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Brief Overview about Bimodal fitting

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Abstract

The cochlear implant (CI) not only restores auditory function but also has numerous benefits on psychomotor development and the maturation of central auditory pathways. In a bimodal fitting, one ear is stimulated electrically and the other acoustically. Candidates for bimodal fitting are people with severe-to profound hearing loss who receive a cochlear implant in one ear and have residual hearing in the non-implanted ear. Combining low-frequency information delivered via a hearing aid (HA) with high-frequency information delivered via a cochlear implant add potential advantages because the two types of information complement each other . Studies examining bimodal fitting have found bimodal benefits in quiet as well as in noise. Bimodal hearing has also been shown to improve quality of life in social activities**.** For children, in addition to better speech recognition in noise, localization and musical perception, bimodal stimulation has been demonstrated to improve language acquisition and outcome**.** It also provides a good and cost-effective nonsurgical alternative to bilateral CI. Although both HA and CI utilize very different signal processing algorithms, the bimodal recipients preferred the sound quality of matched devices and demonstrated improved speech understanding.The CI and HA should be assessed both individually and together. While the technology of the two devices is immensely different, clinicians should be mindful that they are used to process information related to hearing by the same listener. The assessmnt invloved subjective and objective measures. Cilincal recommendation for bimodal fiiting have been established.

Keywords: Bimodal fitting, Bimodal stimulation, residual hearing, speech recognition.

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1. Introduction

Bimodal hearing means combining the benefits of electric hearing using cochlear implant (CI) in one implanted ear with acoustic hearing using hearing aid (HA) in the other non-implanted one. The result is a richer and more natural hearing experience. While bilateral CI is the only option for people with bilateral profound hearing loss, bimodal fitting is considered a noninvasive alternative for people with residual hearing in the other ear [1]. Dorman & Gifford, [2] reported that 60% of unilateral CI recipients had aid able residual hearing in the non-implanted ear and more recently, Holder et al. [3] reported this number had risen to 85% making bimodal candidates the most common patient profile seen by CI clinicians.

2. Candidates for bimodal fitting

Patients with bilateral severe to profound hearing loss: a CI in one ear and a HA on the other, in cases where the contralateral ear has residual hearing. Historically, CIs were only an option for post-lingually deafened individuals with bilateral profound hearing loss. Now that criteria have expanded to include individuals with less severe hearing loss and many of these users present with aidable hearing in the contralateral ear. Patients with asymmetric hearing loss, or when the poorer ear is in the severe-to-profound range but the contralateral ear has hearing loss in the moderate-to-severe range or better [4].

3. Bimodal benefits

For unilateral CI recipients, the benefits derived from the addition of a HA on the contralateral ear is often referred to as bimodal benefits. These benefits can generally be divided into:

- Benefits related to receiving sound into two ears, such as localization, recognizing speech in spatially separated noise, binaural summation and binaural squelch [5]. Bimodal speech in noise benefits could be due to the increased access to the temporal fine structure of speech, such as variations in fundamental frequency (F0), allowing the listener to ‘‘glimpse’’ the sound stream coming from the target talker and thus distinguish it from the noise [6].
- Benefits related to low frequency perception, supported by the additional information within low frequencies provided by acoustically stimulating the residual hearing through a HA. It provides better perception of voice pitch, which allow bimodal listeners to distinguish different talkers and recognize speech prosody (i.e., the pattern,

rhythm, and syllable stress and word emphasis), intonation and emotion [7].

- Benefits for environmental sound recognition: it has been demonstrated that CI listeners generally perform poorly on recognition of environmental sounds. This poor performance may be partially due to a lack of transmission of important low frequency spectro-temporal cues through the CI, which might be more accessible to bimodal listeners [8].
- Benefits for music perception and appreciation: bimodal hearing provides significantly better musical sound quality and music perception abilities over CI-alone listening, including benefits for chord, melody and melodic contour recognition. In addition, D'Onofrio et al. [9] found significant bimodal benefits, over CI-alone listening, for music emotion recognition and musical sound quality ratings across all musical genres.
- Bimodal hearing may improve patient-reported quality of life as a result of more natural sounding speech and reduced listening effort, as well as subjective functional improvements in real life situations [10].
- Specifically for children, bimodal hearing promotes symmetric development of the bilateral auditory pathways for children who have sufficient residual hearing and received an implant with limited delay. This allows symmetric neural conduction in bilateral brainstem pathways. In auditory cortices, expected contralateral representation of each ear rapidly developed within six to ten months of implant use and consistently maintained this expected organization after two years of bimodal hearing experience [11].

