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REVIEW ARTICLE

An introductory overview of bimodal fitting

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Abstract

Background and Aim: In a bimodal fitting, one ear is stimulated acoustically with a hearing aid and the other is stimulated electrically with a cochlear implant. This paper provides a brief summary of the concept of bimodal fitting, binaural hearing and its importance, the hearing benefits of binaural hearing in bimodal fitting, candidacy and hearing aid adjustment in bimodal fitting cases.

Recent Findings: Researches have shown that bimodal fitting offers a wide range of hearing benefits over unilateral cochlear implants, such as better speech perception in noise, better musical perception, and a better understanding of pitch and tone perception and naturalness of sound perception.

Conclusion: Considering the binaural hearing advantages in bimodal fitting users, it can be concluded that users of unilateral cochlear implants who have measurable residual hearing in their non-implanted ear can use a hearing aid in that ear and enjoy binaural hearing advantages. The hearing aid should be fitted in a way to complement the information obtained through cochlear implantation.

Keywords: Bimodal fitting; cochlear implant; binaural hearing

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Introduction

It has been shown that for people with bilateral hearing loss, binaural hearing is superior to monaural hearing for speech intelligibility, orientation and improving performance in daily life. Bilateral hearing stimulation also helps preventing neurological damage caused by hearing deprivation. While bilateral cochlear implant (CI) is the only option for people with bilateral profound hearing loss, bimodal fitting (combining a CI in one ear and a hearing aid in the opposite ear) is a non-invasive alternative for people with residual hearing in other ear [1].

One of the reasons for poor speech performance in people who use CI is that most of these people are implanted in only one cochlea, and therefore have poor and undesirable performance in the case of using binaural cues. By using a hearing aid in the opposite ear to the implanted ear, they can use these symptoms to some extent and increase their performance in speech comprehension. In this case, the CI sends an electrical signal to one ear and the hearing aid sends an amplified acoustic signal to the opposite ear. The combination of these two inputs is called bimodal fitting [2]. In this article, we have tried to address the importance of this issue by studying some articles in the field of bimodal fitting. These articles have been obtained by searching for the keywords (bimodal fitting, cochlear implant, and binaural hearing) in Scopus, PubMed and Google Scholar Databases, over the last 15 years (2004-2019). Out of hundreds of available articles, 59 articles were reviewed.

In this article, we will first review the binaural hearing and its benefits, and then we will have a brief overview of bimodal fitting and its advantages and disadvantages and candidacy, as well as how to adjust the hearing aid in bimodal cases.

Binaural hearing

Binaural hearing is important for speech perception in noise, localization and tracking different speakers in noise. In a normal hearing mechanism, it is possible to use binaural cues to determine the location of the sound source or to improve the intelligibility of the target signal in noise [3]. Binaural hearing enhances a person's ability to combine, compare, and contrast the acoustic signals received from both ears. Auditory stream segregation and localization, which are the hearing benefits of binaural hearing, play an important role in separating the target signal from the noise and competitive resources [3]. Differentiating between noise and speech is necessary in order to hear effectively in noise, it is needed to be able to pay attention to speech and ignore noise, and this distinction is based on the correct encoding of each of them, although this activity can be done monaurally, using binaural hearing can improve this ability [4].

In general, the presence of binaural hearing improves the ability of localization, tracking the signal and controlling the information of one audio source and focusing on another audio source, pay attention to one ear and control the other ear, judge the movement and distance of the audio source [5]. In situation with multiple speakers (fluctuating noise) where listeners encounter the challenging task of separation of simultaneous speeches, the formation of a perceptible auditory object is done using spatial and non-spatial cues, these cues guide selective attention, allowing the individual to focus on the target sound and at the same time exclude noise and competing speakers [6]. In the case of asymmetric hearing loss, unilateral signal extraction reduces performance results compared to binaural situations [3].

Considering the advantages mentioned for binaural hearing and the importance of binaural hearing in separating the auditory stream and improving the efficiency of spatial hearing and also the effect of these factors on various skills such as speech perception in noise, this inference can be used to prescribe hearing assistant devices such as hearing aids and cochlear implants. Because people with bilateral hearing loss need bilateral stimulation and amplification to develop the neural pathway needed for central auditory processing. It should be noticed that the bilateral cochlear implantation is not possible for everyone, but many of these people can use hearing aids if they have residual hearing in the ear opposite to the implanted ear [2]. Various studies have reported the efficiency of some benefits of binaural hearing, such as localization and increased speech comprehension in silence and noise, for people who use bimodal fitting [2,7,8]. In the use of bimodal fitting, by adding a hearing aid to the cochlear implant, low-frequency speech signals are added to the signal received from the cochlear implant and the competitive sound separation process is aided, and the signal separation is possible through binaural processing mechanisms [7]. Bimodal fitting allows the addition of pitch cues through the use of residual hearing at low frequencies, as well as the ability to separate F0 from competing sounds and leading masking release [2].

