to CI-only listening; however in noise, the angle difference between the two listening conditions was comparable.

Participants were divided into two groups based on their aided thresholds in the non- implanted ear using PTA at .5, 1, 2 and 3kHz: Group 1 < 50 dB HL PTA {N = 8}, Group 2 > 50 dB HL PTA {N = 9}.

Group 1 exhibited a significantly smaller mean localization angle difference compared to Group 2 in both quiet and noise conditions.

Conclusion: Although the study sample is small, outcomes suggest important bimodal benefits for sound source localization when aided hearing thresholds provide sufficient audibility.

Key finding: On average, sound localization with bimodal hearing is better than localization with a unilateral cochlear implant

Jang JH, Lee JH, Chang SO, Oh SH. Effect of aided hearing in the nonimplanted ear on bimodal hearing. Otol Neurotol. 2014;35: e270-6.

Bimodal hearing benefits for music appreciation

Bimodal hearing can offer improvements in the perception, enjoyment and engagement in music related activities compared to hearing with a cochlear implant alone. This is because the contralateral hearing aid provides low frequency acoustic amplification which enhances pitch and fine temporal structure to make listening to music a richer and more enjoyable experience.

The studies summarized on the following pages found that when listening to music, on average bimodal hearing users achieved better hearing performance when wideband frequency amplification was used in the hearing aid compared to narrower frequency bands. Furthermore, recognition of musical instruments was superior with bimodal configuration compared with using either a cochlear implant or hearing aid alone.

Bimodal benefit for music perception: Effect of acoustic bandwidth.
D'Onofrio KL et al.

D'Onofrio and Gifford investigated acoustic bandwidth to determine the minimum and optimal bandwidth for bimodal benefit of timbre perception, musical sound quality, and speech understanding. They hypothesized that bimodal perception would improve with increasing audible acoustic bandwidth in the HA ear.

Twelve bimodal listeners and twelve Normal-Hearing (NH) controls completed a music sophistication test. Results confirmed a relatively low level of sophistication and comparable musical background between groups.

Investigators evaluated music perception with timbre perception measures and sound quality using real-world music samples. NH participants listened monaurally and bilaterally with insert earphones. Bimodal participants listened via Direct Audio Input (DAI) for CI-alone, and bimodally via DAI and an insert earphone. Test conditions were: CI-only, CI + HA (<125), CI + HA (<250), CI + HA(<500), CI + HA (<750) Hz, and CI + HA wideband (WB). Investigators also used these conditions to evaluate bimodal participants' monosyllabic word understanding in quiet.

The control group showed no difference in timbre perception when listening monaurally or bilaterally. Bimodal listeners demonstrated their best performance in the bimodal (WB) condition. There was a significant difference between bimodal (<250) and bimodal (WB). Other comparisons were not significant.

Regarding sound quality, NH listeners rated "participant-chosen" higher than "researcher-chosen" songs for monaural and bilateral listening. Bimodal listeners' ratings increased with more acoustic information. Bimodal listeners' ratings reached the NH ratings for "researcher-chosen" songs and surpassed them for "participant-chosen" songs. CI-alone and CI + WB ratings were significantly different.

Bimodal listeners' mean word understanding increased with additional acoustic information and mean improvements were significant between CI-alone and: CI + 250, CI + 500, CI + 750 Hz, and CI + WB.

The relationships between bimodal benefit (CI + WB) and PTA, and between HFPTA and CI + WB bimodal benefit were significant.

Conclusion: Substantial bimodal benefit for individuals with residual hearing in the non-CI ear can be obtained for both speech and music. A trend toward improved performance for all stimuli with increasing acoustic bandwidth was observed.

Key finding: These findings suggest that wideband amplification can improve listening to speech and music for users of bimodal hearing

D'Onofrio KL and Gifford RH. Bimodal benefit for music perception: Effect of acoustic bandwidth. JSLH; 2021, 64: 1341–1353.

Participation of acoustic and electric hearing in perceiving musical sounds.
Duret S et al.

