Benefits of Bimodal Stimulation to Speech Perception in Noise and Silence

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Abstract

Introduction Understanding all the benefits of bimodality with self-assessment questionnaires on the effect of hearing on quality of life is still necessary.
Objective To present whether bimodality still offers hearing benefits to the population who uses acoustic stimulation associated with electrical stimulation.
Methods The present study included 13 participants aged between 16 and 80 years old who were users of cochlear implants from Cochlear Corporation and hearing aids. All patients underwent the Hearing in Noise Test, and their visual analog scale score was obtained. Four-tone means were collected, and the participants answered the Speech, Spatial and Hearing Qualities questionnaire.
Results Bimodal users had an average sentence recognition rate of 76.0% in silence and 67.6% in fixed noise, and the signal-to-noise ratio in adaptive noise was +2.89dB. In addition, a lower level of difficulty was observed in the test using the visual analog scale. The domain with the highest average was auditory qualities (6.50), followed by spatial hearing (6.26) and hearing for speech (5.81). Individuals with an average between 50 and 70 dB of hearing level showed better sentence recognition in silence and noise.
Conclusion Bimodal stimulation showed benefits for users with different degrees of hearing loss; however, individuals who presented greater hearing residue had better performance in speech recognition with noise and in silence in addition to a good perception of hearing quality.

Keywords
- cochlear implant
- hearing aids
- hearing loss
- speech perception

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Introduction

Individuals with hearing loss asymmetry can benefit from the use of the cochlear implants (CIs) and hearing aids (HAs), known as bimodality, as a result of acoustic with electrical stimulation.[1,2] This type of auditory rehabilitation is the most commonly used among populations with CI.[3]

Bimodality can improve communication between individuals with hearing residue in the nonimplanted ear and provide benefits such as improvement in sound localization, speech recognition in both silence and noise, sound quality, melody and music perception, and functional performance in real-life situations.[1,2,4–6]

Compared with unilateral CI, bimodality also provides access to low-frequency sounds and other benefits, such as music perception, speech in background music, pitch discrimination and melody recognition, improvement in more widely perceived sound quality, natural and balance, and less metallic sound and more volume, in addition to reduced listening effort.[4,5,7–9]

Therefore, the present study aimed to present whether bimodality still offers hearing benefits to the population who uses acoustic stimulation associated with electrical stimulation.

Methods

The present observational, analytical, and cross-sectional study was approved under opinion number 5.293.257 through the Research Ethics Committee of Research Ethics Committe of University of Brasilia. All individuals agreed to participate in the research through the Free and Informed Consent Term (TCLE, in the Portuguese acronym) and the Free and Informed Consent Term (TALE, in the Portuguese acronym). The study was conducted at Brasiliense Institute of Otorhinolaryngology, and bimodal, pre-, and postlingual users participated.

The inclusion criteria were as follows:

a) Female and/or male individuals.
b) Severe and/or profound sensorineural hearing loss in the implanted ear.
c) Moderate to profound sensorineural and mixed hearing loss with HAs.
d) Hearing aid users before CI.
e) Individuals who reported benefit from the use of HAs.
f) Hearing age with CI from 4 months.
g) Individuals who showed comprehension skills and were fluent in oral language.

The exclusion criteria were as follows:

Impediments that made it impossible for individuals to participate in this assessment approach.

Procedures

Speech Recognition Test

The Hearing in Noise Test (HINT)[10] was used, which consists of 12 lists with 20 recorded sentences, performed in silence and/or competitive noise. Initially, the test was presented with bimodal stimulation and later unilaterally, that is, CI or HA.

To verify the benefit of bimodal stimulation and each hearing device, the sentences were randomly selected by the software, and the participant was instructed to repeat them. The researcher manually scored the words that were repeated correctly, determining the percentage of correct answers.

The test was performed in a condition of 0° azimuth, 1 m away from the speaker in silence, fixed noise, and adaptive noise. For fixed noise, a signal-to-noise (S/N) ratio of + 10 dB was considered, that is, noise at 55 dB and speech at 65 dB. Regarding adaptive noise, a fixed noise intensity of 55 dB hearing level (HL) was presented, and the stimulus intensity was modified to either more or less. According to the responses, the speech recognition threshold necessary for the individual to identify 50% of the stimuli was determined at the established S/N ratio.

The presentation of adaptive noise took place in two stages. The first was varied by the first four sentences, and the intensity varied from 4 to 4 dB. The second started from the fifth sentence, and the intensity varied from 2 to 2 dB.[11]

Visual Analog Scale

The visual analogue scale (VAS)[12] was used at the end of each test to quantify the level of difficulty in the tests (silence, fixed noise, and adaptive noise) with bimodal stimulation and unilaterally.

Participants were instructed to refer to a score from 0 to 10 through an image with numbers and expressions that indicated the ease or difficulty of the test. Scores closest to 0 would mean the "ease of recognizing the sentences" and 10 indicated the "difficulty of recognizing the sentences."