4. Bimodal hearing versus bilateral CIs

As bimodal hearing clearly offers advantages over unilateral CI, the comparison between bimodal hearing and bilateral CIs must be considered as there are many listening conditions and associated auditory tasks for which there may be performance differences between bimodal and bilateral CI users. Nevertheless, both bimodal and bilateral CI recipients demonstrate binaural summation, but bilateral CI users may exhibit similar or even less binaural summation than bimodal listeners on tasks of speech recognition in quiet or in noise. This is thought to be due to complementary, yet different information provided across ears in a bimodal hearing configuration [12]. Head shadow may also differ across bimodal listening and bilateral CI stimulation. In bimodal listeners, the poorer hearing ear, typically the HA ear, will derive little-to-no benefit from head shadow. Conversely, bilateral CI users generally exhibit symmetrical head shadow across both ears due to the availability of interaural level differences [13]. In addition, binaural squelch (binaural unmasking of speech) is not available for bimodal listeners and not robust for bilateral CI users.

Binaural squelch is mainly dependent upon sensitivity to interaural time difference which is not available across hearing modalities for both bimodal listeners and bilateral CI users [14]. Spatial release from masking is another phenomenon for which hearing with two ears provides significant benefit. Spatial release from masking is thought to be due to a combination of both head shadow and binaural squelch, depending on spectral and temporal characteristics of the signal and distracters as well as the spatial location of signal and distracters. Weissgerber et al. [15] have shown that both bimodal and bilateral CI users derive benefit from spatial release from masking with similar degrees of benefit. Finally, spatial hearing abilities may differ for bimodal and bilateral CI users. Sound localization for bilateral CI users has shown to be significantly better than bimodal hearing can afford. Mechanism driving bilateral CI benefit for both speech understanding & localization thought to be due to availability of interaural level differences cues. In contrast, bimodal listeners generally do not have access to these cuses [16].

5. Challenges of bimodal fitting

The outcomes with bimodal hearing can be highly variable, with some users experiencing more benefits than others**.** In addition, some individuals may even experience interference with integration of electric and acoustic input or variable dynamic ranges between ears, which can create both within-ear and across-ear sound perception difficulties. Spectral mismatch b/w both ears also can lead to unnatural auditory perceptions. Traditional hearing aid formulas are not designed to align the acoustic and the electric signal processing, which is required for optimal bimodal hearing. As they focus amplification in frequency regions that are important for speech understanding, in the range between 1000 and 4000 Hz. However, research has shown that low frequency information (in the range of 250 Hz to 750 Hz) may be the most important to maximize bimodal benefit**.** So, using a traditional fitting formula with a bimodal recipient may result in a misaligned frequency response by providing inappropriate gain across the frequency range of the hearing aid. As they often do not provide enough low frequency gain and may provide too much gain in frequencies where the recipient may not receive benefit because of their degree of hearing loss [17]. Low compression thresholds and moderate compression ratios are usually prescribed in hearing aids while cochlear implants use very different input/output functions. So, using a traditional fitting formula with a bimodal recipient may also result in misaligned loudness growth because the two devices have very different compression thresholds and compression ratios Hearing aid compression thresholds are typically lower than those in a cochlear implant [18].

6. Guidelines for bimodal fitting

In bimodal fitting, harmonious and balanced adjustment of both CI and HA is very important to achieve the desired utility and listening comfort. Therefore, bimodal fitting considerations could be categorized into frequency response of the HA, HA fitting formula, use of frequency lowering technology, synchronization of automatic gain control (AGC) between HA and CI and interaural loudness balancing [19].

- ***Frequency response of the HA***

Generally, the frequency response of the HA needs to be optimal for speech perception. To achieve this, the HA must be capable of wide dynamic range compression (WDRC). The usefulness of a broadband frequency response in HA compared to limited high-frequency amplification have also been examined. Neuman & Svirsky [20] and Davidson et al. [21] reported significant usefulness in cases of broadband frequency response compared to limited high-frequency amplification. This suggests that the response should be band limited only in special occasions, such as feedback problems of the HA, user complaints about poor sound quality or the presence of cochlear dead regions. For patients with confirmed dead regions, limited high frequency amplification produced significantly higher speech detection than broadband frequency bandwidth [22].