This prospective, cross-sectional study included 19 postlingual adults with a CI and contralateral moderate-to-severe hearing loss. All participants exhibited an aided PTA < 60 dB. Twenty-one normal hearing (NH) participants were controls. Participants listened to a music perception test that included sound, syntax, and music sense in HA-, CI-only and bimodal conditions. They completed a music questionnaire that asked questions regarding musical experience, such as quantity of listening, sound quality, instrument identification, and overall significance of and participation in music, as well as the Abbreviated Profile of Hearing Aid Benefit (APHAB). The APHAB divides 24 questions into four categories: Ease of Communication (EC): effort to communicate under relatively favorable conditions, Reverberation (RV): communication in rooms with high reverberation, Background Noise (BN): communication in environments with high background noise, and Aversiveness (AV): unpleasant or disturbing aspects of sounds.

Results showed the NH controls obtained better mean overall music perception scores compared to study participants in HA-only, CI-only and bimodal listening conditions.

Participants performed significantly better in HA-only compared to the CI- only condition; however, bimodal was significantly better than CI-only listening.

Bimodal listening was superior to HA- or CI- only performance for identifying musical characteristics of brightness, roughness, clarity and instruments. HA-only listening exhibited better performance for texture, polyphony and emotion. NH controls performed better on emotion than CI participants.

The APHAB was administered before implantation and after implantation. Results indicated significantly better group mean scores after implantation for all subdomains, with exception of aversiveness that was non-significant. The mean global score was also significantly better after implantation compared to before implantation.

Results of the music questionnaire suggested that on average music was moderately important to participants with 58% (N=11) routinely attending musical events. For 95% (N=18) indicated music was pleasant, 84% (N=16) reported identifying melodies and 89% (N=17) had good rhythm perception, while 63% (N=12) frequently listened to solo and orchestral music.

Conclusion: This music test battery provided useful information regarding music sound quality in the bimodal condition. Music was reported to be moderately important on average, to CI users. While normal hearing individuals outperformed bimodal listeners on musical tasks, bimodal listeners achieved better music outcomes than when using a CI-alone.

Key finding: A hearing aid provides musical information that complements the information available via the cochlear implant and can help improve overall music perception and enjoyment

Duret S, Bigand E, Guigou C, Marty N, Lalitte P, Bozorg Grayeli A. Participation of Acoustic and Electric Hearing in Perceiving Musical Sounds. Front Neurosci. 2021 May 5;15:558421. doi: 10.3389/fnins.2021.558421. PMID: 34025335; PMCID: PMC8131516.

Efficacy of music training in hearing aid and cochlear implant users: A systematic review and meta-analysis. *Shukor NFA et al.*

Shukor and colleagues performed a systematic review and meta-analysis of articles published from 2018-2019 to investigate the therapeutic effects of music training for individuals who used HAs, CI, or both devices (bimodal hearing).

This review included studies comprising 1) children and/or adults with unilateral or bilateral HAs or CI, 2) individuals participating in music training for rehabilitation, 3) before- vs after-rehabilitation result(s) or repeated measures, 4) outcome measure(s) related to speech perception, auditory or musical perception, or communication improvement(s), and 5) randomized or non- randomized controlled trials, cohort studies, and repeated measures describing before and after training results. After applying the researchers' inclusion and exclusion criteria, 15 articles out of 9,021 were selected for review of which 10 were included in the final meta-analysis. These studies included 186 adult (N = 101) and pediatric (N = 85) participants.