Hearing Self-Perception Questionnaire

The abbreviated version of the Speech, Spatial quiz and Qualities of hearing scale (SSQ-12)[13] was applied to participants > 18 years old who were instructed to consider their responses to bimodal stimulation.

The questionnaire evaluated the listening situations of the participants subjectively, quantifying the real situations of communication, such as everyday sounds divided into environmental or speech domains (speech hearing, spatial hearing, and auditory qualities).

In this way, participants were instructed to score their communicative performance from 0 to 10. A score of 10 would mean that the participant was perfectly capable of performing what was described in the question, and 0 would mean that the participant was unable to perform the investigated situation. Participants also marked the option "not applicable" if the question did not represent a situation in their daily routine.

Mean Threshold Tonal Audiometry

Tone average[14] (500, 1,000, 2,000, and 4,000 Hz) of 50 to 70, 71 to 90, and ≥ 91 dB HL of the last pure tone audiometry in the presurgical stage were collected from the medical records to verify the influence and amount of hearing residue in the ear with the Hearing Aids (HA) in the auditory performance with the speech recognition tests.

Statistical Analysis

Descriptive analysis of the sentence recognition test in all conditions (silence, fixed noise, and adaptive noise) of each hearing device and with bimodal stimulation, VAS, and SSQ-12 was performed using the Spearman rank correlation coefficient. The correlation analysis of the sentence recognition test was performed under all conditions (silence, fixed noise, and adaptive noise) of each hearing device and with bimodal technology, VAS, SSQ-12, and audiometry.

Results

The study enrolled 13 participants (male, $n = 4$; female, $n = 9$) aged 16 to 80 years old with a mean age of 49.8 (standard deviation [SD], 22.4) years old. Nine were postlingual, and four were prelingual bimodal users.

All nine participants with postlingual hearing loss had severe and/or profound sensorineural hearing loss in the implanted ear, and eight participants with HAs had moderate to profound sensorineural hearing loss, except one participant who had moderately severe mixed hearing loss in the contralateral ear (►Table 1).

Regarding the hearing age of the 9 participants who had postlingual hearing loss, all were $\geq$ 4 months with CI (4 to 58 months) and $\geq$ 24 months with HAs (24 to 240 months) (►Table 1).

As for the individuals with prelingual hearing loss, four had profound sensorineural hearing loss in the implanted ear, and all had moderate to profound sensorineural hearing loss in the contralateral ear and were using HA (►Table 1).

The prelingual hearing loss age was $\geq$ 10 months old in those with CI (10 to 216 months) and $\geq$ 156 months in those with HAs (156 to 432 months) (►Table 1).

Speech Recognition Test

For silent sentence recognition, all subjects had an average of 76.0% with bimodal stimulation, 69.5% with CI, and 49.1% with AASI (►Table 2).

As for sentence recognition under the fixed-noise condition in the HINT, the subjects had an average of 67.6% with bimodal stimulation, 50.6% with CI, and 35.0% with HA (►Table 2).

Of the 13 subjects evaluated, 10 recognized 50% of the sentence recognition stimuli in adaptive noise with bimodal stimulation, which resulted in an S/N ratio of $+2.89$ dB. Of these subjects, 8 had an average of $+4.81$ dB with CI, and 6 had an average of $+3.72$ dB with HA (►Table 2).

A strong significant correlation ($R = 0.82$) ($p = 0.0001$) of bimodal auditory stimulation and CI in quiet noise and moderate significant in fixed noise ($R = 0.66$) ($p = 0.013$) was observed (►Table 3).

Furthermore, there was no statistical difference between sentence recognition, bimodal stimulation, and the use of HA under the silent ($p = 0.971$), fixed noise ($p = 0.713$), and adaptive noise ($p = 0.783$) conditions (►Table 3).

In addition, no statistically significant difference was observed between sentence recognition, the use of HA, and the use of CI under all conditions (silent, fixed noise, and adaptive noise) (►Table 3).

Visual Analogue Scale

For all subjects, the average VAS in relation to difficulty and effort after sentence recognition under the silent condition was 2.85 with bimodal stimulation and 3.69 with CI. Of them, 12 had an average of 5.17 with HA (►Table 4).