- ***HA fitting formula***

Digeser et al. [23] reported that National acoustic laboratories (NAL) formula or a similar prescription rule is a good starting point in bimodal HA fitting and may even provide a (near)-optimal solution for the majority of bimodal users. Moreover, Ching et al. [24] reported that The National Acoustics Laboratory formula-non linear1 (NALNL1) formula for HA fitting is the proposed fitting method for bimodal fitting cases and provides the desired frequency response. The National Acoustics Laboratory formula-non-linear2 (NAL-NL2) and desired sensation level (DSL) formulas can also be useful. For patients with moderate to severe hearing loss and the experience of using a HA in the opposite ear, DSL v5.0 may provide better speech comprehension and greater utility.

- ***Use of frequency lowering technology***

In bimodal CI users, the type of hearing loss in the non-implanted ear is more or less heterogeneous between subjects (either steep sloping hearing losses or relatively flat hearing losses). When selecting subjects with relatively good low frequency hearing and precipitously sloping high-frequency hearing loss, more benefit from frequency lowering technology can be found [25].

- ***Synchronization of automatic gain control (AGC) between HA and CI***

Matched AGC helps to equalize loudness between HA and CI when the devices are in compression, which is favorable to binaural processing. However, the effects of synchronizing the dynamic compression between HA and CI on auditory performance are varied. Dwyer et al. [26] reported improved spatial hearing abilities with synchronized AGC. Conversely, Vroegop et al. [27] reported that no difference in auditory performance was found when using the same AGC matching. It is evident that more data are needed to provide clarity on this topic.

- ***Interaural loudness balancing***

Due to the different bandwidths of the hearing in both ears and different listening methods, the balance of loudness in HAs and CIs can be difficult. Ching et al. [28] found that loudness balancing has little effect on the final gain. The required gain differed around three to five dB from the gain derived with a standard fitting rule. An exception was that subjects with limited or no HA experience required seven dB less gain compared with a standardized fitting rule. Clinically, to balance the loudness level, broadcast a speech signal from the speaker in front of the patient (zero-degree azimuth) and ask the patient to indicate from which level he hears the sound. Then the volume level settings in the HA is changed so that it finally hears the sound from the midline. The implant settings are not changed because they are assumed to be set at the desired listening level [29].

7. Bimodal hearing assessment and evaluation of patient performance

Individual ear testing of the CI and HA separately allows assessment of the function of each ear by monitoring performance. This facilitates early detection of any change in performance over time which may be attributed to the device, or peripheral or central problems of the listener. Initially, the threshold equalizing noise test (TEN) test should be performed to identify cochlear dead regions. Periodic testing of unaided thresholds of the HA ear should occur annually and is warranted when a decrease in performance is noted. Aided frequency-specific thresholds while using CI and HA should also be tested individually and bimodally. Results can provide information regarding audibility at specific frequencies and can help in making adjustments to each device. Moreover, aided speech recognition scores should be measured to support frequency thresholds [30]. On the other hand, standardized questionnaires can be used to subjectively evaluate the performance. Questionnaires commonly used with pediatric bimodal listeners include the Meaningful Auditory Integration Scale (MAIS) and the Infant-Toddler MAIS (IT-MAIS). With adults, questionnaires such as the Hearing Handicap Inventory for Adults (HHIA) for adults younger than 65 years and the Hearing Handicap Inventory for the Elderly for older adults (HHIE) are useful. Questionnaires specifically designed to evaluate benefits of bimodal hearing, such as localization and hearing in complex listening environments, are of particular value when subjectively assessing bimodal benefit. Examples of this type of measure include the Spatial Hearing Questionnaire and the Speech, Spatial and Qualities of Hearing Scale (SSQ) [31].