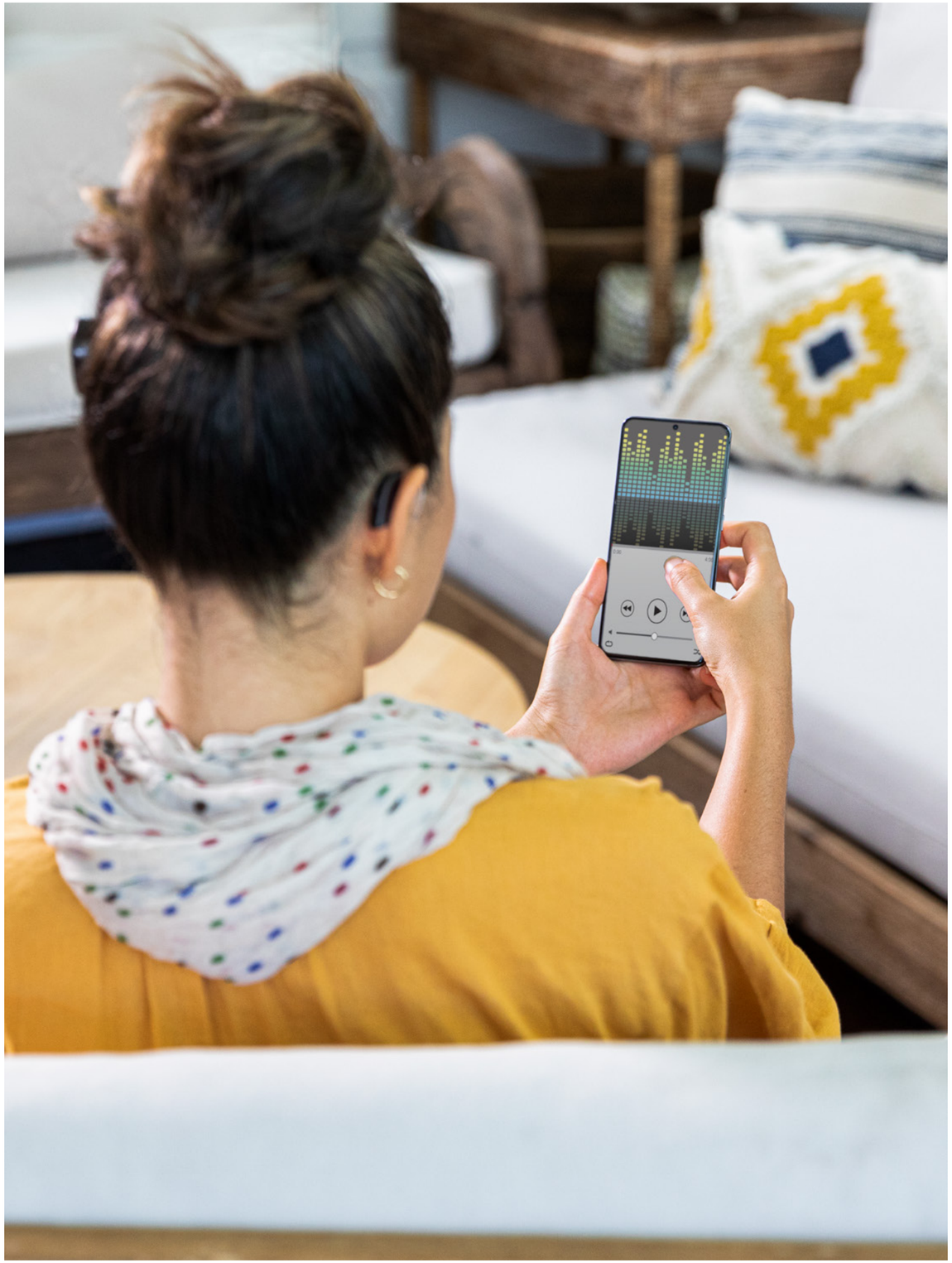
In a pooled analysis, participants' music perception was significantly better after receiving music training. Sub-group analyses revealed that the music rehabilitation effect was greater for children than for adults.

With respect to devices, the effect size for CI-only users was greater than for bimodal listeners, suggesting a stronger treatment effect for CI-only users. Previous music experience did not result in a significant difference, suggesting that musical experience did not impact training effectiveness, although heterogeneity was substantial. Studies evaluating short, intermediate or long training periods found that longer training periods exhibited notably stronger training effects than short-duration training periods.

Conclusion: Outcomes from this systematic review and meta-analysis indicated music training can be effective in aural rehabilitation as it improves hearing and musical perception in adults and children with hearing loss using hearing devices, irrespective of their previous music experience.

Key finding: Music training performed for 12-months or longer can result in better music perception

Shukor NFA, Lee J, Seo YJ, Han W. Efficacy of Music Training in Hearing Aid and Cochlear Implant Users: A Systematic Review and Meta-Analysis. Clin Exp Otorhinolaryngol. 2021 Feb;14(1):15-28. doi: 10.21053/ceo.2020.00101. Epub 2020 Jul 11. PMID: 32646208; PMCID: PMC7904420.



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