Table 1 Characterization of the study participants

n	Sex	Chronological age (years old)	Hearing age (CI)	Hearing age (HÁ)	Deafness	Type and degree of hearing loss (CI)	Type and degree of hearing loss (HA)
1	F	31	7 months	84 months	Postlingual	SNHL profound	SNHL moderately severe
2	F	44	4 months	144 months	Postlingual	SNHL profound	SNHL profound
3	F	64	15 months	240 months	Postlingual	SNHL severe	SNHL severe
4	F	34	12 months	48 months	Postlingual	SNHL profound	SNHL severe
5	M	78	37 months	48 months	Postlingual	SNHL profound	MCSHL moderately severe
6	M	71	11 months	24 months	Postlingual	SNHL profound	SNHL severe
7	F	80	21 months	240 months	Postlingual	SNHL severe	SNHL moderate
8	F	65	58 months	240 months	Postlingual	SNHL profound	SNHL moderately severe
9	M	72	35 months	108 months	Postlingual	SNHL severe	SNHL profound
10	M	16	216 months	156 months	Prelingual	SNHL profound	SNHL severe
11	F	28	11 months	240 months	Prelingual	SNHL profound	SNHL moderate
12	F	38	25 months	432 months	Prelingual	SNHL profound	SNHL profound
13	F	26	10 months	192 months	Prelingual	SNHL profound	SNHL moderately severe

Abbreviation: CI, cochlear implant; HA, hearing aid; MCSHL, mixed conductive-sensorineural hearing loss; SNHL, sensorineural hearing loss.

Table 2 Descriptive statistics of the Hearing in Noise Test in the silent, fixed noise, and adaptive noise conditions of each device and with bimodal stimulation

Variables	*n*	Average	median	Standard deviation	Minimum	Maximum	IQR (Q3–Q1)
Silence							
CI	13	69.5%	61.1%	32.0%	1.3%	99.0%	54.0–91.7%
HA	13	49.1%	52.3%	36.3%	0.0%	98.8%	20.7–73.8%
Bimodal	13	76.0%	86.4%	26.2%	25.7%	100.0%	64.7–97.5%
Fixed noise + 10 dB							
CI	13	50.6%	51.8%	36.1%	0.0%	98.3%	28.9–81.3%
HA	13	35.0%	33.7%	36.5%	0.0%	100.0%	0.0–59.6%
Bimodal	13	67.6%	72.7%	31.5%	0.0%	98.7%	60.3–92.5%
Adaptive noise							
CI	8	+ 4.81dB	+ 3.95dB	+ 5.69dB	−2.10dB	+ 12.60dB	+0.3dB– + 9.2dB
HA	6	+ 3.72dB	+ 3.90dB	+ 3.78dB	−1.00dB	+ 8.80dB	+0.8dB– + 6.1dB
Bimodal	10	+ 2.89dB	+ 2.90dB	+ 3.41dB	−0.80dB	+ 10.00dB	+0.1dB– + 4.0dB

Abbreviation: CI, cochlear implant; HA, hearing aid; IQR, interquartile range; Q1, first quartile; Q3, third quartile.

Table 3 Correlation between types of stimulation in the silent, fixed noise, and adaptive noise conditions

Variables	CI		HA		Bimodal	
	Correlation	*p-value*	Correlation	*p-value*	Correlation	*p-value*
Silence						
CI	1.00	–	–	–	–	–
HA	−0.30	0.313	1.00	–	–	–
Bimodal	0.82	0.001	−0.01	0.971	1.00	–
Fixed noise + 10 dB						
CI	1.00	–	–	–	–	–
HA	−0.29	0.337	1.00	–	–	–
Bimodal	0.66	0.013	0.11	0.713	1.00	–
Adaptive noise						
CI	1.00	–	–	–	–	–
HA	−0.40	0.750	1.00	–	–	–
Bimodal	0.31	0.453	0.20	0.783	1.00	–

Abbreviation: CI, cochlear implant; HA, hearing aid.

As for the fixed-noise condition, all subjects had an average of 2.85 with bimodal stimulation and 4.10 with CI; moreover, 8 had an average of 3.87 with HA (►**Table 4**).

As for the adaptive noise condition, 11 subjects had a mean VAS of 5.91 with bimodal stimulation, 9 had a mean of 7.00 with CI, and 7 had a mean of 6.71 with Hearing Aids (HA) (►**Table 4**).

►**Fig. 1** presents the VAS averages of the subjects under all HINT conditions, silent, fixed noise, and adaptive noise, with bimodal stimulation, ISAD, and CI.

There was weak correlation and not significant between the averages of the level of difficulty using the VAS and the HINT in all the conditions of silent, fixed and adaptive noise, considering a bimodal auditory stimulation and by means of each device. However, we observed a moderate (R = 0.61), non-significant (*p*-value 0.061) correlation between bimodal auditory stimulation and IC in the fixed noise condition (►**Table 5**).

Hearing Self-Perception Questionnaire

As for the SSQ-12 questionnaire, 12 of the 13 subjects > 18 years old answered. The average for the hearing domain for speech was 5.81; for spatial hearing, 6.26; and for auditory qualities with the highest average, 6.50 (►**Table 6**).