Binaural hearing advantages

In general, many positive effects have been reported for binaural hearing, such as better localization with less error [9], better hearing in the presence of background noise and distortion [10], improved auditory discrimination and speech comprehension [11], and better hearing for weaker sounds [12], better sound quality [13], and greater satisfaction with hearing [14]. However, psychoacoustic articles point to three major binaural hearing advantages, which improve hearing

performance in people with normal hearing [15]: head shadow effect (HSE) [16], binaural squelch effect (BSQ) [17] and binaural summation effect (BSU) [18]. HSE occurs when the sources of a target signal, and noise are spatially segregated. When the ear opposite to the noise source is blocked by the HSE, the interaural level difference (ILD) causes signal-to-noise ratio (SNR) mismatch in both ears. The ear opposite to the noise side generally has a higher SNR; therefore, the target signal is more understandable in this ear than the noise-side ear [15]. BSQ or release from masking occurs when the signal and unwanted noise are spatially separated. This release from masking in the presence of noise greatly contributes to the improvement of speech perception. The BSQ needs central auditory processing and results in improved loudness perception when a signal is heard bilaterally, instead of unilaterally [16]. BSU or binaural redundancy is the result of two samples of the same signal from which meaningful information is extracted. In contrast to the BSQ, the BSU does not require spatial separation of noise and signal [17].
Improving speech perception is thought to result from a combination of these advantages (HSE, BSQ, and BSU). All of this may potentially be possible using the bilateral implantation or the bimodal fitting method. Bimodal fitting mode has the added benefit of completing information. This refers to the use of aided acoustic signals (hearing aid) for transmitting low-frequency signals to complement the high-frequency signals provided by electrical hearing (cochlear implant) [1].

Binaural hearing advantages in bimodal fitting
Researches have shown that bimodal fitting offers a wide range of hearing benefits over unilateral CIs, such as better speech perception in noise, better musical perception, and a better understanding of pitch and tone perception and naturalness of sound perception [8,19-21]. In addition, by making binaural cues available, spatial listening and localization, also enhances [20]. Furthermore, bimodal fitting has been shown to improve quality of life in social activities [22]. For children, in addition to better speech recognition in noise, music perception and localization [7,23], bimodal fitting stimulation is effective in improving language acquisition [24,25].
The effect of binaural hearing on improving speech comprehension ability in bimodal fitting people is still controversial and variable. Ching et al. evaluated 21 individuals with bimodal fitting. Although in this study the effects of HSE, BSQ, and BSU were not analyzed separately, but the results showed that speech perception in noise in binaural situation showed a significant improvement compared to monaural mode. This significant improvement in the speech perception in noise was seen both when noise and speech were in the same place and in conditions that were spatially separated [26].
Morera et al. assessed speech perception in the constant SNR in 12 adults using bimodal fitting six months after surgery. In contrast to studies on bilateral implants that showed a significant head shadow effect, in this study it was reported that a significant effect of the head shadow in bimodal fitting cannot be reported. Also, in comparison of bimodal fitting conditions with monaural conditions (implanting alone), the effect of binaural summation effect was not significant. However, they reported a significant effect of binaural squelch effect both when the noise was close to the implant and when the noise was close to the hearing aid [27]. Schafer et al. found that although the benefits of binaural hearing compared to monaural hearing were always present, bilateral implant conditions were not significantly different from those of bimodal fitting. In their study, it was found that in bimodal fitting conditions, the HSE and BSU are obvious and significant [28]. This was in contrast to Morera's report [27], which reported that the only significant benefit of binaural hearing in bimodal fitting was the binaural squelch effect.
Schoof et al. simulated auditory conditions and simulated spatial separation of noise and speech conditions in a study comparing bimodal fitting and bilateral implant conditions. The stimulus was delivered through headphones to 12 individuals with normal hearing and the speech threshold was assessed in different auditory conditions. In the simulated conditions of bilateral