8. Clinical recommendations for bimodal listeners

When working with individuals using bimodal hearing, it is recommended to use an individualized fitting approach to optimize their technology. Once the CI is optimally fit, the HA output should be analyzed and adjusted to meet prescriptive output targets using real-ear verification and adjusted based on results of the TEN test and individual preference. The devices should be optimized by loudness balancing of sounds between ears. Programming adjustments should be made every six months if needed. When testing speech perception bimodally, speech in quiet and noise should be tested to evaluate the benefits of bimodal hearing in complex listening environments [32]. Moreover, it should be noted that while there is clear evidence that binaural hearing is more beneficial than monaural hearing with individuals who have severe-to-profound hearing loss, limited evidence exists to guide clinicians as to when to recommend a bilateral CI to patients. Therefore, individuals often wait until after the activation of their first CI to decide if they would like to pursue implantation of their contralateral ear. While both ears may be in the CI candidacy range, deciding factors are not always audiometric; other reasons to forgo contralateral CI include sedation risk, fear of additional surgery, fear of loss of residual hearing, inability or unwillingness to commit to additional rehabilitation, disinterest in second CI and financial reasons. A second CI should be considered if an individual is not receiving benefit from the contralateral HA or if the individual indicates high motivation for a second CI [32].

References

[1] T.Y. Ching, R. Massie, E. Van Wanrooy, E. Rushbrooke, C. Psarros. (2009). Bimodal fitting or bilateral implantation? Cochlear Implants International. 10(S1): 23-27.

[2] M.F. Dorman, R.H. Gifford. (2010). Combining acoustic and electric stimulation in the service of speech recognition. International journal of audiology. 49(12): 912-919.

[3] J.T. Holder, S.M. Reynolds, L.W. Sunderhaus, R.H. Gifford. (2018). Current profile of adults presenting for preoperative cochlear implant evaluation. Trends in hearing. 22: 2331216518755288.

[4] M.L. Carlson, D.P. Sladen, D.S. Haynes, C.L. Driscoll, M.D. DeJong, H.C. Erickson, L.W. Sunderhaus, A. Hedley-Williams, E.A. Rosenzweig, T.J. Davis. (2015). Evidence for the expansion of pediatric cochlear implant candidacy. Otology & Neurotology. 36(1): 43-50.

[5] R.H. Gifford, M.F. Dorman. (2019). Bimodal hearing or bilateral cochlear implants? Ask the patient. Ear and hearing. 40(3): 501-516.

[6] C.A. Brown, S.P. Bacon. (2010). Fundamental frequency and speech intelligibility in background noise. Hearing research. 266(1-2): 52-59.

[7] D. Başkent, A. Luckmann, J. Ceha, E. Gaudrain, T.N. Tamati. (2018). The discrimination of voice cues in simulations of bimodal electro-acoustic cochlear-implant hearing. The Journal of the Acoustical Society of America. 143(4): EL292-EL297.

[8] M.S. Harris, L. Boyce, D.B. Pisoni, V. Shafiro, A.C. Moberly. (2017). The relationship between environmental sound awareness and speech recognition skills in experienced cochlear implant users. Otology & Neurotology. 38(9): e308-e314.

[9] K.L. D'Onofrio, M. Caldwell, C. Limb, S. Smith, D.M. Kessler, R.H. Gifford. (2020). Musical emotion perception in bimodal patients: Relative weighting of musical mode and tempo cues. Frontiers in Neuroscience. 14: 114.

[10] C. Pals, A. Sarampalis, M. van Dijk, D. Başkent. (2019). Effects of additional low-pass–filtered speech on listening effort for noise-band–vocoded speech in quiet and in noise. Ear and hearing. 40(1): 3-17.

[11] M.J. Polonenko, B.C. Papsin, K.A. Gordon. (2019). Cortical plasticity with bimodal hearing in children with asymmetric hearing loss. Hearing research. 372: 88-98.

[12] R.J. Van Hoesel. (2012). Contrasting benefits from contralateral implants and hearing aids in cochlear implant users. Hearing research. 288(1-2): 100-113.

[13] R.H. Gifford, M.F. Dorman, S.W. Sheffield, K. Teece, A.P. Olund. (2014). Availability of binaural cues for bilateral implant recipients and bimodal listeners with and without preserved hearing in the implanted ear. Audiology and Neurotology. 19(1): 57-71.

[14] A. Kan, H.G. Jones, R.Y. Litovsky. (2015). Effect of multi-electrode configuration on sensitivity to interaural timing differences in bilateral cochlear-implant users. The Journal of the Acoustical Society of America. 138(6): 3826-3833.

[15] T. Weissgerber, T. Rader, U. Baumann. (2017). Effectiveness of directional microphones in bilateral/bimodal cochlear implant users—Impact of spatial and temporal noise characteristics. Otology & Neurotology. 38(10): e551-e557.