There was a moderate significant correlation between bimodal stimulation and the auditory domain for speech in fixed noise (R=0.64) (p-value 0.025) (►**Table 7**) There was a weak and non-significant correlation of the (R-values) of SSQ 12 domains with the (R-values) of sentence recognition in

Table 4 Descriptive statistics of the difficulty level in the Hearing in Noise Test in the silent, fixed noise, and adaptive noise conditions of each device and with bimodal stimulation

VAS	*n*	Average	Median	Standard deviation	Minimum	Maximum	IQR (Q3–Q1)
Silence							
CI	13	3.69	2.00	3.42	0.00	9.00	1.0–6.0
HA	12	5.17	5.00	3.13	1.00	10.00	2.7–7.3
Bimodal	13	2.85	4.00	2.54	0.00	8.00	0.0–4.0
Fixed noise + 10 dB							
CI	10	4.10	4.00	2.81	0.00	8.00	2.0–6.7
HA	8	3.87	3.00	2.64	1.00	9.00	2.0–5.2
Bimodal	13	2.85	4.00	2.54	0.00	8.00	0.0–4.0
Adaptive noise							
CI	9	7.00	7.00	1.87	4.00	10.00	6.0–8.0
HA	7	6.71	8.00	2.69	3.00	10.00	4.5–8.5
Bimodal	11	5.91	6.00	1.37	3.00	8.00	5.0–7.0

Abbreviation: CI, cochlear implant; HA, hearing aid; IQR, interquartile range; Q1, first quartile; Q3, third quartile; VAS, visual analog scale.

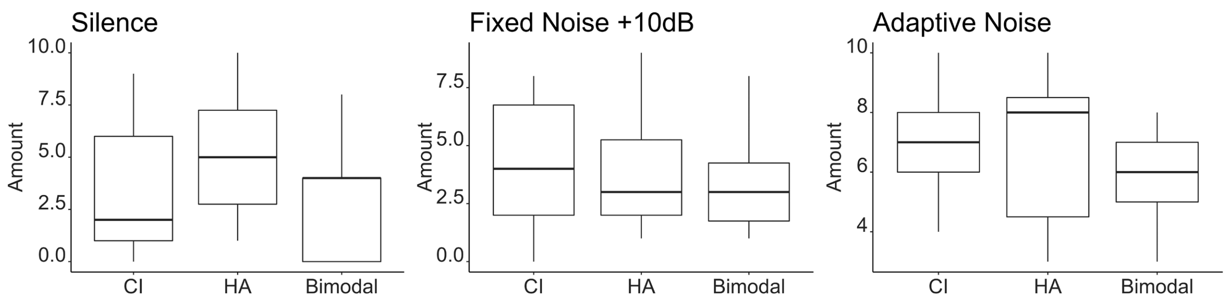

Fig. 1 Medians and first and third quartiles of the difficulty level using the Visual Analog Scale after performing the *Hearing In Noise Test* in the conditions of silence, fixed noise, and adaptive noise of each device and with bimodal stimulation. **Abbreviation**: CI: cochlear implant; HA: hearing aids

Table 5 Correlation between the levels of difficulty in the Hearing in Noise Test of each device and with bimodal stimulation in the condition of silence, fixed noise, and adaptive noise

VAS	CI		HA		Bimodal	
	Correlation	*p-value*	Correlation	*p-value*	Correlation	p-value
Condition of silence						
CI	1.00	–	–	–	–	–
HA	−0.28	0.375	1.00	–	–	–
Bimodal	0.54	0.056	0.25	0.440	1.00	–
Fixed noise + 10 dB						
CI	1.00	–	–	–	–	–
HA	0.15	0.781	1.00	–	–	–
Bimodal	0.61	0.061	0.10	0.818	1.00	–
Adaptive noise						
CI	1.00	–	–	–	–	–
HA	0.20	0.741	1.00	–	–	–
Bimodal	0.08	0.841	−0.03	0.953	1.00	–

Abbreviation: CI, cochlear implant; HA, hearing aid; VAS, visual analog scale.

Table 6 Descriptive Statistics of Individuals in the Speech, Spatial, and Qualities of Hearing Scale Questionnaire considering the domains of speech hearing, spatial hearing, and auditory qualities

Domains	*n*	Average	Median	Standard deviation	Minimum	Maximum	IQR (Q3–Q1)
|Hearing for speech	12	5.81	5.30	1.98	3.60	9.40	4.0–7.2
Spatial hearing	12	6.26	6.15	1.93	3.00	9.00	5.2–8.0
Auditory qualities	12	6.50	6.38	2.40	2.25	11.80	5.2–7.3

Abbreviation: IQR, interquartile range; Q1, first quartile; Q3, third quartile.