implant, a significant improvement was observed on the speech reception threshold, which was due to the head shadow effect (7.5 dB), and the binaural summation effect (0.5 dB). In the case of bimodal fitting, the only binaural summation effect was significant and caused a large improvement (10.2 dB) on speech reception threshold [29]. Kokkinakis and Pak examined the advantages of binaural hearing in bimodal fitting people, and the average improvement in speech comprehension threshold due to the HSE was 6.7 dB, the BSQ was 2.9 dB, and the result of the BSU was reported to be 7.6 dB. In their study, they compared the advantages of binaural hearing in two groups of bilateral implantation and bimodal fitting and it was found that there is no statistically significant difference between the two groups in the amount of head shadow effect and the binaural squelch effect. But the binaural summation effect in the bimodal fitting group was higher and had a significant difference with the bilateral implantation group. This suggests that bimodal fitting individuals are likely to benefit much more from the integrity of redundancy information obtained binaurally than those with bilateral CIs. In other words, the transmission of information and low-frequency acoustic signals by hearing aids complements the high-frequency information transmitted by CIs [30]. Lotfi et al., reported improved mean of speech perception in noise score caused by the HSE, BSQ and BSU was, respectively, 3.13, 1.42 and 2.04 dB, indicating greater binaural advantages and hence improved speech perception in noise score, under bimodal fitting condition in comparison with CI alone [31]. According to these studies, it can be concluded that in the case of bilateral implantation, the HSE is the main advantage of binaural hearing to improve speech recognition in noise and the relative contribution of the BSQ and BSE to improve speech comprehension ability in noise is still unclear. In the case of bimodal fitting, the results presented by the existing studies are inconclusive and no definite and coordinated results have been presented yet regarding the effects of head shadow, binaural squelch and binaural summation effect in speech perception in noise.

Candidates for bimodal fitting

Candidates for bimodal fitting are people with severe and profound hearing loss who receive CIs and they have residual hearing in the non-implanted ear. While a CI provides accurate speech comprehension, especially in quiet listening conditions, it does not produce good low-frequency sounds. In bimodal fitting, this deficiency can be compensated by providing amplification of low-frequency sounds (by hearing aid) in the non-implanted ear [32]. More access to low-frequency sounds can improve auditory function because these sounds contain phonological and prosodic information consonant voicing and acoustic cues and particularly the fundamental frequency [33]. Therefore, all recipients of unilateral CIs who have some degree of aidable residual hearing in the opposite ear should be considered as bimodal fitting candidates.

Hearing aids fitting in cases of bimodal fitting

In bimodal fitting, harmonious and balanced adjustment is very important to achieve the desired utility and achieve listening comfort. Common clinical methods of hearing aid fitting for bimodal fitting cases include loudness balancing, frequency lowering, and adjusting the bandwidth.

Several fitting methods are available for adjusting the hearing aid in the case of bimodal fitting, but some confusion about the optimal adjustment method remains in these cases, as the benefits of adding a hearing aid to cochlear implants vary considerably from patient to patient. Although non-implanted ear thresholds and the benefits of bimodal fitting are inversely related [8,19], however, it does not provide effective clinical guidance for adjusting hearing aids in most patients with moderate to severe sensory hearing loss in the non-implanted ear which is because of lack of prospective studies with a large number of samples that provide data guidance for clinical connections. However optimized adjustment in bimodal fitting persons is of great clinical importance to provide maximum benefit to patients [34].

Generally two general principles are necessary to adjust the hearing aids in cases of bimodal fitting. First, the frequency response of the hearing aid needs to be optimal for speech perception, and the hearing aid needs to amplify sounds for low, middle, and high-intensity inputs to a comfortable level of hearing. Second, when the hearing aid is used with CIs, the volume should be balanced between the two ears and the volume for the low, medium, and high inputs should be maintained at a comfortable listening level. To achieve the first principle, the hearing aid must be capable of wide dynamic range compression (WDRC) and can be adjusted using a suitable prescription method such as national acoustic laboratories (NAL) formula. This fitting method increases speech comprehensibility while keeping the overall pitch constant over a wide range of input intensities. To achieve the second principle, we can use the loudness balance method to adjust the gain in the hearing aid for different inputs in such a way that the loudness of speech between the two ears to be the same [7].

The National Acoustics Laboratory formula-non-linear1 (NAL-NL1) formula for hearing aid fitting is the proposed fitting method for bimodal fitting cases and provides the desired frequency response [26]. The National Acoustics Laboratory formula-non-linear2 (NAL-NL2) and desired sensation level (DSL) formulas can also be useful [35]. Numerous studies have been performed on the suitability of different fitting methods of NAL. In evaluating the usefulness of the NAL fitting method, some patients preferred to use higher gains, while others preferred to use lower gain. Some studies have also reported that the NAL prescription formula provides the best mental adjustment [34]. The NAL-NL2 and DSL formulas are both suitable fitting methods for bimodal fitting users. For people with moderate to severe hearing loss and the experience of using a hearing aid in the opposite ear, DSL v5.0 may provide better speech comprehension and greater utility [36]. Numerous studies have also examined the usefulness of a broadband frequency response in hearing aids compared to limited high-frequency amplification. The majority of studies reported significant usefulness in cases of broadband frequency response compared to limited high-frequency amplification [37,38]. However, these studies do not include people with dead regions of the cochlea. In contrast, some evidence suggests that limited frequency bandwidth and high-frequency amplification may significantly increase speech recognition scores in some patients [39]. One of these studies tested the presence of cochlear dead regions and showed that for patients with confirmed dead regions, limited high-frequency amplification produced significantly higher speech detection than broadband frequency bandwidth [39,40].