[16] E.J. Macaulay, W.M. Hartmann, B. Rakerd. (2010). The acoustical bright spot and mislocalization of tones by human listeners. The Journal of the Acoustical Society of America. 127(3): 1440-1449.

[17] L.A. Reiss, R.A. Ito, J.L. Eggleston, D.R. Wozny. (2014). Abnormal binaural spectral integration in cochlear implant users. Journal of the Association for Research in Otolaryngology. 15(2): 235-248.

[18] Warren, S.E. and Dunbar, M.N. (2018): Bimodal Hearing in Individuals with Severe-to-Profound Hearing Loss: Benefits, Challenges, and Management. Seminars in hearing, 39(4), 405–413.

[19] J.T. Holder, M.A. Holcomb, H. Snapp, R.F. Labadie, J. Vroegop, C. Rocca, M.S. Elgandy, C. Dunn, R.H. Gifford. (2022). Guidelines for best practice in the audiological management of adults using bimodal hearing configurations. Otology & neurotology open. 2(2): e011.

[20] A.C. Neuman, M.A. Svirsky. (2013). Effect of hearing aid bandwidth on speech recognition performance of listeners using a cochlear implant and contralateral hearing aid (bimodal hearing). Ear and hearing. 34(5): 553-561.

[21] L.S. Davidson, J.B. Firszt, C. Brenner, J.H. Cadieux. (2015). Evaluation of hearing aid frequency response fittings in pediatric and young adult bimodal recipients. Journal of the American Academy of Audiology. 26(04): 393-407.

[22] J.J. Messersmith, L.E. Jorgensen, J.A. Hagg. (2015). Reduction in high-frequency hearing aid gain can improve performance in patients with contralateral cochlear implant: a pilot study. American journal of audiology. 24(4): 462-468.

[23] F.M. Digeser, M. Engler, U. Hoppe. (2020). Comparison of bimodal benefit for the use of DSL v5. 0 and NAL-NL2 in cochlear implant listeners. International journal of audiology. 59(5): 383-391.

[24] T.Y. Ching, P. Incerti, M. Hill. (2004). Binaural benefits for adults who use hearing aids and cochlear implants in opposite ears. Ear and hearing. 25(1): 9-21.

[25] L.C. Veugen, J. Chalupper, L.H. Mens, A.F. Snik, A.J. van Opstal. (2017). Effect of extreme adaptive frequency compression in bimodal listeners on sound localization and speech perception. Cochlear Implants International. 18(5): 266-277.

[26] R.T. Dwyer, C. Chen, P. Hehrmann, N.C. Dwyer, R.H. Gifford. (2021). Synchronized automatic gain control in bilateral cochlear implant recipients yields significant benefit in static and dynamic listening conditions. Trends in hearing. 25: 23312165211014139.

[27] J.L. Vroegop, N.C. Homans, M.P. van der Schroeff, A. Goedegebure. (2019). Comparing two hearing aid fitting algorithms for bimodal cochlear implant users. Ear and hearing. 40(1): 98-106.

[28] T.Y. Ching, M. Hill, J. Brew, P. Incerti, S. Priolo, E. Rushbrook, L. Forsythe. (2005). The effect of auditory experience on speech perception, localization, and functional performance of children who use a cochlear implant and a hearing aid in opposite ears: el efecto de la experiencia auditiva sobre la percepción del lenguaje, la localización y el desempeño funcional en niños que usan un implante coclear y un auxiliar auditivo en el oído opuesto. International journal of audiology. 44(12): 677-690.

[29] K. Kokkinakis, N. Pak. (2014). Binaural advantages in users of bimodal and bilateral cochlear implant devices. The Journal of the Acoustical Society of America. 135(1): EL47-EL53.

[30] K. Uhler, A. Warner-Czyz, R. Gifford, P.W. Group. (2017). Pediatric minimum speech test battery. Journal of the American Academy of Audiology. 28(03): 232-247.

[31] S. Gatehouse, W. Noble. (2004). The speech, spatial and qualities of hearing scale (SSQ). International journal of audiology. 43(2): 85-99.

[32] S.E. Warren, M.N. (2018). Dunbar In Bimodal hearing in individuals with severe-to-profound hearing loss: benefits, challenges, and management, Seminars in Hearing 2018. Thieme Medical Publishers. 405-413.