Table 7 Correlation between Speech, Spatial, and Qualities of hearing Scale with Hearing in Noise Test in each condition of silent, + 10 dB fixed and adaptive noise, device, and bimodal stimulation

Variables	Hearing for speech		Spatial hearing		Auditory qualities		Total	
	Correlation	*p-value*	Correlation	*p-value*	Correlation	*p-value*	Correlation	*p*-value
Silence								
CI	0.42	0.173	0.36	0.253	0.12	0.720	0.20	0.528
HA	−0.05	0.870	−0.14	0.653	0.24	0.452	0.02	0.948
Bimodal	0.49	0.108	0.38	0.224	0.22	0.483	0.22	0.499
Fixed noise								
CI	0.38	0.216	0.32	0.314	0.17	0.606	0.22	0.496
HA	−0.01	0.982	−0.19	0.548	0.26	0.413	0.05	0.887
Bimodal	0.64	0.025	0.44	0.158	0.44	0.150	0.41	0.193
Adaptive noise								
CI	−0.45	0.268	0.36	0.389	−0.05	0.935	−0.07	0.882
HA	−0.20	0.714	−0.52	0.288	−0.43	0.419	−0.60	0.242
Bimodal	−0.45	0.222	−0.17	0.666	−0.36	0.339	−0.33	0.391

Table 8 Correlation between the audiometry means and performance in the Hearing in Noise Test in the conditions of silence, fixed noise at + 10 dB, and adaptive

Audiometry Averages	Silence		Fixed noise + 10dB		Adaptive noise	
	n	Average	*n*	Average	*n*	Average
50–70 dB NA	5	71.0%	5	54.0%	4	+ 4.4 dB
71–90 dB NA	4	29.0%	4	23.0%	1	+ 0.0 dB
≥ 91 dB NA	4	42.0%	4	23.0%	1	+ 4.5 dB

HINT in the quiet and adaptive noise conditions with bimodal auditory stimulation (►**Table 7**). Thus, there was a weak and nonsignificant correlation of the (R-values) of SSQ 12 domains with the (R-values) of sentence recognition in HINT in all conditions (quiet, fixed, and adaptive noise), with HA or CI (►**Table 7**).

Mean Threshold Tonal Audiometry

Participants with audiometry means of 50 to 70 dB HL had a greater recognition of sentences under silent (71.0%) and fixed noise (54.0%) conditions, and the S/N ratio of 4 participants under adaptive noise was + 4.4 dB (►**Table 8**).

The average values for 71 to 90 dB HL were 29.0% in silence and 23.0% in fixed noise, and the S/N ratio of one participants under adaptive noise was +0.0 dB (►**Table 8**).

The mean values for ≥ 91 dB HL were 42.0% in silence and 23.0% in fixed noise, and the S/N ratio of one participant under adaptive noise was + 4.5 dB (►**Table 8**).

Discussion

With the expansion of new CI indications for different degrees of hearing loss, the present study aimed to present whether bimodality still offers hearing benefits to the population who uses acoustic stimulation associated with electrical stimulation.

Speech Recognition Test

In the HINT, the results of the descriptive analysis for the sentence recognition test with bimodal stimulation were 79.2% under silence and 71.8% under fixed noise conditions, and the average S/N ratio under adaptive noise was + 2.08 dB. These results were in line with the literature, mainly in relation to the means of silence and fixed noise, corroborating with better means of sentence recognition and Speech Recognition Threshold scores from other studies.[15,16]

In addition, we observed that the results of the present study were similar regarding the CI averages being lower than those in bimodal stimulation[15,16] under the conditions of silence, fixed noise with S/N ratio of + 10 dB, and adaptive noise. The finding that the individuals were better in the recognition of AzBio phrases with an S/N ratio of + 10 dB is similar to that from the study by Dorman et al.[17]

Considering such benefits and that this study showed variation in the interquartile range (►**Table 2**) of subjects in sentence recognition with HA alone, we recall that studies (18-20) have shown that there are subjects for whom acoustic stimulation alone provides little or no speech understanding, but that there is significant bimodal benefit, thus agreeing with the results of this study that HA appears to contribute to bimodal benefit in the speech test when we look at ►**Table 2**. The results of the present study showed variation in the minimum and maximum results of individuals in sentence recognition; however, we observed that the hearing aid seems to contribute to the bimodal benefit in the speech test, even with no statistical difference.

In view of this, studies[21–24] have described that HAs offer access to redundant information, via binaural summation and unique or complementary information that is not well transmitted by modern CI systems. Thus, this makes us consider the contribution of the relationship of the results of users who benefited from HAs with better auditory performance using both devices in the sentence recognition test.

From the results of the present study, we found minimum and maximum averages in the sentence recognition in silence and with noise which were similar to those of other studies. Regarding the percentage, the average benefit expected for bimodal stimulation was $\sim$ 10 to 20% for speech recognition in silence and $\geq$ 10 to 30% for speech recognition with noise.[18–20,25–29]

We emphasize that weak correlations were found with no significant difference between the significant difference in the use of bimodal auditory stimulation with ISAD in silence ($R = -0.01$), in fixed noise ($R = 0.11$) and in adaptive noise ($R = 0.2$), however, there are benefits in the descriptive analysis of all conditions of sentence recognition in silence (76%), fixed noise (67.6%) and adaptive (+2.89dB) when we added the use of HA to the CI. In this sense we agree with Banhara et al.,[30] who did not find significant differences in the recognition of monosyllables, nonsense syllables, sentences in silence and in the S/N +10dB ratio, although there were individual benefits in speech perception with the use of HA in the non-implanted ear. Nobre et al.[31] also found no statistical difference in disyllable words in silence and in the S/N +10dB noise, but found benefits individually reported by individuals. Furthermore, perhaps the benefits found in the present study refer to the superior perceptual results to speech compared to listening only with CI,[21–24] such as suprasegmental aspects.