Hearing aid and cochlear implantation balance

Due to the different bandwidths of the hearing in ears and different listening methods, the balance of loudness in hearing aids and cochlear implants can be difficult. Numerous studies have examined the different methods of hearing aid adjustment required to achieve loudness balance. In particular, some studies show that listeners prefer lower gain in the NAL formula to create a loudness balance, while others report that the hearing aid gain for a balance is almost equivalent to the NAL-revised (NAL-R) prescription gain settings [34].

One way to balance the loudness level is to broadcast a speech signal from the speaker in front of the patient (0 degree azimuth) and ask the patient to indicate from which level he hears the sound. Then the volume level settings in the hearing aid 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 [30].

Discussion

At first, the audiologists/otologists thought that two different inputs, one electrical through cochlear implants and one acoustic through hearing aids, might cause more adverse effects and binaural interference than using a cochlear implant alone. Studies on hearing aid users have also shown that although the use of bilateral hearing aids in most cases improves the performance of the person, but there have been reports that the use of bilateral hearing aids weakens the performance of the person compared to unilateral mode, and in the case of binaural condition their speech comprehension is less than in monaural condition. Perhaps because there is a difference between the degree and type of hearing loss in the two ears, the signal coming from the two ears creates unusable information in the brain or creates information that cannot be combined [41,42]. The use of hearing aids and cochlear implants together is more complicated because the inputs of the two ears are different (electrical and acoustic) and the previous idea was that these two types of inputs cannot be combined to create the binaural hearing advantages. Studies have shown that in bimodal fitting users, the binaural hearing advantage in quiet is due to the use of low-frequency speech components. People who have receive a slight amplification at middle and high frequencies benefit most from bimodal fitting, suggesting that hearing aid amplification at middle and high frequencies may interfere with cochlear implant information in the opposite ear [43]. The mechanism of creating binaural hearing advantages in bimodal fitting people depends on the ability to combine the complemented information of the speech in the acoustic input with the speech information in the electrical input [44]. However, many studies in this field have mainly reported the improvement of a person's performance in bimodal fitting compared to cochlear implantation alone and it has also been found that at least 50% of people who have hearing loss in the opposite ear to cochlear implantation (90 dB threshold and slightly better at 500Hz) prefer to use a hearing aid in the opposite ear for their CI and not the CI alone [2,8,45]. Flynn and Schmidtke reported that bimodal fitting users reported benefits in speech comprehension in noise, localization, own voice perception, and music perception [46]. Ching et al. reported the benefits of using head shadow effects and the effect of the binaural summation effect [47] and Schafer et al. reported the benefits of the binaural squelch effect [48] over the use of bimodal fitting. But each person's capacity to achieve the benefits of the binaural hearing advantages depends on the amount of the residual hearing in the hearing aid recipient's ear, the cochlear implant processing range, and possibly individual central abilities. In general, according to several studies in this field, the use of hearing aids in the opposite ear to cochlear implants provides the benefits of binaural hearing. For example, Fitzpatrick et al. reported improved speech comprehension in noise [49]. Cullington and Zeng reported in a study that bimodal fitting users were more successful in recognizing speech in noise at low-frequency sounds, and this is not the case with high-frequency sounds. This study concludes that cochlear implant users should use bimodal fitting when they have little residual hearing at low frequencies. And usually the main auditory residue in the opposite ear to cochlear implantation is at low frequencies and there is no measurable auditory residue at middle and high frequencies [50]. It should be noted that the results on the usefulness of bimodal fitting in speech comprehension have been reported various, such as Tyler et al., Dettman et al., Morera et al., Potts et al., Ullauri et al. and Dorman et al. have reported that speech perception in quiet in bimodal fitting mode is better than monaural mode [2,27,51-54]. In addition, numerous other studies have reported improved speech perception in noise in the bimodal fitting position [2,27,54-62). But in a study, for example, Mok et al. reported that some people with hearing aids in the opposite ear to cochlear implants have poor performance, it is possibly because amplification of middle and high frequencies by hearing aids can interfere with information with cochlear implants in the opposite ear [43].

Conclusion

Considering the binaural hearing advantages in bimodal fitting users, it can be concluded that users of unilateral cochlear implants who have measurable residual hearing in their non-implanted ear can use a hearing aid in that ear and enjoy binaural hearing advantages. The hearing aid should be fitted in a way to complement the information obtained through cochlear implantation.

Conflict of interest

The authors declared no conflicts of interest.

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