Regarding adaptive noise, 13 of the participants identified 50% of the stimuli presented with bimodal stimulation, presenting an average positive S/N ratio of 2.08 dB. Thus, HAs contributed to this condition. When the participants were evaluated with both devices, studies have shown that performance improves in a bimodal listening situation compared with CI alone.[21–24] Moreover, Dorman et al.[32] found improvements of 17 to 23 percentage points for sentence recognition under noise, corroborating the results of the present study, although the present study benefits through the S/N ratio.

In the present study, we considered the hearing age with a CI of 4 months; however, we did not correlate the hearing performance of the individuals before implantation, although the literature describes that between 6 and 12 months there are benefits in the performance of AzBio phrase recognition with noise under the conditions of +10 dB and + 5 dB S/N ratios.[33] The bimodal pre- and postlingual users with CI in the present study were of hearing age that demonstrated benefits when viewed with the speech recognition test results.

Visual Analogue Scale

Through the HINT and VAS, the number of participants who performed the HINT under silent, fixed noise, and adaptive noise conditions corresponds to the total number of study participants. However, when we verified the descriptive analysis of the VAS, the number does not match to what is observed in the HINT. Thus, it is understood that in participants who scored 0% under one condition in the auditory recognition test, the level of difficulty was not questioned, as the score of the individual in the listening condition was not underestimated.

Bräcker et al.[34] used the VAS in individuals with normal hearing after a speech perception test in noise condition, referring that the greater the background noise, the greater the effort of the individual. This corroborates our results in the speech recognition test under noise condition, mainly in the adaptive condition, where the noise intensity varied more or less according to the responses found. Thus, there was a higher level of difficulty with one of the devices compared with bimodal stimulation.

In our results, the averages of the difficulty level were low with bimodal stimulation under the silent, fixed noise, and adaptive noise conditions. This finding agrees with those of the studies[10–13,15,16] that classified bimodal speech recognition as significantly less difficult and less effortful compared with listening only with CI. However, our results have shown levels of difficulty with CI and/or HAs.

The results obtained from the present study indicated how difficult or easy the listening situation is in HINT, whether with bimodal stimulation or with other devices unilaterally and bilaterally. Lee et al.[35] reported that speech recognition in noise is affected by the S/N ratio, which can be observed in our results under fixed noise conditions at + 10 dB and adaptive noise through the VAS.

Hearing Self-Perception Questionnaire

The self-perception of the individuals who answered the SSQ 12 questionnaire was better in the domain of "hearing qualities"in the descriptive analysis, results that are concomitant with other studies[2–9,36–38] regarding the sub-item of "hearing qualities", this one referring to the situations of: "segregation of sounds"; "simultaneous voice flows"; "identification of sounds"; "quality and naturalness"; and "listening effort".[13]

Regarding "auditory segregation", the subjects in this study had better mean scores in both the auditory qualities domain and the fixed noise condition, with moderate significant correlation ($R = 0.64$), in the hearing-to-speech domain. Studies report that, such segregation can be achieved when a listener can distinguish the target speaker from distracting speakers, this allows the listener to separate the source from the competing background.

Furthermore, the results obtained from the present study regarding individuals who answered the SSQ-12 and HINT questionnaires corroborate those from the study by Lenarz et al.[42] that the self-report of the individual when evaluated using a questionnaire, that is, the handicap, became more comprehensive than the speech recognition tests. From the results, we found better averages in the recognition of sentences in silence and with noise on bimodality and on the SSQ-12 questionnaire.

Mean Threshold Tonal Audiometry

In the study by Dorman et al.,[32] the percentages were higher with bimodal stimulation than with CI alone for AzBio phrases in noise, especially when the hearing loss averages with HAs were < 60 dB HL. This finding agrees with the results of the present study, in which the averages in the performance in the HINT were higher for participants with 50 to 70 dB HL.

In the present study, the sentence recognition performances of participants who had an average of ≥ 91 dB HL in the contralateral ear, that is, with HAs, were higher under silent and fixed noise, and thus decreased the performance under adaptive noise, than in participants who had averages between 50 and 70 dB HL and 71 and 90 dB HL.

Thus, even in the absence of considerable bimodal benefit as described in the present study by means of 71 to 90 and ≥ 91dB HL for speech understanding in the HINT, the qualitative benefit reported by the individual was perceptibly obtained with HAs in the contralateral ear being clinically and functionally significant.[43]

Studies have also demonstrated that auditory thresholds without auditory residue in the low-frequency range are not related to the bimodal benefit or only weakly correlated with the bimodal benefit.[18,26,44,45] In the present study, we found that in participants with averages between 71 and 90 and ≥ 91dB HL of sentence recognition performance in silent and noise conditions, respectively, in the HINT, when subjected to adaptive noise, their number decreased, correlating with what the literature describes in that the weak relationship was largely driven by bimodal users with higher auditory thresholds.[25,26]

Conclusion

All study participants with different degrees of hearing loss benefited from bimodal stimulation. However, participants who presented higher auditory residue benefited from bimodality in the speech recognition test in both silent and noise conditions, with good self-perception of hearing quality.

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Conflict of Interests
The authors have no conflict of interests to declare.

References

1 Edwards B. The distortion of auditory perception by sensorineural hearing impairment [Internet]. Houston: Audiology Online; 2020. Acessed on 02/12/2022. Available at: http://www.audiologyonline.com
2 Generoso GF, Magalhães ATM, Goffi -Gomez MVS, Tsuji RK, Bento RF. Self-reported perception of unilateral cochlear implants on the contralateral use of hearing aid. Disorder Communication. 2019;31(03):369–379
3 Vroegop JL, Goedegebure A, van der Schroeff MP. How to Optimally Fit a Hearing Aid for Bimodal Cochlear Implant Users: A Systematic Review. Ear Hear 2018;39(06):1039–1045
4 Holder JT, Reynolds SM, Sunderhaus LW, Gifford RH. Current profile of adults presenting for preoperative cochlear implant evaluation. Trends Hear 2018;22:2331216518755288
5 Kong YY, Stickney GS, Zeng FG. Speech and melody recognition in binaurally combined acoustic and electric hearing. J Acoust Soc Am 2005;117(3 Pt 1):1351–1361
6 Gfeller KE, Olszewski C, Turner C, Gantz B, Oleson J. Music perception with cochlear implants and residual hearing. Audiol Neurotol 2006;11(Suppl 1):12–15
7 Ching TY, Incerti P, Hill M. Binaural benefits for adults who use hearing aids and cochlear implants in opposite ears. Ear Hear 2004;25(01):9–21
8 Gfeller K, Turner C, Oleson J, Kliethermes S, Driscoll V. Accuracy of cochlear implant recipients in speech reception in the presence of background music. Ann Otol Rhinol Laryngol 2012;121(12): 782–791
9 Gfeller K, Turner C, Oleson J, et al. Accuracy of cochlear implant recipients on pitch perception, melody recognition, and speech reception in noise. Ear Hear 2007;28(03):412–423
10 Arieta MA. HINT Brasil speech perception test in normal-hearing and hearing aid users: attention to hearing health [dissertation]. Campinas: Postgraduate Program in Public Health. Faculty of Medical Sciences of the State University of Campinas; 2009
11 Arieta AM, Couto CM, Costa EA. HINT Brazil speech perception test in groups of subjects exposed and not exposed to occupational noise. Rev. CEFAC. Ago 2013;15(04):786–794
12 Wewers ME, Lowe NK. A critical review of visual analogue scales in the measurement of clinical phenomena. Res Nurs Health 1990;13(04):227–236
13 Noble W, Jensen NS, Naylor G, Bhullar N, Akeroyd MA. A short form of the Speech, Spatial and Qualities of Hearing scale suitable for clinical use: the SSQ12. Int J Audiol 2013;52(06):409–412
14 WORLD HEALTH ORGANIZATION (WHO) Prevention of blindness and deafness. 2020. Accessed on 05/28/2020. Available at: http://www.who.int/publications-detail/basic-ear-and-hearing-care-resource
15 Crew JD, Galvin JJ III, Landsberger DM, Fu QJ. Contributions of electric and acoustic hearing to bimodal speech and music perception. PLoS One 2015;10(03):e0120279
16 Brown CA, Bacon SP. Achieving electric-acoustic benefit with a modulated tone. Ear Hear 2009;30(05):489–493

17 Dorman MF, Gifford RH, Spahr AJ, McKarns SA. The benefits of combining acoustic and electric stimulation for the recognition of speech, voice and melodies. Audiol Neurotol 2008;13(02):105–112
18 Gifford RH, Dorman MF. Bimodal Hearing or Bilateral Cochlear Implants? Ask the Patient. Ear Hear 2019;40(03):501–516
19 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;21:2331216517699530
20 Gifford RH, Dorman MF, Sheffield SW, Teece K, Olund AP. Availability of binaural cues for bilateral implant recipients and bimodal listeners with and without preserved hearing in the implanted ear. Audiol Neurotol 2014;19(01):57–71
21 Liu YW, Tao DD, Chen B, et al. Factors Affecting Bimodal Benefit in Pediatric Mandarin-Speaking Chinese Cochlear Implant Users. Ear Hear 2019;40(06):1316–1327
22 Luo X, Chang YP, Lin CY, Chang RY. Contribution of bimodal hearing to lexical tone normalization in Mandarin-speaking cochlear implant users. Hear Res 2014;312:1–8
23 Yang HI, Zeng FG. Bimodal benefits in Mandarin-speaking cochlear implant users with contralateral residual acoustic hearing. Int J Audiol 2017;56(sup2):S17–S22
24 Zhou Q, Bi J, Song H, Gu X, Liu B. Mandarin lexical tone recognition in bimodal cochlear implant users. Int J Audiol 2020;59(07):548–555
25 Kessler DM, Wolfe J, Blanchard M, Gifford RH. Clinical Application of Spectral Modulation Detection: Speech Recognition Benefit for Combining a Cochlear Implant and Contralateral Hearing Aid. J Speech Lang Hear Res 2020;63(05):1561–1571
26 Illg A, Bojanowicz M, Lesinski-Schiedat A, Lenarz T, Büchner A. Evaluation of the bimodal benefit in a large cohort of cochlear implant subjects using a contralateral hearing aid. Otol Neurotol 2014;35(09):e240–e244
27 Dunn CC, Tyler RS, Witt SA. Benefit of wearing a hearing aid on the unimplanted ear in adult users of a cochlear implant. J Speech Lang Hear Res 2005;48(03):668–680
28 Sheffield SW, Gifford RH. The benefits of bimodal hearing: effect of frequency region and acoustic bandwidth. Audiol Neurotol 2014;19(03):151–163
29 Firszt JB, Reeder RM, Holden LK, Dwyer NYAsymmetric 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;39(05):845–862
30 Banhara MR, Nascimento LT, Costa OA, Bevilacqua MC. Combined use of cochlear implant and sound amplification device individual in adults. Distúrb Comun 2004;16(01):27–33
31 Nobre RA, Bevilacqua MC, Nascimento LT. Combined use of cochlear implant and individual sound amplification device in children. Distúrb Comun, São Paulo 2009;21(02):229–238
32 Dorman MF, Cook S, Spahr A, et al. Factors constraining the benefit to speech understanding of combining information from low-frequency hearing and a cochlear implant. Hear Res 2015;322:107–111
33 Kelsall D, Lupo J, Biever A. Longitudinal outcomes of cochlear implantation and bimodal hearing in a large group of adults: A multicenter clinical study. Am J Otolaryngol 2021;42(01):102773
34 Bräcker T, Opie J, Nopp P, Anderson I. Introducing real-life listening features into the clinical test environment: Part I: Measuring the hearing performance and evaluating the listening effort of individuals with normal hearing. Cochlear Implants Int 2019;20(03):138–146
35 Lee JY, Lee JT, Heo HJ, Choi CH, Choi SH, Lee K. Speech Recognition in Real-Life Background Noise by Young and Middle-Aged Adults with Normal Hearing. J Audiol Otol 2015;19(01):39–44
36 Sucher CM, McDermott HJ. Bimodal stimulation: benefits for music perception and sound quality. Cochlear Implants Int 2009;10(Suppl 1):96–99
37 Potts LG, Skinner MW, Litovsky RA, Strube MJ, Kuk F. 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;20(06):353–373
38 Devocht EMJ, Janssen AML, Chalupper J, Stokroos RJ, George ELJ. The benefits of bimodal aiding on extended dimensions of speech perception: intelligibility, listening effort, and sound quality. Trends Hear 2017;21:2331216517727900
39 Gifford RH, Sunderhaus L, Sheffield S. Bimodal hearing with pediatric cochlear implant recipients: effect of acoustic bandwidth. Otol Neurotol 2021;42(10S):S19–S25
40 D'Onofrio KL, Gifford RH. Bimodal benefit for music perception: effect of acoustic bandwidth. J Speech Lang Hear Res 2021;64(04):1341–1353
41 Zhang T, Dorman MF, Spahr AJ. Information from the voice fundamental frequency (F0) region accounts for the majority of the benefit when acoustic stimulation is added to electric stimulation. Ear Hear 2010;31(01):63–69
42 Lenarz T, Muller L, Czerniejewska-Wolska Het al. Patient-related benefits for adults with cochlear implantation: a multicultural longitudinal observational study. Audiol Neurotol 2017;22(02):61–73
43 Holder JT, Holcomb MA, Snapp Het al. Guidelines for Best Practice in the Audiological Management of Adults Using Bimodal Hearing Configurations. Otol Neurotol 2022;2(02):e011
44 Blamey PJ, Maat B, Başkent D, et al. A retrospective multicenter study comparing speech perception outcomes for bilateral implantation and bimodal rehabilitation. Ear Hear 2015;36(04):408–416
45 Zhang T, Spahr AJ, Dorman MF, Saoji A. Relationship between auditory function of nonimplanted ears and bimodal benefit. Ear Hear 2013;34(02):133–141

